WATERSHED MANAGEMENT

PART 1

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in
water resources

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WATERSHED MANAGEMENT

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PART 1 OF THE PROCEEDINGS OF A SYMPOSIUM ON WATERSHED MANAGEMENT IN WATER RESOURCES DEVELOPMENT

EDITED BY

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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 by 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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PREFACE

Lincoln Papers in Water Resources Numbers 8 and 9 comprise papers presented at a Symposium on Watershed Management in Water Resources Development. The Symposium was sponsored by the New Zealand Association of Soil Conservators together with Lincoln College and was held at Lincoln College from 20th to 22nd August 1969.

The Programme was as follows:

Wednesday, 20th August

Morning Chairman—J. W. Ramsay, (President, N.Z. Association Soil Conservators).

WHAT IS WATERSHED MANAGEMENT?

Dr W. A. Laycock, (Range Scientist), **Mr P. E. Packer,** (Senior Project Leader, Watershed Management Research)—United States Intermountain Forest and Range Experiment Station, Utah.

"Watershed Management in the United States: Concepts and Principles."

Professor J. R. Burton, (Professor of Agricultural Engineering, Lincoln College).

"The Sensitivity of Streamflow Characteristics to Changes in Land Use."

OBJECTIVES OF WATERSHED MANAGEMENT

J. P. C. Watt, (Soil Conservator Special Projects, Otago Catchment Board).

"Land Management for Water Yield and Water Quality."

J. A. Hayward, (Tussock Grasslands and Mountain Lands Institute).

"Land Management for Soil Stability. An Hypothesis of the Problem of Erosion in South Island Hill and High Country."

INFLUENCES OF THE "NON-MANAGEMENT" VARIABLES

A. C. Archer, (Scientist, Grasslands Division, D.S.I.R., Lincoln).

"The Influences of Aspect. An Example from the Alpine, Sub-alpine Ecosystem in the Twin Stream Catchment."

Afternoon Chairman—B. Douglass, (Lecturer in Soil Conservation, Lincoln College).

T. N. O'Byrne, (Water and Soil Division, Ministry of Works, Dunedin).

"The Influence of Rock Type and Relief on Water Supply in North Island Cretaceous-Tertiary Hill Country."

C. L. O'Loughlin, (Scientist, Forest and Range Experiment Station, Rangiora).

"The Influence of Snow on Streamflow from the Camp Stream Catchment, Craigieburn Range."

P. J. Grant, (Ministry of Works, Hydrological Survey, Napier).

"The Influence of Precipitation Type, Duration and Intensity."

THE INFLUENCE OF "MANAGEMENT" VARIABLES

J. Y. Morris, (Scientist, Forest and Range Experiment Station, Rangiora).
"Forest Influences."

Mr J. G. Hughes, (Management Officer, Tussock Grasslands and Mountain Lands Institute).
"Is Pastoral Farming Compatible with Watershed Management?"

Dr A. F. Mark, (Botany Department, Otago University); **Miss J. A. Rowley,** (Plant Physiology Division, D.S.I.R., Palmerston North).
"Hydrological Effects in the First Two Years Following Burning and Severe Grazing of Snow Tussock Grassland."

M. E. Yates, (Field Research Officer, Water and Soil Division, Ministry of Works, Wellington).
"The Effect of Modifying Cover Type by Man and Animals on Some Flow Characteristics in Some New Zealand Experimental Basins."

I. R. Falconer, (Drainage Officer, Department of Agriculture, Dunedin).
"The Role of Small Structures for the Control and Use of Water."

Thursday, 21st August

Morning Theme: DOWNSTREAM CONSIDERATIONS

Chairman—T. D. Heiler, (Senior Research Officer, N.Z. Agricultural Engineering Institute, Lincoln College).

D. C. Best, W. R. Howie, (Water and Soil Division, Ministry of Works, Wellington).
"The Role of the Channel System in Determining Streamflow Characteristics."

P. Farlay, (formerly Engineer, Manawatu Catchment Board, Palmerston North).
"Flood Routing Methods and Techniques in the Lower Manawatu Scheme."

Dr A. J. Sutherland, (Senior Lecturer Civil Engineering, Canterbury University).
"Sediment Movement in Streams."

B. E. Milne, (District Electrical Engineer, N.Z. Electricity Department, Palmerston North).
"Siltation in Mangahao Power Project."

G. G. Natusch, (Investigation Engineer, Power, Ministry of Works, Wellington).
"Opportunities for Multiple Use of Hydraulic Structures."

Afternoon Theme: SOCIO-LEGAL CONSIDERATIONS

Chairman—Dr K. F. O'Connor, (Officer in Charge, Grasslands Division, D.S.I.R., Lincoln).

D. Reynolds, (Farm Advisory Officer, Department of Agriculture, Fairlie).
"Upstream Abstractions of Water as a Factor Limiting Downstream Development."

A. J. Gillies, (Chief Engineer, Otago Catchment Board).
"Formulating a Water Policy."

D. S. G. Marchbanks, (Chairman, Water Allocation Council, Wellington).

"Criteria for Water Allocation, Use and Conservation."

Afternoon Tea.

A. F. Wright, (Soil Conservator), **T. Koutsos,** (Engineer)—Marlborough Catchment Board, Kaikoura.

"River Drainage and Erosion Control for Kaikoura."

G. A. G. Frengley, (Senior Lecturer Farm Management Department, Lincoln College).

"Economic Principles of Multipurpose Resource Use."

Professor W. B. Johnson, (Professor of Geography), Canterbury University).

"The Benefits from an Understanding of Human Behaviour, in Programme Planning and Implementation."

Friday, 22nd August

Panel Discussion.

"The Integration of Upstream and Downstream Proposals for Water Resources Development."

Chairman—Professor J. R. Burton.

A panel, consisting of all speakers will discuss questions from the floor. Questions will be submitted in writing during Wednesday and Thursday. After discussion by the panel, each question will be opened to the floor.

Review of Symposium—Professor J. R. Burton.

"What does Watershed Management mean in New Zealand?"

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WATERSHED MANAGEMENT IN THE UNITED STATES:

CONCEPTS AND PRINCIPLES

P. E. Packer and W. A. Laycock[1]

INTRODUCTION

History abounds with accounts of man's failures to recognise, control and conquer the devastating effects of floods, soil erosion and sediments from steep mountainous lands. Learned men mostly agree that the tragic downfall of highly developed civilizations was not conquest of the land by invaders nor the loss of fertile fields but rather the relentless encroachment of sediment from the mountain watersheds down the rivers into the canals and ditches. A vital question is whether the men of today are able to cope with the landscape more adequately than were the men of Mohenjo-Daro - an archaeologically famous city civilization that flourished from 2,500 to 1,500 B.C. on the Indus Plain in what is now west Pakistan. The equally vital answer is not necessarily affirmative, because men are so much more numerous today and their destructive capabilities and actions are so much more ingenious that new problems in watershed management are developing faster than the old ones can be evaluated and dealt with.

Like these ancient civilizations, America's phenomenal development can be attributed largely to exploitative use of natural resources, including water, that emanate

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from the soil. Also like those ancient civilizations, America has had her share of flood, erosion and sedimentation problems resulting from such exploitations.

Settlement of America began more than 400 years ago; however, what is probably the first consideration given in the United States to watershed management as an inseparable part of land management appeared only 76 years ago. This initial consideration was contained in a bulletin entitled "Forest Influences", which was published in 1893 by the Division of Forestry (now the United States Forest Service). This bulletin described the nature and characteristics of watershed protection problems and summarised the deficiencies of information. It also proposed a programme as a basis for managing and protecting the nation's forest and range lands in the interests of improving stream flow and controlling erosion. In 1905, the National Forest system was established in the United States to protect publicly owned natural resources from wasteful destruction. At that time, Secretary of Agriculture James Wilson enunciated the policy under which these lands have since been administered: "You will see to it that the water, wood, and forage in the reserves are conserved .... and used wisely". Thus, regulated stream behaviour and maintenance of soil stability were first advanced in America as guiding principles of land management.

During the last 65 years, federal agencies and universities have gradually acquired some understanding of the basic relations between land use and the runoff and sedimentation that follow logging, grazing, burning and cultivating. Research has progressively revealed new insights into the changes in water behaviour that result from man's alterations of vegetal cover and soil. This research, coupled with experience, has taught us that the relations between land management treatments and the hydrologic and soil stability behaviours of forest and range lands are not simple ones and that any land management decision is also a watershed management decision.

Since the National Forest system was created, some methods of managing the timber and forage resources have been improved. Most of these improvements were developed mainly in the interests of better production of timber and

forage. Until quite recently, few of these improvements were directed specifically at betterment of watershed conditions, although some of them have effected betterment incidentally. During the past 35 years, and especially within the past 15 years, a growing awareness has developed among land managers regarding the need for management methods and practices designed specifically to provide desired conditions of streamflow and stability of soil. In many places, new management methods and practices are needed to maintain effective control of water and soil movement under continued timber harvesting, grazing and recreational uses. In other places, improved methods must be developed to regain control over water and soil on watersheds where is has been lost through overuse, abuse, or catastrophe. In still other places, new methods and techniques are needed by management to improve water-yielding characteristcs of watersheds, especially the amount and quality of water and the time of year when it appears as streamflow. Paramount to and cutting across all of these management needs, however, is the predominant concept of land husbandry that has evolved in the United States, namely multiple-use management.

This symposium provides an opportunity to summarise important watershed management principles as they apply to problems of maintaining and restoring satisfactory watershed conditions and improving water yields - all within the framework of the multiple-use concept.

MAINTAINING PROTECTIVE WATERSHED CONDITIONS

Probably the most urgent watershed management problems are those of maintaining the normal hydrologic functioning of watersheds under continued resource use without creating the need for watershed rehabilitation. A concept has developed in America to the effect that two general kinds of information about watershed management are needed to provide solutions to these maintenance problems. One is early development of protection criteria or guides for such activities as road building, logging and grazing. The other is development of quantitative relations that express the hydrologic effects of land management treatments on streamflow and soil stability characteristics of forest and range watersheds.

Forest Watersheds - Opportunities for destruction of protective vegetation and disturbance of the soil mantle increase with forest land use. Such destruction and disturbance usually reduce infiltration and storage capacities of the soil mantle which in turn increase overland flow and erosion from watershed slopes. Although the detachment and movement of soil on site is not necessarily synonymous with movement of soil into stream channels, unchecked soil erosion eventually leads to sediment production. Consequently, forest management activities that produce hydrologic conditions leading to overland flow and soil erosion usually have the potential for damaging streamflow quality by sedimentation.

Research at a number of locations in America has shown that streamflow from undisturbed forests is generally clear except during periods of high discharge that result from heavy rainfall or rapid snowmelt. Illustrative of this are turbidities of streamflow from the following: long undisturbed forest watersheds on the Coweeta Experimental Forest in western North Caroline (Dils, 1957); at the Fernow Experimental Forest in West Virginia (Reinhart et al, 1963); on the Hubbard Brook Experimental Forest in New Hampshire (Lull and Reinhart, 1963); and at the H.J. Andrews Experimental Forest in western Oregon (Pacific Northwest Station Annual Report, U.S. Forest Service, 1961). During non-storm periods, streamflow turbidities range from about 1 to 11 parts per million. Under most storm conditions, they remain well under 11 parts per million, which is the accepted standard for drinking water. In some instances, extreme storm conditions may produce turbidities of more than 100 parts per million.

There has been an increased recognition of the need to determine the effects of various forest treatments on water quality; this has led to a few studies concerning the effects that timber cutting has on streamflow and water quality when the cutting is disassociated from the other disturbances that normally accompany logging. The first such study was the now classic Wagon Wheel Gap experiment in Colorado (Bates and Henry, 1928). Other more recent studies have been conducted on entire watersheds to evaluate the unconfounded effects of timber cutting on water quality (Hoover, 1944; Dils, 1957; Lieberman and Hoover, 1951; Southeast Station Annual Report, U.S. Forest Service, 1960). These studies, although few in

number, show that timber cutting without the disturbance of logging results in increased streamflow but without appreciable acceleration, if any, of overland flow and soil erosion. In other words, with the possible exceptions of increases in streamflow temperatures and some increases in bank erosion caused by higher streamflow peaks, timber cutting does not adversely affect water quality.

While numerous studies have determined the amount of soil disturbed by logging and some have attempted to measure sediment yields, few have been concerned with the direct effects of logging on water quality, unconfounded by the effects of roads. Several studies have indicated the magnitude of soil disturbance caused by different methods of logging (Garrison and Rummell, 1951; Fowells and Schubert, 1951; Trimble and Weitzman, 1953; Steinbrenner and Gessel, 1955; Wooldridge, 1960; Haupt, 1960; Dyrness, 1965, 1967). Collectively, these studies show that, compared to high-lead cable systems of logging, tractor logging disturbs more area, compacts the soil on a larger percentage of the disturbed area, causes more intensive compaction of the soil, results in greater reduction of soil permeability and produced larger amounts of overland flow and soil erosion. Measurements of logging disturbance and of soil eroded from logged areas are not necessarily a measure of damage to streamflow quality. Such measurements, however, do indicate the potential damage to which water quality is vulnerable where skid trails concentrate water, intersect other skid trails, and encroach upon or drain directly into stream channels.

Other studies in the United States illustrate the reduction in or prevention of watershed damage that can be achieved by careful planning and execution of logging operations (Wilm and Dunford, 1948; Dils, 1957; Kidd, 1963; Reinhart, Eschner and Trimble, 1963). These studies show that stream turbidity caused by logging usually occurs primarily during the logging operation and decreases rapidly, often even in the first year, after logging. They also show that watershed erosion and damage to water quality can be greatly reduced or even prevented by carefully locating skid trails or skid roads that have gentle grades on sites that do not encroach upon stream channels, and by providing effective drainage of skid roads to eliminate concentrations of overland flow.

Timber harvesting, especially in forests of the western United States, is being extended further into rugged mountainous terrain. As more roads are built in increasingly steeper topography, the potential for soil erosion and sediment damage to water quality increases accordingly. None of man's activities that disturb vegetation and soil in forests are greater precursors of soil and sediment damage than the construction of roads. Despite almost universal use of roads and the fact that roads are generally built for access prior to logging, a surprisingly small amount of information is available about the net effects of roads on surface runoff, soil erosion and water quality (Anderson, 1954; U.S. Forest Service, 1961; Copeland, 1963; Packer and Christensen, 1964; Packer, 1967). These studies, together with experience gained from many logging operations, reveal that roads, especially those built without adequate drainage facilities or which are located too close to streams, are much more responsible for damage to soil and deterioration of water quality in forests than is any other management activity.

In the United States most of the quantitative information about the combined effects of timber cutting, road construction, and logging on watershed conditions and water quality has been obtained from timber harvest operations on experimental watersheds (Dils, 1957; Rich et al, 1961; Rice and Wallis, 1962; Anderson, 1962; Intermountain Forest and Range Experiment Station, U.S. Forest Service, 1965; Leaf, 1966). This research confirms the conclusion that logging can sometimes increase sedimentation considerably, depending upon the location and drainage of skidways, the erodibility and stoniness of soils, and the rapidity of revegetation of disturbed areas. It also lends emphasis to the conclusion that roads on which surface runoff can concentrate because their drainage facilities are inadequate or roads that are located too close to water courses to accommodate the needed width of intervening buffer strips, are, without doubt, the main cause of poor water quality in forests. Such roads can produce thousands of tons of sediment per square mile per year - depending upon inherent soil erodibility, steepness of topography and magnitude of storm runoff.

In a few places research has been successful in isolating the effects that various road and watershed factors have on soil erosion and sediment production from forest roads (Trimble and Sartz, 1957); Haupt, 1959a, 1959b, Packer and Christensen, 1964; Packer, 1967). This research shows that erosion of road surfaces is primarily influenced by road characteristics that can be controlled through proper design and construction and by watershed characteristics that cannot be altered readily. Furthermore, sediment transport down slope from logging roads is influenced mainly by controllable road design characteristics, by watershed characteristics that are alterable through management, and by the age of the roads. Guides that define the kinds and degrees of design, construction and maintenance care needed to insure stable roads have been developed.

Range Watersheds - In many parts of the western United States heavy grazing during the last hundred years or less has increased overland flow and soil erosion, often with serious consequences including frequent flash floods, increased damage to lowlands, and rapid sedimentation of reservoirs. Numerous studies have demonstrated repeatedly that abuse of range land results in adverse hydrologic consequences. These studies show, generally, that under sparse plant cover the normal hydrologic processes of infiltration, percolation and storage that produce seepage flow are upset, resulting in undesirable overland flow and soil erosion. Since 1915, the effects of changes in ground cover due to land use on sediment yields have been evaluated on the oldest continuously observed pair of range watersheds in the world, the A and B watersheds atop the Wasatch Plateau in central Utah. Records from these two watersheds demonstrate remarkably well that erosion control is almost completely dependent on proper functioning of hydrologic processes (Meeuwig, 1960). They show that on the same kind of land, in fact even on the same piece of land, where the plant cover, hydrologic processes and soil stability have become deteriorated by overgrazing, re-establishment of dense vegetal cover results in resumption of normal operation of hydrologic processes that produce seepage flow of water through the soil mantle and hence stable soil surfaces. Thus, the generalisation that overland flow and

soil erosion vary inversely with the amount of total ground cover is valid. Little need, if any, exists for further demonstrations as proof of these relations.

Between the extremes of ground cover conditions, only a very few studies have been made to establish the specific characteristics of plant cover and specific soil conditions required to control overland flow and soil erosion effectively (Packer, 1951, 1953, 1963; Marston, 1952; Meeuwig, 1965). These studies have revealed some very important relations. They show that on several range types in Utah, Idaho and Montana the density of plant and litter cover is the single most important site factor affecting soil erosion. This one variable accounts for 52 to 80 percent of the explained variance in erosion. Such other soil factors as bulk density, porosity, organic matter content and soil texture, as well as the site factor of slope gradient, are also important, but their relative importance varies with range types and geologic parent materials. Additional unpublished information exists from current research to suggest strongly that a minimum ground cover density of 60 to 70 percent may, with few exceptions, be required to control overland flow and soil erosion on western mountain ranges. This information is sufficiently conclusive for a few range types to warrant its adoption as a watershed protection requirement on those types.

Even fewer studies have been made to determine the kind and intensity of grazing use that will provide or maintain plant cover and soil conditions needed for watershed protection. Effective watershed management on most of our western ranges continues to be handicapped by lack of specific information about protective plant cover and soil requirements and especially about acceptable limits of grazing use. It is extremely important that specific protection requirements be carefully established because it is the difference between these desired conditions and those actually existing on any given range that determines the leeway, if any, for safe grazing management.

The last decade has witnessed an increasingly widespread interest in problems connected with a soil termed "non-wettability". In some places, such as the chaparral brush fields of the Sierra Nevada and southern California mountains, this soil condition is emerging as a potent force in accelerating overland flow and soil erosion following

fires (DeBano, 1966). Non-wettable soils have been reported at a number of locations in the ten far western states. These occurrences have been associated with grassland range, chaparral brush lands and especially coniferous forests. The susceptability of soils to water repellency appears closely related to soil texture. Coarse-textured soils, containing more than about 50 percent sand, become water repellent much more readily than those containing larger amounts of silt and clay (DeBano and Letey, 1969). This development suggests that methods and techniques for managing forests and ranges on coarse-textured soils may need to be more stringent, or at least different, than where soils are finer-textured.

RESTORING PROTECTIVE WATERSHED CONDITIONS

All land uses are potential precursors of floods, soil erosion and sediment production. Abusive or excessive uses, if allowed to proceed sufficiently far, inevitably result in these conditions. Ordinarily, these excessive uses must be guarded against because natural recovery of satisfactory hydrologic characteristics and soil stability by damaged watersheds frequently proceeds so slowly as to be unacceptable to good land management. Under such conditions, corrective action must be taken to hasten recovery to a level of satisfactory watershed conditions. A significant part of watershed management in the United States has been devoted to the development and application of appropriate watershed rehabilitation treatments.

Forest Watersheds - Wildfire and faulty road building practices have been and still are the two chief causes of forest watershed damage in the United States. In the 19th century, millions of acres of the United States were burned, some from natural causes and others purposely or carelessly. Fires were commonly used by the pioneers to clear forest and brush lands for crops or forage. Early in this century the tremendous toll taken each year by fire began to gain recognition. All fire was condemned as harmful and destructive. Finally it became clear that the need was great for more thorough knowledge concerning the effects of fire on vegetation and watershed values. Research was needed to develop methods and techniques for preventing and controlling wildfires. Concomitantly, watershed managers

became concerned about development of methods and techniques for rehabilitating fire-damaged watersheds, as well as evaluating the watershed impacts of prescribed fire.

While fire and floods on America's watersheds are intimately related, probably nowhere are they related more importantly than on the steep chaparral-covered mountains that lie above densely populated cities of southern California. Here, research has shown that following fire, a nurse crop of barley or mustard is initially much more effective in helping to stabilize slopes than are seeded perennial grasses (Rice, Crouse and Corbett, 1963). This research also shows that rehabilitation of fire-damaged watersheds by contour-furrowing or contour-trenching and seeding is much more effective than are attempts to stabilize drainage channels by building check dams to lessen channel downcutting. Research has also indicated the important role of dense, deep-rooted vegetation in binding the soil in place on these steep mountain slopes. Conversion of brush to grass to facilitate fire control in southern California resulted in four times more soil slips following heavy rainstorms (Corbett and Rice 1966). Wetting agents applied to non-wettable soils following fire were found to reduce debris movement by as much as 95 percent and increase the establishment of grass on watersheds by four-fold. Increased infiltration from the application of wetting agents has persisted for as long as one year (DeBano 1966).

The hill lands of the upper coastal plain in northern Mississippi were originally forested with pine and hardwoods. When cleared for agriculture, most of them eroded severely. Data from small watersheds on these hill lands indicate excellent opportunities for reducing runoff and sediment by changing land use and cover types. Rehabilitation by establishing pines on actively eroding abandoned fields has in two decades reduced sedimentation to amounts which are probably not in excess of the geologic normal for undisturbed climax forests of the southern United States (Ursic and Dendy, 1963).

Logging roads that were never properly designed, constructed or provided with adequate drainage are a ready source of sediment and may continue to erode indefinitely unless corrective action is taken to stabilize them. Their rehabilitation generally consists of providing adequate

drainage, criteria for which have been developed in a number of places (Trimble and Sartz 1957; Haupt 1959; Packer and Christensen 1964; Packer 1967). Following installation of drainage facilities, revegetation of many road surfaces can be accomplished by scarifying the road surface and broadcast seeding with a mixture of adapted grasses (Kidd and Haupt 1968). Usually steep cut and fill slopes require seeding followed by mulching held in place by some kind of netting. Occasionally fertilisers will improve plant cover establishment (Bethlahmy and Kidd 1966).

Several kinds of plants are being propagated and tested extensively for rehabilitation of road-cut-and-fill slopes and strip-mine spoil banks in Idaho and Utah. One of these plants, squaw carpet (*Ceanothus prostratus*), is a prostrate spreading shrub indigenous to the Sierra Nevada of California. Each node of this plant produces roots and its low-growing, spreading characteristics appear to be ideal for improving or maintaining soil stability. Tests are underway to determine the range of adaptability and usefulness of squaw carpet in erosion control under adverse conditions.

Range Watersheds - Considerable research has been done in the United States to develop methods for restoring protective plant cover to deteriorated range watersheds. Numerous publications are available which prescribe methods and species for rehabilitating the better sites. Virtually all of the rehabilitation research on rangelands has been empirical in nature. This research was intended for sites where the combined environmental conditions offer the best chances for success; this accounts for the rather large fund of practical knowledge that has been developed for rehabilitating those sites. Unfortunately, this approach to the range watershed rehabilitation problem has not provided a fund of basic knowledge concerning the limiting factors of the environment and physiological tolerances of plants needed to extend application of rehabilitation treatments to harsh sites. The environment of large acreages of damaged watershed is so harsh and inhospitable that conventional empirical rehabilitation techniques have met with almost complete failure. New research approaches to rehabilitation of harsh sites were begun in the last several years and include: definitive characterisation of microenvironments; determining physiological tolerances of potential

soil-stabilising species to environmental stresses; and, finally, the matching of appropriate species to sites having known levels of environmental harshness.

Rehabilitation techniques necessarily vary according to conditions of soil, vegetation physiography and the degree to which erosion has progressed. Where watershed conditions have become so deteriorated that exclusion of grazing and natural revegetation alone cannot regain control of overland flow and erosion, some means of mechanical control becomes necessary. Contour terraces have been used as a soil conservation measure in many parts of the world for centuries. By comparison the use of contour trenches for controlling floods and soil erosion on forest and rangelands is relatively new. Contour trenches were initially applied successfully for flood and erosion control on the Davis County Experimental Watershed in northern Utah in the early 1930s (Bailey and Croft 1937). The principle of contour trenching - to retain and get water into the ground where it falls, thus preventing overland flow, erosion, and sedimentation - has proved so sound and effective that thousands of acres of badly eroded flood-source areas in the western United States have been trenched and many more thousands of acres are scheduled for such treatment.

Since contour trenches were first used 35 years ago, design and construction specifications have changed considerably. Two types of trenches have been found useful. One is the outsloped type for use on gentle slopes up to about 16 degrees. The other is the insloped type for use on steeper slopes up to about 35 degrees (Bailey and Copeland 1961). Care is needed in selecting sites that are adaptable to the contour trench system. Soil depths, mass stability of the soil, rock outcrops and slope gradient all influence a decision to contour trench. A minimum of 24 to 30 inches of soil depth is necessary because the contour trench is a structure to hold water until it can be disposed of by infiltration. Trenching should not be attempted on areas having a history of mass soil movement or slumping. Neither should it be attempted on sites having a substratum of impervious clay.

Although contour trenches have proved effective in deterring erosion, they are of temporary benefit and would

soon fill with sediment and become ineffectual if sufficient plant cover to control overland flow and erosion were not established. Even where methods for successfully restoring plant cover to deteriorated watersheds have been developed, failures sometimes occur. These are due mainly to faulty construction methods, poor planting techniques or vagaries of weather.

Closely allied to the problem of rehabilitating harsh range sites is the problem of determining how and to what extent less seriously damaged watersheds can be grazed and still be restored to an acceptable level of protection. While some badly depleted areas require special revegetation measures and complete protection from grazing during the rehabilitation period, by far the larger proportion of American ranges, even though damaged to some degree, still retain the potential for natural recovery to protective watershed conditions provided they are not further damaged by trampling and excessive forage removal. For example, moderate grazing that removed one-third of the herbage on an open ponderosa pine-bunchgrass range in Colorado produced only half as much soil erosion as heavy grazing that removed nearly two-thirds of the herbage (Johnson 1953). On bunchgrass ranges in Idaho, disturbance of even 10 percent of the ground surface by trampling where the ground cover is less than 70 percent causes substantial further reduction in ground cover, enlarges bare soil openings, and increases overland flow and soil erosion (Packer 1953). This suggests that even light use on this kind of range may be too much. These and other investigations have shown that heavy grazing use is detrimental to effective control of storm runoff and soil movement and that protection from grazing can and usually does have a beneficial influence. Little, if any, research has been done, however, to determine what grazing use short of complete protection can be made of damaged ranges while they are recovering. Likewise, very little has been done to determine precisely what grazing use can be made of rehabilitated ranges without again causing deterioration.

IMPROVING WATER YIELDS

Today, the problem of inadequate water supplies is no longer restricted to the semiarid and arid western United States. At one time or another all regions, including the

humid East, have experienced serious deficiencies in water supplies. Most of the interest concerning water in the United States has been related to development facilities to control it and put it to use after it enters larger tributaries and main streams. Unfortunately, until recently at least, there has been much less concern about controlling water where it first falls on the land in greatest abundance and where it is most susceptible to management for control; namely, on upstream forest and range watersheds. Despite attempts to measure quantitatively the influence of forests on streamflow at Wagon Wheel Gap, Colorado as early as 1911 (Bates and Henry 1928), only recently has the need to improve the quality of streamflow been recognised as a nation-wide problem. Too often, watershed management objectives have been passive - devoted to maintaining the status quo by preventing or correcting watershed damage. Little effort has gone into management of public lands for the specific positive objective of water production.

Forest Watersheds - The Wagon Wheel Gap study demonstrated conclusively that cutting the aspen and coniferous vegetation on one of the paired watersheds did, in fact, increase streamflow. In this respect, it proved a technique and demonstrated that water yield changes could be quantitatively evaluated. Since the early 1930s, other research has been conducted in the United States to determine how much, when and under what conditions of climate, soil and topography different forest treatments affect water yield (Dunford and Fletcher 1947; Hewlett and Hibbert 1961; Hoover 1944; Kovener 1956; Love 1955; Rich, Reynolds and West 1961; Rothacher 1965; Rowe 1963; U.S. Forest Service 1964; Eschner 1965; Schneider and Ayer 1961; Tennessee Valley Authority 1961, 1962; Harrold et al. 1962). Evidence from studies on the 14 research areas cited here suggests some generalisations about the effects of forest treatments on water yields. Collectively, these studies demonstrate conclusively that reduction of forest vegetation increases and reforestation decreases water yields. They also reveal wide variation in the magnitude of changes in water yields in different locations. They suggest that a practical upper limit of water yield increase appears to be about 1/6 inch per year for each percent reduction in forest cover, but most treatments produce less than half this amount.

Strong evidence exists to the effect that, in well-watered regions, streamflow response is proportional to changes in forest cover. As new forest grows, following cutting, streamflow increases decline. Depending on climate, soils and topography, response in streamflow may be almost immediate or, on the other hand, considerably delayed.

It is the authors' opinion that the United States is on the threshold of opportunity for improving water yields through forest watershed management. Research has provided much information, too little of which has been applied. Considering such factors as treatable areas, range of precipitation, present water-yielding characteristics, likely rotation periods for forest products and probable persistence periods of forest treatments for increasing water yields, it has been estimated that the potential for increased water yields that could become available in any given year as a result of normal forest management practices on forest lands of the eastern United States is about 5 million acre-feet. A similar estimate for forest lands of the western United States, exclusive of chaparral-woodland, phreatophyte and western alpine areas, is about 1.5 million acre-feet. It should be apparent that water yields can be increased only from the cut-over portions of a forest. Future yields of water from managed forest lands will depend upon the amount and characteristics of vegetation occupying those lands at any given time, and not upon the quantity of vegetation originally removed.

In the western United States, many watersheds are covered with brush and others support an open woodland of small trees. Research has shown that conversion of brush-covered watersheds to native grasses and forbs that consume less water but still stabilise the soil can materially increase water yields without appreciably increasing soil erosion (Pillsbury et al. 1961). It has been estimated that conversion of brush and woodland cover to grasslands, particularly in the southwestern United States, has the potentiality for increasing streamflow by nearly 1 million acre-feet in any given year.

About 16 million acres of phreatophytic vegetation occupy the flood plains of streams in the western

United States. Predominant kinds of vegetation occupying these sites include salt-cedars, willows, cottonwoods and alders. Reductions in consumptive use of water by phreatophytic vegetation, as a result of eliminating these species, has been estimated to have the potential for increasing annual streamflow by approximately 5.5 million acre-feet.

Indeed, watershed management is truly on the threshold of opportunity and can play an important role in providing at least part of the additional water supply required by increasing population pressures. The remaining question now is not whether water yields can be improved, but rather how they can be improved most effectively and economically from place to place. These aspects of the problem require much more research.

Range Watersheds - Need for improved water yields has directed attention to some mountainous rangelands as a possible source of additional water or as an area where timing of streamflow might be altered. Studies in Utah (Luss and Orr 1950) and Colorado (Martinelli 1965) indicate that the use of artificial barriers fitted to the landscape in accordance with prevailing wind direction and velocity can increase the amount of snow trapped and deeply drifted in natural catchment areas. Here, snowmelt may be delayed sufficiently to lower streamflow peaks and prolong summer streamflow. Opportunities for snow management to accomplish these objectives exist on about 10 million acres of subalpine and alpine lands in the western United States, many of which are used for summer grazing. It has been estimated that spring snowmelt peaks could be reduced and late summer streamflow increased by as much as 1.25 million acre-feet through the use of mechanical and/or vegetative treatments to drift more snow on high elevation ranges.

SUMMARY AND CONCLUSIONS

In the preceding sections we have outlined a considerable amount of information which can be applied in the management of forest and range watersheds. We would like to re-emphasize that any land use is a form of watershed management and that any alteration of the hydrologic

processes on the furthest upstream areas affects not only these immediate areas but also the remainder of the watershed. Thus, destructive land use which reduces plant cover, disturbs soil and increases runoff and erosion on upstream areas is a destructive form of management for the entire watershed. Without doubt, the most important watershed problems for which management solutions are needed are those concerned with how to continue timber harvesting, grazing, mining and recreational uses of watersheds without causing undue damage to soil and water. Increasing pressures from an expanding population for the multiple uses afforded by our forest and range watersheds emphasize the need for accelerated research to provide answers and for more intensive management application of those answers.

Of more immediate danger to soil and water are those problems concerned with restoration of satisfactory hydrologic and soil stability conditions to damaged watersheds; however, these problems are not nearly so widespread as, and therefore are not of equal importance with, the watershed maintenance problems. Not only is research needed to further develop and refine requirements for such restoration but management must also demonstrate greater willingness to make the investments necessary to rectify damaging effects on soil and water of past misuses and abuses. Finally, of somewhat less urgency in the authors' opinion, but nevertheless of still great importance, are those problems concerned largely with manipulation of vegetation to influence the amount, quality and timing of water yields delivered as streamflow from forest and range watersheds. The order of magnitude of such influences are now quite well known and management to favourably influence water yields can and should be initiated in some places without further delay. In other situations, research still needs to develop methods and techniques for improving water yields that are more effective and economical than those presently available.

DISCUSSION

Q. Contour trenching is obviously an expensive technique. What are the criteria for allocating funds for this work?

A. This is a very complex question. The simplest answer is that the decision to allocate funds depends primarily on the downstream risks.

Q. Afforestation may reduce water yields. Does this create a conflict of interests?

A. In some areas, yes. On one hand we have the demands of the strict conservationists, on the other we have the demands of the "tin-roofers" who want to maximise water yields.

Q. Is there a danger that contour trenches will convert overland flow into channel flow and thereby increase its soil carrying capacity?

A. No, these are absorption banks, not diversion ditches.

Q. How widespread is the use of detergents on non-wettable soils?

A. So far their use has been confined to experimental areas.

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THE SENSITIVITY OF STREAMFLOW CHARACTERISTICS TO CHANGES IN LAND USE

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INTRODUCTION

Watershed management has been defined [1] as the management of the natural resources of a drainage basin primarily for the production and protection of water supplies and water-based resources, including the control of erosion and floods, and the protection of aesthetic values associated with water. Water resources development is a broader and much more comprehensive field of endeavour, involving the conception, planning, design, construction and management or operation of facilities, both natural and man-made, for the conservation, control and utilisation of water.[2]

Watershed management is clearly an integral part of water resources development; in particular it seeks, by manipulation of land use factors, to modify the streamflow characteristics of the river basins, small and large, which are the basis of all water resources development systems. It is closely related to the field of soil conservation, although the latter has as its primary objective the prevention of soil erosion and consequent damage to water quality and flood-risk property, as well as the preservation of soil fertility and land beauty.[1]

Many experiments and demonstrations have indicated that land use changes can exert significant effects on streamflow characteristics, and it is by no means unusual for conservation enthusiasts to make extravagant claims about the effects of forestation, for example, on flood flows and sediment production. It is the purpose of this paper to put such claims into some perspective as well as to emphasise the vital role of watershed management in the context of water resources development.

STREAMFLOW CHARACTERISTICS AND BASIN SENSITIVITY

Before entering a discussion of the effects of land use on streamflow characteristics we must first identify the characteristics with which we are concerned. In general these will include -

a. Water yield of the basin, i.e. long-term volume of runoff.

b. Flood flows from the basin, i.e. peak rates of runoff.

c. Water quality, where this refers to chemical and biological quality and does not include sediment in suspension or bed load.

d. Erosion rates and sediment yield.

The objective of watershed management is to control or at least influence these characteristics by manipulation of the land use on the upper reaches of the basin. There is ample evidence, at least in qualitative terms, that poor or unwise land use can significantly and sometimes spectacularly affect each of them. It is by no means certain, however, that a direct reverse affect applies; for example, improvements in land use (if in fact the term "improvement" can be defined in this context) may not necessarily effect desirable changes in basin yield or flood magnitudes. Furthermore, it is by no means certain that land use changes which have been shown to produce significant effects on the streamflow characteristics of plots or small experimental catchments will have anything like the same effects when applied on the broad scale over a large basin.

This paper is primarily concerned with the first two of these characteristics, which relate to volumes and amounts of runoff. In regard to these, Chow[3] has enunciated a fundamental but neglected hydrologic concept, that river basins differ markedly in their response to rainfall inputs and land use changes. The many complex and interrelated factors which determine the shape of the hydrograph of runoff from a river basin cause most small basins to

behave quite differently from most large basins, depending largely on their sensitivities to land use changes and variations in input rainstorm characteristics. Chow classifies basins as hydrologically "large" or hydrologically "small" in terms not only of size but also of the relative effects of the dominant factors governing hydrograph shape. "Small" basins are those whose runoff characteristics are highly sensitive to changes in land use or short-term changes in input rainfall intensity. "Large" basins, on the other hand, are those which are relatively insensitive to such changes. In a nutshell, the small basin is one whose runoff characteristics are largely determined by the factors which govern overland flow. In large basins, where channel storage rather than overland flow is the predominant factor influencing the shape of the hydrograph, response to these sensitivities is greatly suppressed. On such basins major changes in land use may have insignificant effects on runoff characteristics. Chow suggests that small basins may range up to about 1000 acres in area, although much larger basins may sometimes be sensitive to land use changes and it is possible for two basins of about the same size to differ markedly in their response to land use influences.

RUNOFF CHARACTERISTICS OF THE SMALL BASIN

The factors affecting the shape of the hydrograph of runoff from a small basin in which channel storage effects are negligible can be demonstrated from theoretical considerations.

Consider such a small basin, as shown in plan in Figure 1. This diagram shows contours of time of travel to the basin outlet, or isochrones. Integration of the successive areas between the isochrones and the basin outlet yields the time area contributing diagram, shown in Figure 2a, whose shape is given by the expression $a = g(t)$. Figure 2b shows the excess rainfall hyetograph, a diagram representing the rate at which effective rain, i.e. total rainfall minus losses, including interception, depression and infiltration losses, occurs. Its shape is given by the expression $P_e = x(t)$.

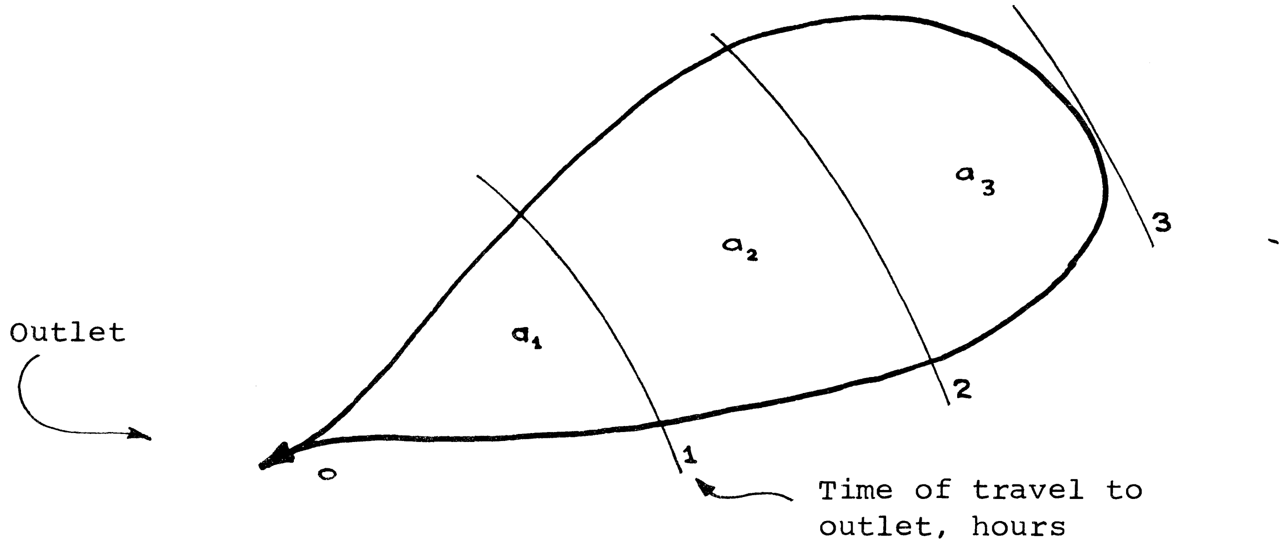


Figure 1 - Isochrone Map of Basin

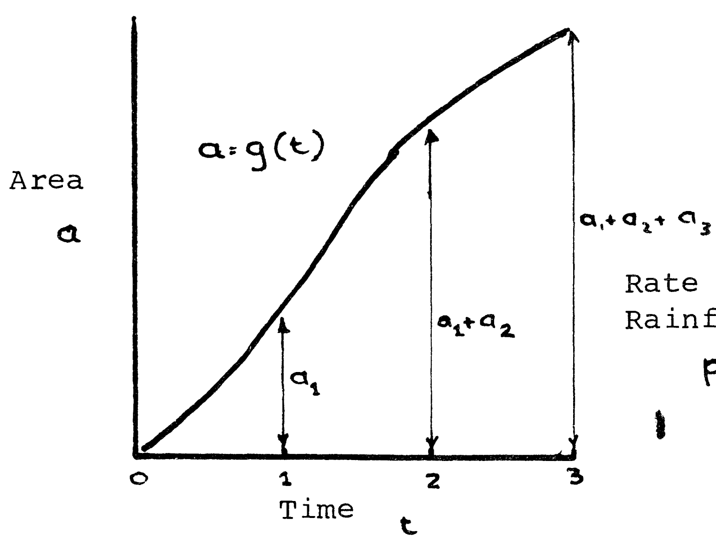


Fig. 2a - Time Area Contributing Diagram

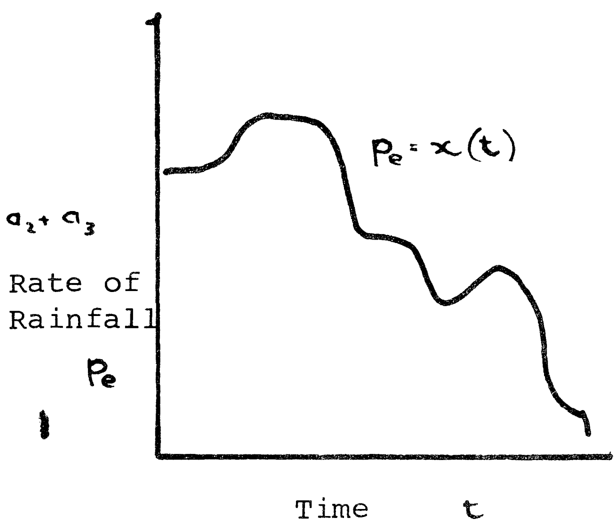


Fig. 2b - Excess Rainfall Hyetograph

The shape of the runoff hydrograph from the storm depicted in Figure 2b can readily be shown to be represented by the expression

$$q_T = \int_0^T x(T-t)\, g'(t)\, dt \qquad \ldots\ldots.(1)$$

This expression merely states that the shape of the hydrograph is a function of the shape of the excess rainfall hyetograph and the shape of the time area diagram. If one of the expressions within the integral is constant, the hydrograph shape depends only on the shape of the other. For example, if the rate of excess rainfall is constant, the shape of the hydrograph is simply the shape of the time area contributing diagram, the ordinate of the runoff hydrograph at any time t being the ordinate of the time area contributing diagram at the corresponding time t, multiplied by the rate of excess rainfall. Thus if the rate of excess rainfall is reduced by 25 percent, the peak rate of runoff will also be reduced by 25 percent. The rate of runoff is therefore largely influenced by those factors which affect the rate of excess rainfall. For constant loss conditions, variations in the rate of total rainfall will directly affect the rate of runoff and the basin is clearly sensitive to changes in rainfall intensity. On the other hand, for a constant rate of total rainfall, changes in land use which increase the rate of infiltration, for example, will reduce the rate of effective rainfall and so directly reduce the rate of runoff. The basin is therefore also sensitive to changes in land use. Some of these effects are illustrated in Figure 3.

The simplified equation discussed above is based on the assumption that there are no delaying storage effects, such as detention or channel storage, which would act to attenuate the theoretical hydrograph represented by Equation (1) and reduce its peak. The expression $g'(t)$ is the differential of the time area contributing diagram; the graph which this expression represents is called the incremental time area diagram for the basin. For a hypothetical catchment with no storage effects this represents the instantaneous unit hydrograph for the basin, i.e. the

hydrograph of runoff which would result if one inch of excess rain was precipitated instantaneously onto the basin. For a real basin the instantaneous unit hydrograph is essentially the incremental time area diagram routed through all the storages in the basin. If we express this unit hydrograph by $q_i = h(t)$, then Equation (1) can be re-written in the form

$$q_T = \int_0^T x(T-t)\, h(t)\, dt \qquad \ldots\ldots.(2)$$

which is an expression for the hydrograph of runoff from a real basin, in terms of the hyetograph of excess rainfall and the instantaneous unit hydrograph. This equation can be applied to basins of any size, the instantaneous unit hydrograph being an integral expression of all the <u>physical</u> characteristics of the basin which affect the shape of the runoff hydrograph it produces. The extent to which it is dominated by storage characteristics is a function of the routing effects of the variety of storages on the basin, which will be discussed in further detail in the next section of this paper, and determines whether or not the basin behaves as a "small" one or a "large" one in the hydrologic sense.

RUNOFF CHARACTERISTICS OF THE LARGE BASIN

In most watershed management problems the basin for which land treatment measures are proposed represents only a small sub-area of a much larger basin, made up of a number of sub-areas connected by an extensive channel system. This greatly complicates the problem of estimating the effects of the proposed changes on, say, flood peaks or sediment yields at the lower end of the basin.

The mechanics of this problem have been explained in some detail by Leopold and Maddock in the classic discussion of watershed management effects presented in their book "The Flood Control Controversy",[4] which might be considered essential reading for all participants in this symposium. The following section is based largely on their discussion.

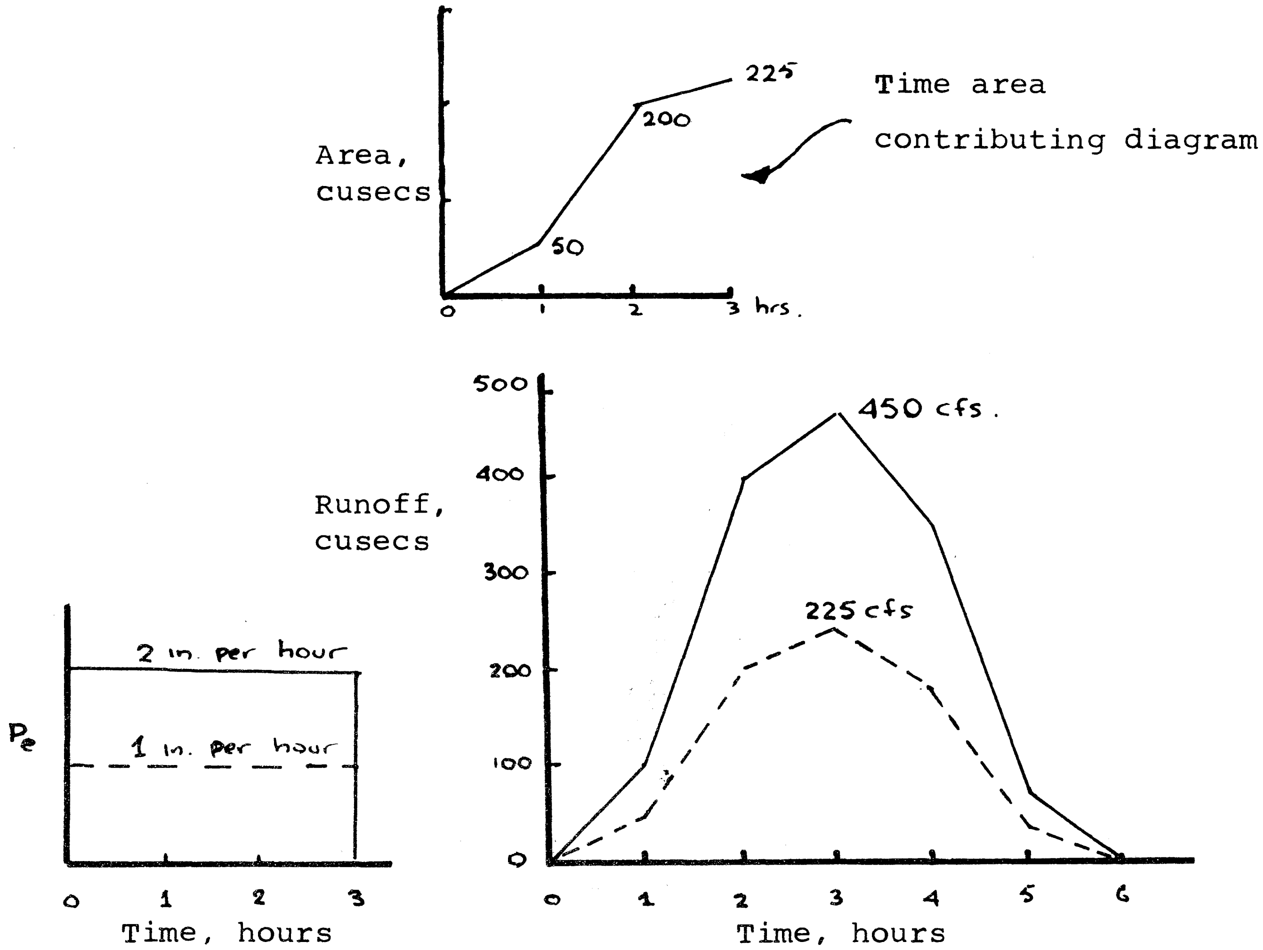
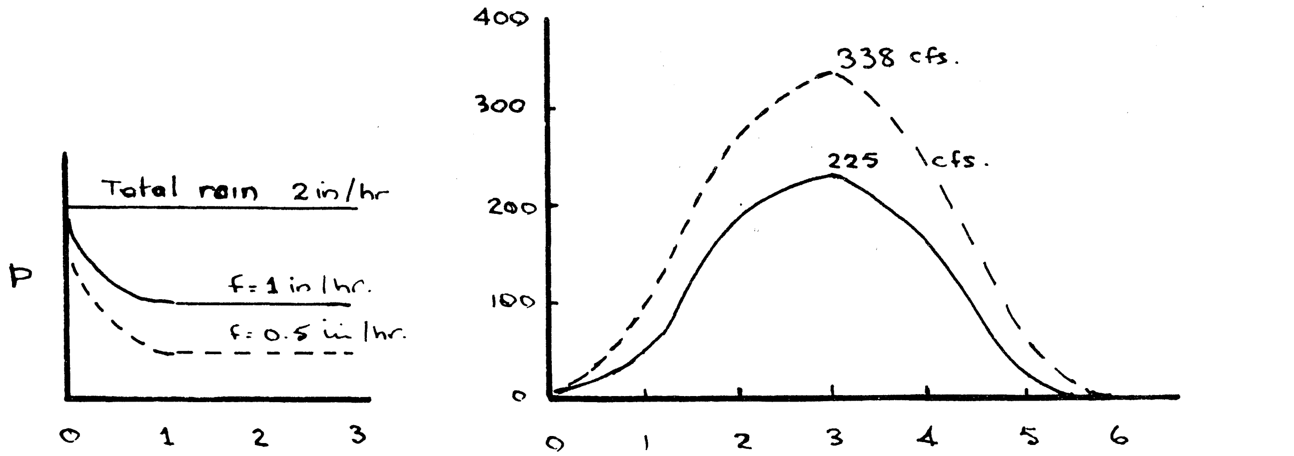


Figure 3 - (a) <u>For Constant Loss, Doubling Rate of Effective Rainfall Doubles Rate of Runoff</u>



(b) <u>For Constant Total Rain, Doubling Infiltration Capacity Reduces Rate of Runoff</u>

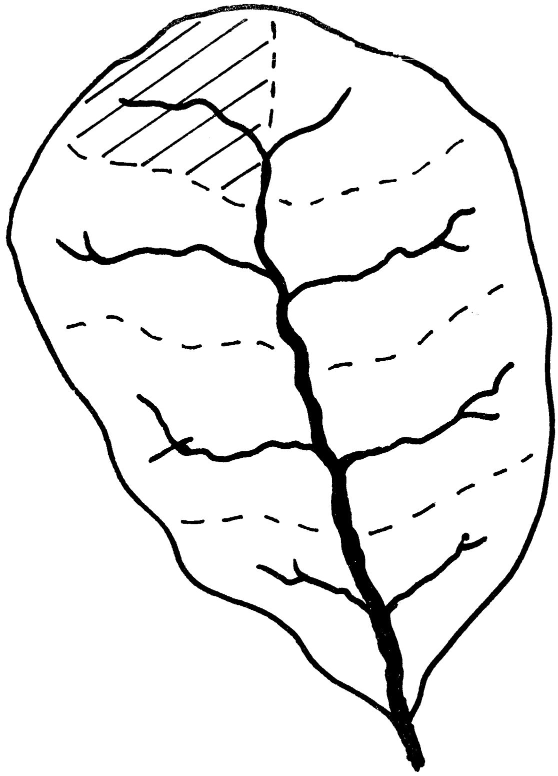


Figure 4 - Large Basin Comprising a Number of Sub-Areas

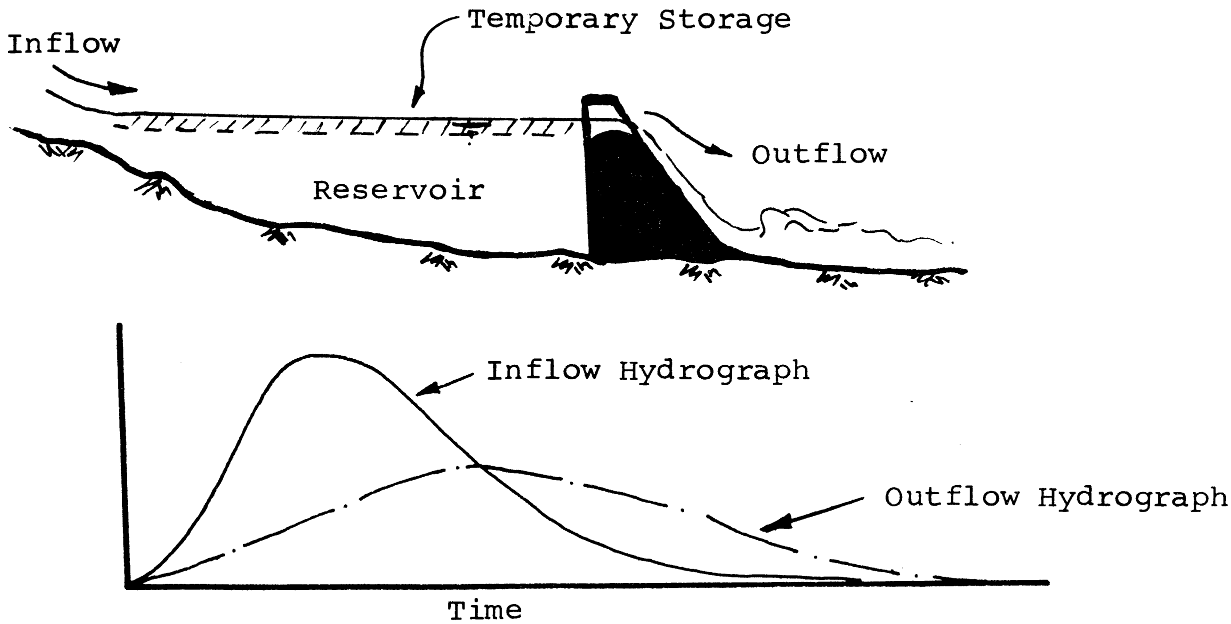


Figure 5 - Routing Effect of a Reservoir

Figure 4 shows a hypothetical catchment made up of a number of sub-areas. Consider first that rain falls only on the small hatched sub-area at the upper end of the catchment and a resultant flood wave travels downstream to the basin outlet.

On its passage downstream this hydrograph will be modified in shape because of the storage effects of the stream channel, which generally have the effect of delaying and attenuating the flood wave and reducing its peak. The simplest example of this routing effect is found in a simple reservoir, as shown in Figure 5. As water flows into the reservoir, it causes a build-up in storage level which produces the head necessary to produce outflow from the spillway. The effect of this temporary storage of water is to reduce the rate of outflow as compared with the rate of inflow, by an amount which depends on the storage capacity - elevation characteristics of the reservoir and the hydraulic characteristics of the spillway.

A flood hydrograph passing down a river channel is subject to two kinds of routing effect; translation in time, and attenuation or reservoir-type routing. In a long, uniform channel the storage effect may be negligible; a stream section which has considerable storage capacity above normal streamflow level may however act very much as a reservoir and produce a considerable reduction in flood peak as the flood wave passes downstream. Figure 6 illustrates this point for the case of a specific flood wave routed downstream through three successive channel sections. Figure 7 shows schematically how the same effect would reduce the flood peak as the hydrograph produced by the small sub-area of Figure 4 passes downstream to the basin outlet.

The channel section downstream of the sub-area will increase progressively in capacity as the area above it increases in size. As the flood hydrograph from the sub-area passes downstream it will therefore only surcharge the stream banks for a relatively short distance, until the channel capacity becomes great enough to accommodate the

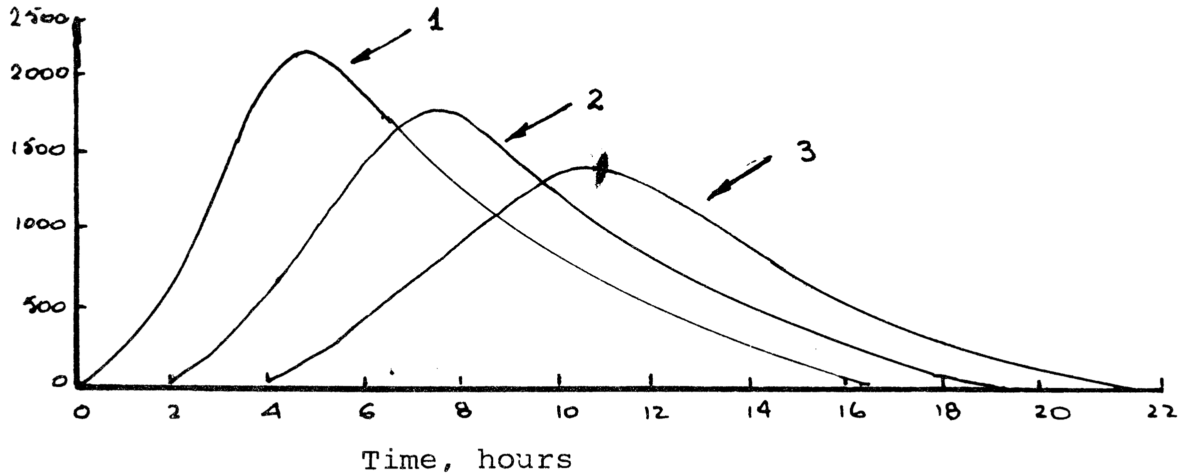


Figure 6 - Routing of Flood Hydrograph Down a River Reach

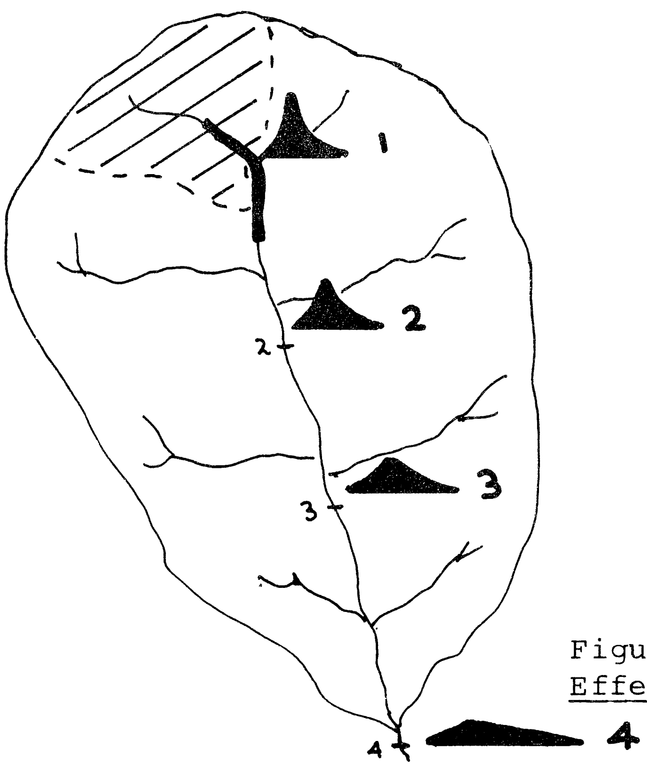


Figure 7 - Routing Effect of Channel System

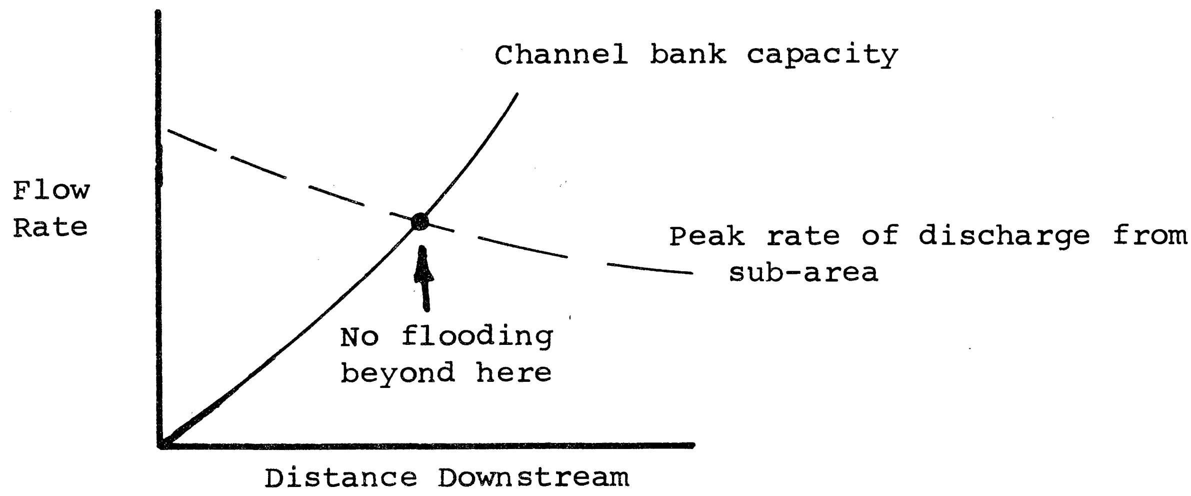


Figure 8 - Extent of Flood Downstream of Sub-area

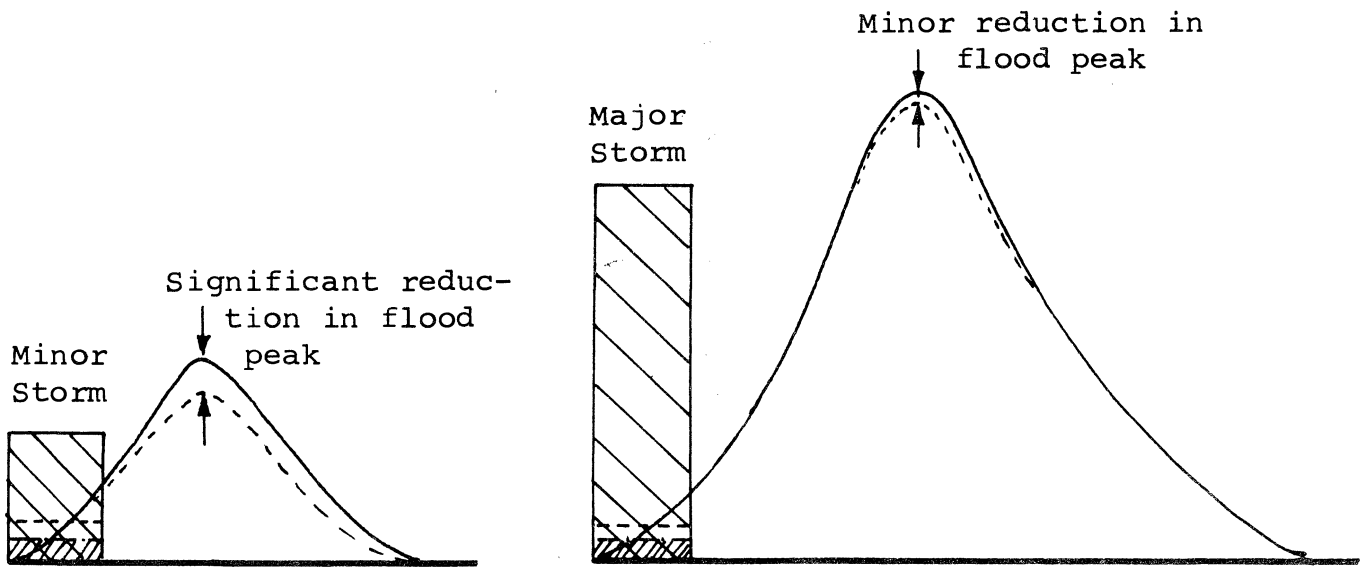


Figure 9 - Effect of Increased Loss Rate on Minor and Major Storms

flood discharge. This effect is illustrated schematically in Figure 8. The stream section subject to flooding downstream of the sub-area is shown as a heavy line on Figure 7.

Although the sub-area under discussion may be one which is highly sensitive to land use changes, it will therefore be clear that the effect of any change will become less and less important as the flood wave passes downstream, due firstly to the routing effect of the stream channel system and secondly to the fact that the area subject to flooding is only a relatively short section of the channel immediately downstream of the sub-area in any case.

A third point of some significance is that the effects of such a change on the rate of effective rainfall over the sub-area is in the form of a more or less constant loss rate which becomes relatively less significant as the total amount of rainfall increases. Thus a land use improvement measure which increases the overall loss rate by 10 points an hour may have a major effect on a storm of low recurrence interval but only a very minor effect on a great storm, as indicated in Figure 9. The practical magnitude of such changes should also be emphasised. Whilst it is not uncommon in infiltrometer measurements to obtain infiltration capacity rates of the order of three inches per hour and more, a detailed study of available loss rate figures from large catchments in New Zealand, Australia and the U.S.A. [5,6] has shown that actual average loss rates are in fact very much lower than this, being only of the order of 5 to 20 points per hour for New Zealand conditions.

Consider now the effect of a rain spread uniformly over the whole basin so that each sub-area contributes runoff to the basin outlet. The situation is depicted in Figure 10. Because of the delaying and attenuating effects of the stream channel system, the flood hydrographs from each sub-area will arrive at different times and the combined total flood hydrograph for the basin will have a peak rate of discharge much lower than the simple total

of all the sub-area peaks. Thus, proceeding downstream from the most remote sub-area, the peak discharge will increase as the contributing area increases but the discharge per unit area of contributing catchment will decrease, as shown for a real example in Figure 11.

From the foregoing it should be clear that a land treatment change which has caused a major reduction in flood peak on one of the sub-areas may have a negligible effect on the peak discharge at the outlet of the basin. Even if all the sub-areas were so treated, the attenuating and delaying effect of the channel system would appreciably reduce the effect at the basin outlet. In practice, in any case, it is clearly not possible to effect drastic land use changes over all the sub-areas of a major basin, as should be evident from a consideration of the nature of the mountain catchments of South Island rivers such as the Waimakariri or the Rakaia.

Finally, reference again to Figure 8 will indicate that even if all the sub-areas can be controlled, either by land treatment or the construction of detention reservoirs, in such a way as to reduce sub-area flood peaks substantially, the effects will only be felt so far downstream of each sub-area as the channel capacity is exceeded. In a major, catchment-wide storm the whole channel system may be surcharged, regardless of such measures, and prevention of widespread flooding can only be achieved by specific flood control measures in the lower basin. Effective control of the entire basin requires the integration of both upstream and downstream measures: upstream watershed management practices and downstream river control practices are clearly complementary, one alone being no substitute for the other. The watershed manager and the river control engineer must therefore function as a team if overall management of the waters of the basin is to be achieved.

The preceding discussion has been concerned with flood flows, which allow of fairly rational analysis. The same general arguments can be postulated, however, to indicate the relative importance of watershed management

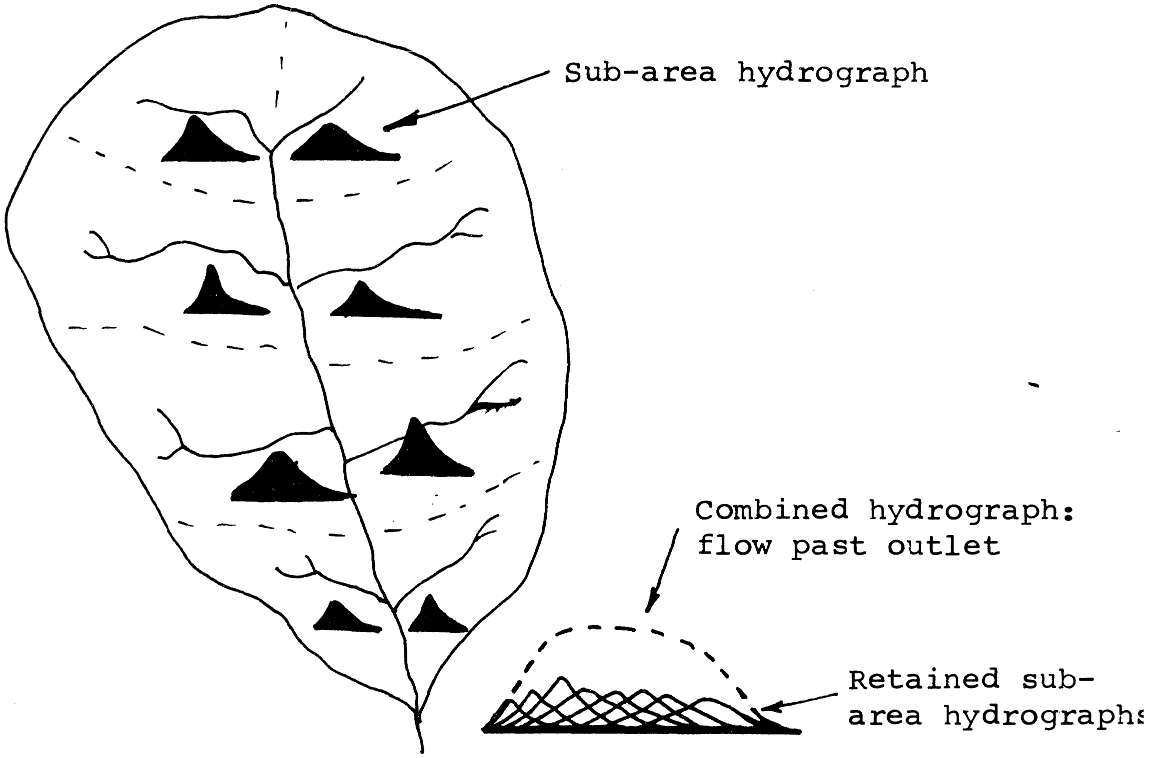


Figure 10 - Flood Flows from Basin-Wide Storm

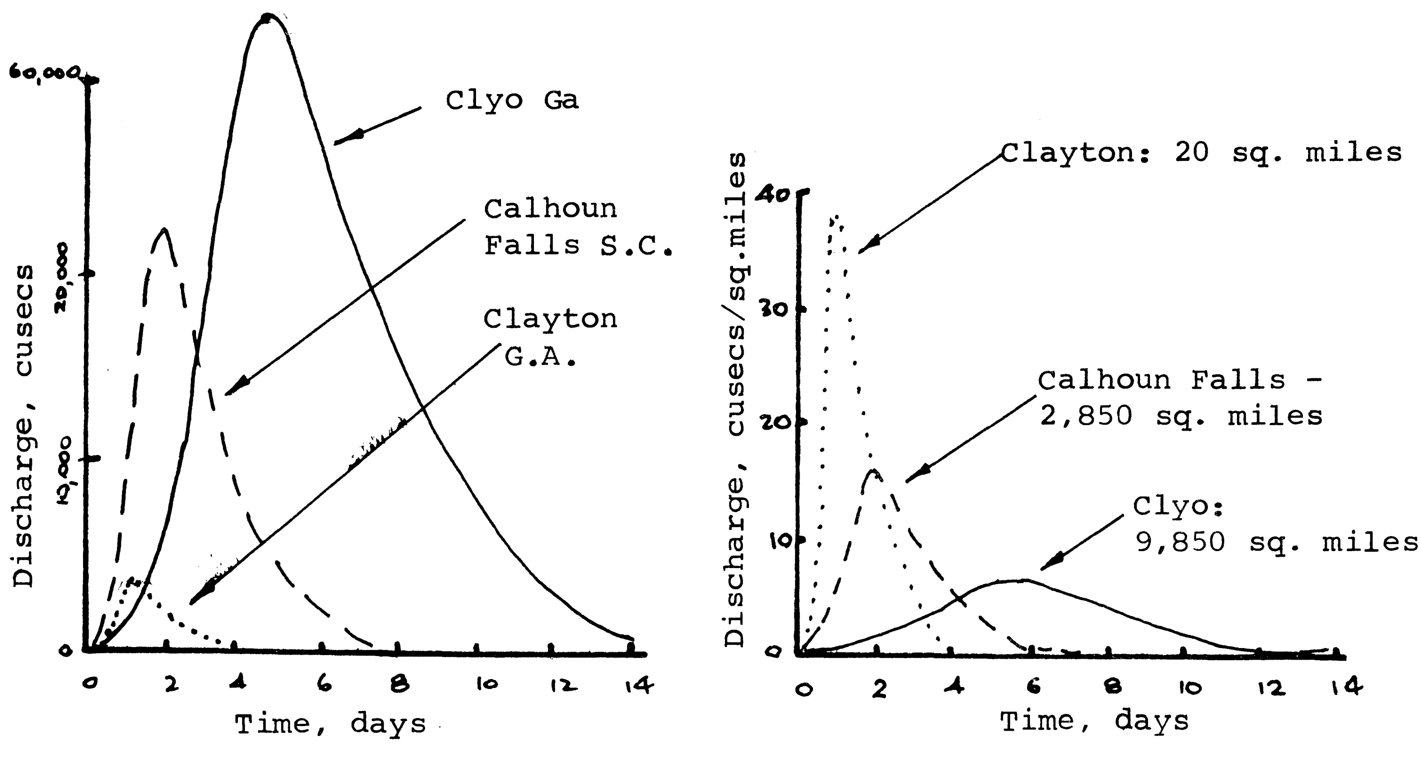


Figure 11 - Movement of a Flood Hydrograph Down the Savannah River (see ref. 1)

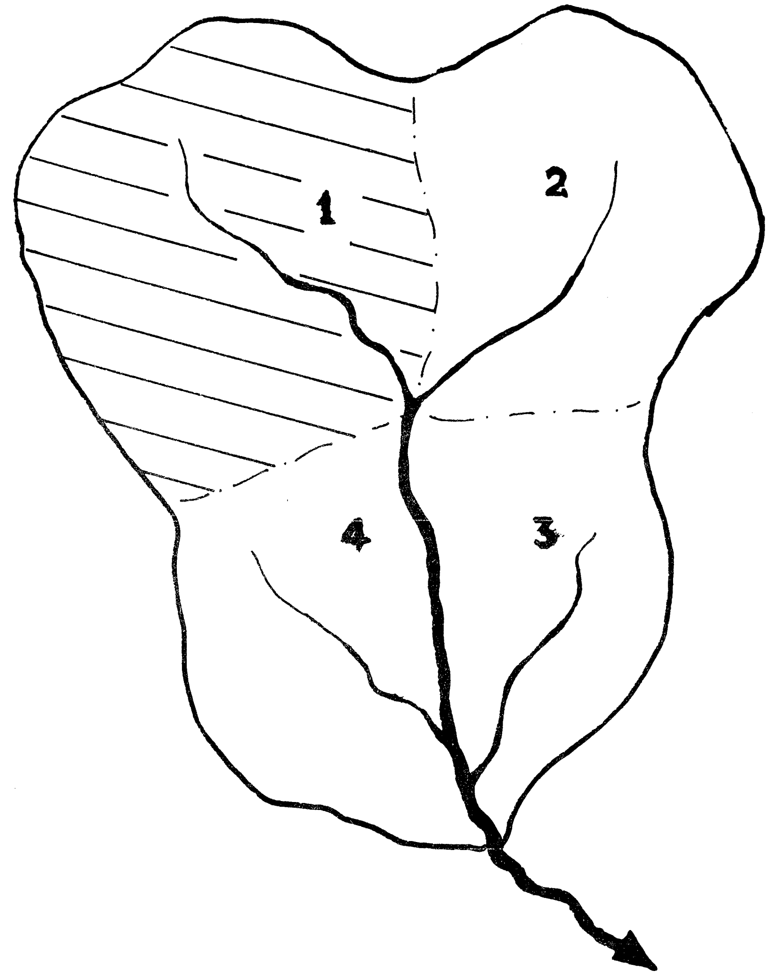


Figure 12 - Hypothetical Basin Comprising Four Sub-Areas

in the manipulation of basin yield, water quality or sediment movement. The essence of the preceding discussion might be paraphrased as follows -

a. Land treatment measures are most likely to be effective on basins which are sensitive to changes in rainfall intensity and whose runoff characteristics are dependent largely on overland flow. Such basins are defined as hydrologically small and are not likely to exceed a few square miles in area.

b. On larger basins the effects of land treatment changes are largely suppressed by channel storage effects in the stream channel system.

c. The relative effect of land treatment at downstream sites become proportionately less as the magnitude of the flood-producing storm increases.

d. Watershed management effects on small sub-areas of a large basin are most beneficial immediately downstream and control of flood flows further down the basin requires extensive use of river control engineering techniques. Conversely, no amount of downstream engineering can be expected to have any effect on flooding or sediment yield from the sub-areas of the catchment. Watershed management and downstream flood control are clearly complementary facets of the overall problem of river basin development.

QUANTITATIVE EFFECTS OF LAND USE CHANGES ON STREAMFLOW CHARACTERISTICS

The preceding discussion has been largely qualitative. Practical problems of watershed management and river basin development pose the need for specific, quantitative answers from which the likely effects of a proposed treatment can be evaluated in terms of cost and benefit. As an example, the author and others have recently been asked to give specific numerical values for the effects of forestation on the Waimakariri Basin to an elevation of

3000 feet, in terms of physical changes in flood flows, water yield, water quality and sediment movement.

It might be considered reasonable to pose such a question, on the grounds that an enormous amount of research has been conducted during this century into the effects of forestation and other forms of land treatment on water yields, flood flows and erosion. The reports of this research comprise a vast literature, which is as inconclusive as it is extensive.

The most comprehensive recent survey of the literature on the effects of land management on water yield was presented by A.R. Hibbert at an international symposium on forest hydrology held at Pennsylvania State University in 1965.[7] Following a detailed analysis of 39 forest treatment experiments from several countries, Hibbert concluded that -

"The following generalisations can be made:

1. Reduction of forest cover increases water yield.

2. Establishment of forest cover decreases water yield.

3. Response to treatments is highly variable and, for the most part, unpredictable."

Fifteen years earlier Leopold and Maddock[4] analysed the results of some 400 plot and watershed experiments conducted by staff of the U.S. Soil Conservation Service. The basins concerned were all small, 80 percent being less than 100 acres in area with a median size of only 2½ acres. There was a very considerable variation in the results obtained and no useful quantitative data could be drawn from them, the major conclusion being that the bulk of the experimental data had never been properly analysed. Whilst some startling effects of land treatment were recorded on small plots, in many cases these resulted from impractical treatments. Particularly noticeable was the wide variation in results - in an analysis of the effects

of terracing on individual storm runoff volumes, for example, results varied from complete elimination of runoff to a 40 percent increase in runoff. It was generally concluded by the authors that whilst the qualitative effects of land management on erosion and runoff had been adequately demonstrated, very little in the way of quantitative results had been obtained, particularly from large catchments.

Similar conclusions were drawn a few years later by Sharp, Owen and Gibbs [(8)] in a study of the results of a number of land treatment experiments in the western U.S.A. In this study records from some seventy-five river basins, ranging in area from 225 square miles to 8490 square miles, were analysed but the results were inconclusive. In no case was it determined whether or not changes in land use had significantly affected streamflow. Additional analysis of some 120 experimental basins, mostly only a few acres in extent, yielded somewhat more definite results, indicating that conservation practices might reduce surface runoff by from 25 to 40 percent, particularly in dry years. There was no evidence that these findings could be extrapolated to larger catchments.

This study did serve to emphasise the complexity of hydrologic processes and to point out the inadequacy of most of the data collection procedures used - in general, experimental errors in the measurement of such simple parameters as rainfall and runoff were considerably greater than the magnitude of the changes which were being investigated, and in most cases many possible parameters such as rainfall intensities, storm patterns, soil moisture characteristics etc. were not measured at all. The authors did however conclude that for large basins at least 25 percent of the total area would have to be subjected to a given form of land treatment before any significant effects of that treatment could be measured.

Notwithstanding the results of these comprehensive surveys, many authors have drawn quite positive conclusions from land treatment studies, particularly in relation to the effects of forest removal or reforestation on water yields and flood flows. Thus Nakano,[(9)] on the basis of

16 to 22 years of record on small forested catchments in Japan, claimed that the removal of forest vegetation increased annual runoff by from 8 percent to 24 percent, low flows by from 74 percent to 84 percent and peak flows by from 69 percent to 114 percent. Anderson,[10] in studies of the effects of forest removal on large basins in the Pacific North West, claimed that logging over 168 square miles of the 4,840 square mile Willamette Basin had increased the peak flood from the whole basin by 30 percent, and in another study[11] of a series of basins ranging from 5.7 to 7,280 square miles was confident enough to claim that the clear felling of 1 square mile of forest in the area below the snow-line would increase flood peaks by 103 cusecs!

By comparison, some authors have shown an increase in water yield following an increase in forest cover. Thus Black[12] has shown an increase in yield from an 180 square mile basin in New York State during reversion from farming land to mature forest, whilst several Russian authors[13] have shown an increase in water yield following afforestation. Ivanov[14] and others have in fact claimed that there is an optimal proportion of forest cover for a large basin, below and above which flood flows increase and water yields decrease.

Any student of the literature becomes discouraged at about this point, and is likely to revert to Hibbert's conclusion that "response to treatments is highly variable and, for the most part, unpredictable". Whilst this may give satisfaction to those who have been subjected to extravagant claims from conservation enthusiasts about the overwhelming advantages of their favourite treatment practice, it is frustrating in the extreme for those who might be required to plan watershed management treatments and justify them on economic grounds. It is highly disturbing when one considers the magnitude of some of the land treatment proposals now being made for parts of New Zealand, such as the Poverty Bay - East Cape area, and realises that hundreds of thousands of dollars are likely to be expended on projects whose outcome is "for the most part, unpredictable". If the available data are insufficient

for the making of rational decisions about land treatment measures, decisions will nevertheless be made. There is a clear and urgent need for some alternative approach which will at least provide an approximate but quantitative estimate of the effects of proposed land use changes. A possible means for doing so is the subject of the final section of this paper.

SENSITIVITY ANALYSIS AS A GUIDE TO WATERSHED MANAGEMENT

A major reason for the lack of conclusive, quantitative evidence from the vast amount of hydrologic research described in the literature cited has been the failure of the researchers concerned to appreciate the complex and stochastic nature of the runoff process. In most cases the accepted form of analysis has been a multivariate correlation between a few major and often inadequately measured parameters, and there has been little attempt to understand the essential mechanics of the process under investigation.

In the past decade there has been a concentrated effort, particularly amongst engineering hydrologists, to understand and simulate the runoff process itself and identify and quantify the physical parameters which govern the relationship between rainfall and runoff. This investigation has taken two main directions. On the one hand there have been many attempts to represent the basin analytically as a linear or non-linear system, expressing the rainfall-runoff relationship in terms of the convolution integral given earlier as Equation 2, which relates runoff to rainfall input and the instantaneous unit hydrograph of the basin. On the other hand, several investigators have attempted to represent the basin by a parametric physical model, usually simulated in the digital computer, which incorporates such phenomena as interception, infiltration, interflow, soil moisture storage and so on. A third approach, still in its infancy, is to use an hydraulic scale model of the basin, on which artificial rainfall is applied via an overhead sprinkler system and the flow of water over the model surface is studied and measured.

Many of the models mentioned above have successfully been used for flood prediction and one of the second class of parametric models, the Stanford Mark IV watershed model[15] is in commercial use for water resources development planning. Their effectiveness as predictors of likely land use changes is restricted, however, by the dearth of quantitative field information about the effects of these changes on the basin parameters; a rather unfortunate reflection on the great accumulation of hydrologic data which has been made around the world in connection with land use investigations of the type discussed in the preceding section of this paper.

Whilst most of the models referred to have been designed to produce accurate predictions of flood peaks or yield volumes for the design of hydraulic structures, it is by no means essential to place specific numerical values on land treatment effects. In most cases the establishment of a break-even point, below which a proposed treatment can be justified and above which it cannot, is all that may be necessary to decide whether or not it should be implemented. Suppose, for example, that a computer model has been developed for a large basin and the possible forestation of a specific sub-area is being considered. Even though no information whatever is available about the change in loss rate to be expected on the sub-area after it has become fully forested, the introduction of several trial values for this loss rate into the model may show, for example, that a value of at least three inches per hour will be necessary to achieve a 5 percent reduction in flood peak at the basin outlet. In other words, three inches per hour is the break-even point for the loss rate on the sub-area if a reduction in flood peak of at least five percent is the accepted design criterion. Since a loss rate of this magnitude is greatly in excess of what might be expected from any forested area, the basin is evidently insensitive to forest treatment on the particular sub-area under investigation and the proposal can be rejected without the need for any specific numerical estimate of its effects. An hydrologic sensitivity analysis of this type can thus provide a useful tool for decision making, even in the absence of accurate quantitative data; in line with the

current trend for the classification of hydrology into sub-fields, e.g. parametric hydrology, stochastic hydrology, etc., this approach might be called ball-park hydrology!

There is nothing particularly novel about this technique, which is based on the standard procedure used by engineers of the Agricultural Research Service of the U.S. Department of Agriculture to assess the effects of land treatment measures (16) and essentially involves the routing of assumed sub-area discharges downstream to the basin outlet. Whereas, however, that procedure depends upon "hydrologic soil cover complex" numbers which have been evaluated for a large variety of U.S. conditions, the suggested technique depends primarily upon the concept of basin sensitivity. Its application does not necessarily require a digital computer, but does depend upon a reasonable amount of basic hydrologic data from the basin concerned. Consider, for example, the basin shown in Figure 12, which comprises four sub-areas, and suppose the possible effects of land treatment on the hatched sub-area are to be investigated with regard to possible reduction in the 100 year flood peak at the basin outlet. Sufficient hydrologic data are required to derive unit hydrographs at the outlet from each sub-area, to route flood hydrographs for assumed loss conditions downstream to the basin outlet, and to estimate the temporal and areal pattern of the 100 year design storm. The amount of additional information needed beyond this minimum will depend upon the precise nature of the problem; if, for example, the basin appears to be highly sensitive to changes in loss rate on the hatched sub-area, more detailed information about this area will be needed and a special programme of data collection might have to be implemented.

Under New Zealand conditions even this simplified technique of sensitivity analysis may be difficult or impossible to employ effectively because of deficiencies in the available data from the basin under investigation. Consider, for example, the case of the Waimakariri basin, now being studied by the author and others. This basin has a total area of 1,420 square miles, rising in the Southern Alps at elevations as high as 8,000 feet and

crossing the Canterbury Plain to discharge into the Pacific Ocean just north of Christchurch, the second largest city in the Dominion, which it has flooded on several occasions in the past 100 years. There are only two streamflow gauging stations on this river, one near the mouth and the other where it emerges from the mountains at the Waimakariri Gorge, and neither of these has a very satisfactory rating curve. There are no gauging stations anywhere in the upper catchment; the type of sensitivity analysis discussed above is not feasible on this basin unless synthetic unit hydrographs can be derived for the sub-areas from some form of mathematical model, a possibility which is now under investigation.

In the course of a search for alternative basins having suitable sub-area gaugings, made in the hope of providing some verification of possible synthetic model approaches, it became apparent that there are few really suitable data networks anywhere in the South Island. Since it is inevitable that major land use changes of one form or another will eventually be proposed for most of the large basins in New Zealand, there is a serious need for a carefully planned extension of the national data collection network to ensure that sufficient information becomes available at least to undertake the type of simplified sensitivity analysis discussed herein on all major basins. So far as the effects of land treatment on flood flows are concerned, sufficient data for the derivation of sub-area unit hydrographs can quickly be collected by installing pressure-type recorders on appropriate sites for two or three years and ensuring that ample streamgauging manpower is available to rate these sites for every major rise recorded. For the collection of data on water yield and sediment movement much longer periods of record are desirable, but even records of a few years duration would provide some basis for quantifying the essential parameters sufficiently to undertake a sensitivity analysis.

Regional Water Board staff, now faced with the need to measure their total water resources to meet the objectives of the Water and Soil Act, should consider this aspect carefully in relation to any proposed augmentation of their

data collection networks. Any hydrologic data collection programme in New Zealand, where resources of equipment and manpower will always be limited, should be problem oriented and designed to answer specific questions about the mechanics of basin behaviour; there is little point in collecting data for data's sake in hydrology. The same problem should be emphasised in relation to the national Experimental Basin programme, which should aim at a supporting understanding of the runoff process rather than at the proliferation of ad hoc land use experiments of the type so justifiably criticised by Leopold and Maddock or Sharp, et al (Op. cit.). It is reassuring to note that this point has been amply appreciated in the planning of recent experimental basin programmes.

Finally, it is pertinent to comment on the ultimate purpose of an investigation into the effects of changes in land use on streamflow characteristics. In New Zealand it has at last become fashionable to make cost-benefit analyses of water development proposals. In the case of the recent Poverty Bay-East Cape investigation[17] for example, an attempt was made to justify large scale forestation on the basis of a cost-benefit analysis which depended upon estimates of the likely effects of forest introduction on soil erosion and flood flows. The current Waimakariri investigation, referred to earlier in this paper, was initiated in an attempt to provide figures with which a proposal for large-scale forestation might be justified on the grounds of its effects on streamflow characteristics.

But how relevant are such effects in the final analysis? What is the economic significance, for example, of a five percent reduction in the mean annual flow of the Waimakariri when the river is devoid of any form of water resource development project and no revenue whatever is derived from water sales? What is to be gained by reducing the 100 year flood peak from 160,000 cusecs to 140,000 cusecs, when a major levee system to accommodate 160,000 cusecs has just been completed? It would be more logical (and would certainly be easier!) to justify proposed land treatment measures on the Waimakariri solely in terms of the greater production they engender on the upper basin as

a consequence of higher stocking rates or increased logging potential, rather than to attempt to justify them in terms of possible reductions in soil erosion or flooding: no matter how appealing the latter might be to politicians, general public or the mass media.

Clearly, there can be no standardised approach to benefit-cost analysis in water resource development, any more than there can be to hydrologic analysis: each problem is different and must be tackled on its own terms. One advantage of the sensitivity analysis approach discussed above is that it provides a basis for deciding whether or not a project should be justified on hydrologic grounds. If a basin is insensitive to land treatment changes on a particular sub-area, there is no point in attempting to justify proposals for that sub-area in terms of downstream flood mitigation, no matter how desirable these proposals might be from other viewpoints. If, on the other hand, the basin response is highly sensitive, considerable expenditure on hydrologic and economic investigation might be essential before a valid decision can be reached. If nothing else, sensitivity analysis must lead to economy in data collection by identifying those areas for which precise data are needed, as distinct from those for which approximate information is adequate.

CONCLUSION

Watershed management is an important and integral part of river basin development. It has clear limitations, however, and is more likely to be beneficial to the area within and immediately downstream of that treated than to the basin as a whole. In advocating the adoption of large-scale land treatment measures, particularly on the basis of the experimental treatment of small trial areas, careful attention must be given to the hydrologic differences between "small" and "large" catchments and the relative significance of overland and channel storage effects as determinants of basin behaviour.

Although there is an extensive literature on the effects of land treatment on streamflow characteristics, much of it is inconclusive and provides little guidance for the planning of specific watershed management proposals. A form of sensitivity analysis to determine the likely response of the basin to changes in sub-area condition is a useful tool for assessing the likely effects of land treatment on runoff. At the present time most New Zealand basins are inadequately instrumented for any detailed analysis of basin sensitivity and a planned extension of the national data collection network is an essential prerequisite to the inevitable development of large-scale land management practices.

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LAND-USE IN RELATION TO WATER YIELD AND WATER QUALITY

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SUMMARY

Conservationists have been described as people "who, in one way or in many ways, are concerned that the relationship of Man and Nature evolve in directions that are more beneficial to Man, and more acceptable to Nature". (Fisher, 1969) The role of the watershed manager is that of a conservationist working toward and maintaining an ecological balance in catchment areas. He is at the same time managing the catchment according to objectives which have been carefully determined from an examination of the downstream demands on the catchments water resources. Where possible his management policy is co-ordinated with other catchment-uses, so that the area is in fact being "used" to the full.

This paper examines the extent to which the watershed manager may, by adopting particular land-use methods and techniques, influence water yields and their regimen. The effect of land-use on various components of the water cycle (viz precipitation, interception, evapotranspiration, depression storage, infiltration and overland flow, and soil moisture storage) are considered from a theoretical standpoint that recognises that the magnitude of influence varies according to the size of the catchment, the kind of land involved, and the time increment of the precipitation that is considered. (e.g. individual rainfall event, monthly total, annual total.)

The paper reviews New Zealand experience in the effect of land use on water supply and discusses the results of some overseas experiments that should have at least qualitative relevance in this country.

Water quality has been defined as "that condition of water affecting adversely or beneficially any use or uses to which the water may be put". (O'Connor, 1968) The quality requirements of different uses are outlined and the various parameters of water quality are discussed with special reference to those that may be influenced by land-use and management.

The paper concludes with an assessment of watershed management objectives for the New Zealand situation, and the attitudes being shown toward them.

INTRODUCTION

Conservationists have been described as people "who, in one way or in many ways, are concerned that the relationship of Man and Nature evolve in directions that are more beneficial to Man and more acceptable to Nature" (Fisher 1969). The role of the watershed manager is first and foremost that of a conservationist working toward and maintaining an ecological balance in catchment areas. In this way he is ensuring control of the water resource insofar as the resource can be controlled by land management. The type of control that is required must be determined from a careful appraisal of the downstream demands on the catchment's water resource, and the watershed manager's task is to determine the probable hydrologic impact of alternative uses on various areas within a catchment and to devise a management plan which harmonises land-use with downstream demands for supply and control of water. In this way watershed management truly evolves for the benefit of Man and in a manner that is acceptable to Nature. The following discussion looks at the relationship between land-use and the two most important downstream demands - the control of water and the influence on water quality.

LAND-USE AND WATER YIELD

The immediate question that comes to anyone's mind when thinking about water as a catchment "product" is, "to what extent can land-use affect 'how much' and 'when' water appears in the stream?" The I.H.D. experimental basin programme is designed to look at this very question. The results from these empirical studies are awaited with interest, but their interpretation and extrapolation to other areas requires in the first instance a full

appreciation of the relative significance of the processes and factors influencing the behaviour of a catchment. We can start by looking at the conventional components of the water balance in a catchment, in relation to the effect that land-use may or may not have on them.

<u>Land-use and Precipitation</u> - The kind, amount and rate of precipitation is determined by meteorologic conditions and circumstances. However, precipitation may be modified by land-use. Fog-drip at the edge of forests has been observed overseas to significantly increase the precipitation and any musterer in our high country will testify to the amount of moisture that is caught by tussocks during fog or low cloud conditions when it has not been actually raining. The actual significance must vary according to the local situation, but the point may be made that any process towards denudation reduces the importance of this factor. Any land-use which may influence overhead temperatures could also affect precipitation. Precipitation is caused by conditions that favour the release of water vapour from the air, and temperature changes are important in this regard. Convectional storms are not infrequently associated with burnt of denuded areas, at least in the eye of the local soil conservator, and it has been conjectured that temperature differentials immediately above the area may have contributed to the initiation of precipitation. It has also been argued that temperature changes over afforested areas influence precipitation in those areas. However, in the New Zealand situation forests tend to be where the rainfall is, rather than the converse. Techniques using snow fences and patterned cutting of timber have been developed overseas to hold snow in a particular catchment and to induce snow drifts which take longer to melt out in the spring. As far as catchment response is concerned, precipitation patterns are thereby influenced. Artificial augmentation of precipitation by irrigation and cloud-seeding falls rather outside the present discussion. Interesting as land-use/precipitation relations may be, it can only be concluded that with the exception of snowpack management, the inter-relationship is strictly academic rather than practical.

Land-use and actual evapotranspiration - Potential evapotranspiration is determined by the climate of the area. However, the actual value can vary according to the amount of moisture on the surfaces and in the soil, and according to the ability of the vegetation to make use of it. If we are considering flood-flows in streams this factor is unlikely to be of any real significance since actual evapotranspiration is principally governed by physical conditions that will have no appreciable magnitude during high intensity rainstorms. However, in the long term it is important to note that apart from deep percolation this is the only parameter than can divert water from streamflow. From a practical management point of view it is generally agreed that the replacement of deep-rooted vegetation with shallow-rooted will leave more water available for stream-flow, provided that soils are sufficiently deep and extensive enough to permit significant reduction in evapotranspiration and provided there is a water surplus over and above that required to satisfy soil storage. It is also interesting to note that a vegetated catchment is continuously drawing water and that the loss due to evapotranspiration is likely to be much greater than for a denuded catchment where a covering of fine soil is insulating the lower layers from moisture depletion. However, here we have an important inter-relationship to consider - that of the influence the vegetative cover has on the capacity of the soil to take more water in.

Land-use and Interception - The term 'interception loss' may be defined as rainfall per storm retained by the standing vegetation and evaporated without adding to moisture in the soil. Some investigators also include the litter layer with interception.

Our interest in actual interception values lies in assessing the value of different cover types in reducing the water available for flood runoff. The actual amount of moisture that a plot of vegetation can hold above ground level depends on its 'wettability', morphology, and certain rainfall characteristics such as intensity, duration and direction. Rarely is interception measured directly - in most studies it is taken as the difference between gross rainfall and that which reaches the ground by stem-flow and throughfall. Being a ' difference' any errors are

accumulated in the figure. The relationship of evaporation with inferred interception must also be carefully considered when interpreting values for interception.

The proportion of precipitation held by interception is relatively large for light showers. Aldridge and Jackson (1968) recorded no measurable throughfall in 14 foot manuka for showers less than 5 points, and Aldridge (1968) recorded no measurable throughfall in gorse for showers less than 7 points. However, the proportion held by interception falls rapidly for larger rainfalls and becomes only a small proportion of the major flood producing storms. Hoover (1962) concludes that while canopy interception does operate to lessen water reaching the stream during flood it is of major importance only in the smaller storms. For storms larger than 2 inches he concludes that based on present information, interception in forests would be less than 20 points. To the 20 points intercepted by the canopy must be added that intercepted by the litter. This figure is perhaps in the order of 1-2 points per ton of litter. In the absence of fire, 10 tons of litter per acre or more might be expected. The litter interception value per acre may be 20 points in this instance giving a total interception of up to 40 points of rainfall.

In considering the water balance of a site, it may be concluded the interception is of considerable importance especially in areas where rainfall events are dominated by low-intensity characteristics. Patric (1966) working on mature coniferous forest of south east Alaska reports an interception loss of about 25% of annual rainfall, while at Taita (N.Z.) Aldridge and Jackson (1968) report a 39% interception figure in manuka. The dry topsoil conditions under radiata pine noted by Watt and Leslie (in press) at Dunedin also testifies to the importance of interception under generally low-intensity rainfall conditions. This interception is often considered a 'loss' to the catchment, since it never directly contributes to soil moisture or stream flow. The extent to which it may reduce transpiration is a favourite debating point. McArthur in the discussion of Downes' (1964) paper comments that litter interception losses in protected eucalypt catchments in Australia

account for up to 60 points per rainstorm and contends that this significantly reduces stream flow.

A good deal more information is needed on the interception characteristics of other cover types before any useful land-use interpretations can be made. However, it must be noted that the influence on flood flows is likely to be minimal and that the influence on other flow characteristics will depend on whether a net gain in water is in fact achieved, and whether site characteristics can in fact make good this gain.

<u>Land-use and Depression Storage</u> - Water conservation techniques such as dams, contour works, etc. can increase the depression storage in a catchment, although their effectiveness during floods depends upon their ponding size and upon the associated infiltration and soil-depth factors. Precipitation that comes in rates or quantities greater than the capacity of the catchment to cope must appear as flood flow. With regard to stream flow over a longer period, any conservation measure which contributes to retarding water on the catchment must contribute to a more stable stream-flow regime providing evaporation rates are not excessive. Again the magnitude of the effect must vary according to parameters such as soil depth and infiltration capacity.

<u>Land-use, Infiltration and Overland Flow</u> - Whether or not overland flow occurs, is determined by the infiltration capacity of the soil. It is well established that a good vegetation cover with little soil compaction and adequate litter is a prerequisite to good infiltration rates. Kittredge (1948) concluded that the difference in infiltration between forested and cropped soils may be in the ratio 100:2 in the surface inch, and preliminary investigations in New Zealand indicate important influences being exerted on infiltration by vegetation conditions. Biological activity in the top soil horizons also influences infiltration as recently demonstrated by Stockdill and Cossens (1969) who observed a near doubling in infiltration over a 5 hour period following the introduction of earth-worms to a tussock block.

For peak runoff, the characteristics of most importance are the initial infiltration rate and the rate at which this decreases with time. The U.S.D.A. hydrologic

classification of soils is based on this principle.

A significant factor in the infiltration process is the concentration of a large amount of precipitation at the base of a plant. Patric (1966) concluded stem-flow in mature coniferous forests to be hydrologicallty unimportant, but varying species of Californian chapparral show 8% to 30% of the annual precipitation reaches the ground by stem-flow (Hamilton and Rowe, 1959). Hoover (1953) records 16%-18% of the annual precipitation delivered directly to the base of young loblolly pines. Aldridge and Jackson (1968) and Blake (1965) have recorded 23% and 31% respectively stem-flow as a percentage of total precipitation in manuka. A similar process probably occurs in tussocks. The significance of all this is the concentration of water where infiltration is likely to be greatest, and this 'conditioning' of the soil surface by plants is of great importance in water control.

Land-use and changes in soil-moisture storage -

The actual amount of precipitation that can contribute to soil storage is governed by three factors: the capacity of the soil to take more water in, the ability of the soil to allow water to infiltrate from the surface, and the ability of the soil to eliminate under gravity, water already in it.

The total water storage characteristics of a given area are governed by physical properties of the soil. Depth and porosity are the parameters of most significance. Land-use can influence these properties: practices which induce accelerated erosion reduce the depth of soil, and rooting characteristics of vegetation can be expected to influence the macroporosity in the upper layers although McDonald (1961) studying some physical properties of greywacke-derived soils failed to find significant changes in porosity between pasture and virgin sites. In examining the available water storage capacity of soils in a municipal supply catchment near Dunedin, Watt and Leslie (in press) differentiated between soil-detention storage, which they took as the stream-available portion, and soil-retention storage which they took as both the plant-available portion and that portion of soil moisture below the plant physiologists' 'wilting point'. To determine the soil detention storage an

estimate was made of macroporosity in the A and B horizons and this was related to the relevant depth to give a crude quantitative value (e.g. 8" topsoil @ 12% plus 22" subsoil @ 6% equals 2.28"). They then classified the whole catchment into arbitrarily defined hydrologic groups and by bringing slope into consideration as well, developed a soil-management-area concept that related the hydrologic grouping with potential for future management. The concept follows closely that of Leven and Willians (1967).

The capacity of the soil to take more water in is also influenced by the depleting effect of vegetation, and here differences in rooting depth and differences between evaporation and transpiration are important. In theoretically comparing losses from bare ground, grass and forest, Hoover (1962) reasons that over a 14 day period assuming a 0.25" evaporation per day, <u>bare ground</u> would lose 1.4" by a decreasing evaporation loss from only the top 15". <u>Grass</u> would lose 3.0" from the top 30" thus dropping the soil moisture to wilting point. And <u>forest</u> would lose 3.5" from 6 ft plus, the loss rate of 0.25" being maintained for the period.

The ability of the soil to eliminate water under gravity is largely an inherent characteristic but may be aided in certain circumstances by land management. Deep rooted legumes and some trees would be expected to aid percolation, while graded deep-ripping and land drainage have important consequences. In conditions where the permeability of the surface soil layers is high, water may move laterally through the soil to give a subsurface runoff. While this runoff can contribute to the flood runoff it does not carry appreciable sediment, and characteristically spreads the flow over a longer period, thus reducing the peak.

The land management technique known as "keylining", developed by Yeoman in Australia is perhaps the most positive attempt made to deliberately manage and utilise the soil moisture storage for agricultural purposes. Keylining involves cultivation techniques and supplemental irrigation, and has itsmajor impact in ironing out minor fluctuations in rainfall distribution.

CATCHMENT BEHAVIOUR A SINGLE PROBLEM:

The foregoing discussion of the influence of land-use on various components of the water balance emphasises the inter-relationships that occur. In looking at the effect of land-use it must be emphasised that the behaviour of a catchment is a single problem in which the interactions between the different components of the water balance are often more important than the individual characters.

Furthermore, over-riding these interactions within and between the components of the water balance is the dominating consideration of catchment dimension. Hydrologically functional catchments can be considered as having four dimensions - length, breadth, depth and a response that is in the 'time' dimension. Length and breadth give the surface area of a catchment and it can be argued that as far as water yield from such an area is concerned, the depth dimension is also intimately connected. The smaller the catchment area considered, the smaller is the depth dimension, and factors closely related to surface conditions assert an increasingly dominant influence on water yielding characteristics. As catchment areas increase these surface conditions assert a lesser influence, and water yielding characteristics become increasingly related to sub-surface conditions and channel storage characteristics.

This depth dimension takes into consideration infiltration, percolation and storage processes that have already been discussed to some extent. Deep soils not only have inherently a generally greater capacity for water storage, but if managed so that the condition of the soil surface is inducive to infiltration, water during a particular storm may be transferred to a slow-moving phase which will not affect the stream-flow during the flood period. It must be remembered, however, that the waterholding capacity inherent with depth may be modified by the porosity; a yellow-grey earth on 6 ft loess may have a lesser capacity than 18" yellow-brown earth on gravel.

The 'time' dimension is introduced because the water yielding characteristics of any catchment are all time-dependent. In the long-term the water yield from a

catchment can be simplified as equalling the precipitation less evapotranspiration losses and deep percolation. In the shorter term, interception, depression storage, and soil moisture deficits have also to be considered, while in the very short term stream-flow response will be directly related to the nature of a particular precipitation event, and the influence of land management may be all-important, or unimportant.

LAND-USE AND WATER YIELD - SOME OBSERVED RESPONSES

So much for the theoretical aspects of the influence of land-use on water yield. Without elaborating on a detailed examination of the pertaining circumstances it would be useful to list a few apparent responses to changes in the land-use regime that have been observed in New Zealand. Each deserves careful interpretation and extreme caution should be exercised in attempting to extrapolate these empirical observations outside of the particular circumstance. In no way does the list pretend to be exhaustive.

1. Golden Downs Forest, Nelson - Conversion of scrubland to exotic forest has resulted in secondary streams which were permanent in all but dry periods now flow only during periods of rainfall (Reference in paper (Anon) presented at 7th N.Z. Science Congress, Auckland, 1951.).

2. Flagstaff Forest - Dunedin - Conversion of manuka scrubland to exotic forest has reduced annual yields possibly in the order of 4.5 area inches per annum (Watt and Leslie, in press).

3. Upper Clutha Valley, Otago - Improvement in cover following rabbit destruction on brown-grey and yellow-grey earths in Central Otago has resulted in more consistent base flows and an apparent reduction in flood flows (J. Scurr, pers. comm.).

4. Glenmark, North Canterbury - The introduction of contour structures on downland resulted in creeks all flowing at a much lesser volume and for a longer period of time than previously. No runoff was observed from areas pasture-furrowed until after three inches of rain had fallen (Wilkie, 1962).

5. Makara Soil Conservation Reserve - Wellington - Preliminary analysis of the influence of oversowing and topdressing on unimproved intensively grazed pastures has shown some decrease in annual runoff, a probable increase in infiltration, an increase in surface detention, a reduction in the number of days on which flow occurs, a reasonably uniform decrease in the percentage occurrence of given daily runoffs over the greater part of the flow range, no change in rise time of individual hydrographs, an increase in depletion time of hydrographs, decreased peak discharges and decreased runoff in individual hydrographs (Toebes, Scarf and Yates 1968).

6. South Otago Downs, Clinton - Land drainage by tiling and mole ploughing has contributed to an apparently steadier flow regime in small creeks and has possibly reduced flood flows from small catchments, especially during the winter months, (I. Falconer, pers. comm.).

LAND-USE AND WATER QUALITY

Water quality has been defined as "that condition of water affecting adversely or beneficially any use or uses to which the water may be put", (O'Connor, 1968). Acceptance of this definition requires some consideration of the quality requirements of different uses. Lush (1969 in press) discussing the quality requirements in municipal watersheds supplying water for domestic use stresses the need for collecting as clean and safe a product in the first instance and emphasises that water treatment processes should always be regarded as a second line of defence. International standards for drinking water have been determined by the World Health Organisation (W.H.O. 1963), and the N.Z. Board of Health grading of domestic water supplies is based on these standards, (Dom. Lab. Report 2064, 1963). Problems of water quality control in municipal supply catchments has been discussed in some detail in the Proceedings of the Municipal Watershed Management Symposium, (Univ. Massachusetts, 1965).

Wider tolerances may be allowed for irrigation and stock water although there must be maximum tolerance levels in different situations. Excessive amounts of silt, algal growth, slimes and debris interfere with

mechanical aspects of irrigation. Fireman and Hayward (1955) list the four major characteristics determining quality of water for irrigation in the U.S.A. as being: the total concentration of soluble salts, the concentration of sodium and the proportion of sodium to calcium plus magnesium, the concentration of bicarbonate, and the occurence of the minor elements such as boron in amounts that are toxic. As yet these parameters are not limiting in the New Zealand situation although Cossens and Rickard (1968) note marked increases in salinity with distance downstream for certain creeks in Central Otago carrying irrigation drainage. They also noted rises in salinity levels in races that traverse Tertiary clays from which they apparently derive soluble salts. Hydro-electric use of water demands water free of debris and sediment, while special industries have their own particular requirements. The North Island paper industry for example has had problems with fine pumice sediment affecting the quality of the end product, while the food processing industries naturally require water of the highest quality.

The changes that may be caused by a particular land-use or catchment activity are listed in Table 1 which emphasises the most common effects. It is possible that any one activity could in fact cause many or all of the changes. These changes may be broadly classified as chemical, physical, and biological.

Chemical changes - Agricultural and pastoral land-use are effecting chemical changes in surface waters in New Zealand. Fish (1963) correlates observations to show that eutrophication resulting from development of farmland in areas near Rotorua has produced an inferior environment for trout. Phosphate levels are also apparently intimately connected with the weed problem in certain lakes in the Waikato (Hill, 1967). The same author also noted evidence for an increase in nitrate levels proceeding down the chain of lakes in the Waikato system. Both nitrogen and phosphate in surface waters are important because of their contribution to water enrichment. In New Zealand soils it is unlikely that much phosphorous is leached through the soil layers. Most phosphorous appearing in surface waters is washed from the soil surface either in solution or absorbed on

Table 1

<u>Principal Changes in Water Caused by Land-use or Catchment Activity</u>

(Adapted from Pollution Control Council, Pacific Northwest Area 1961)

Changes in Quality of Water	Earthworks and construction Activity	Agriculture	Grazing	Forestry	Mining	Recreation
Bacterial contamination	X	X	X	X	X	X
Turbidity	X	X	X	X	X	X
Taste and odour	X	X	X	X	X	X
Colour	X	-	-	X	X	-
Mineral solutes	X	X	-	-	X	-
Acidity	-	-	-	-	X	-
Toxic chemicals	-	X	-	X	X	-
Oil and Petrol	X	-	-	X	X	X
Objectionable solids	X	-	-	X	-	X
Temperature	X	X	-	X	X	-
Erosion sediments	X	X	X	X	X	-
Nutrients	-	X	-	-	-	-

the colloidal fraction of the runoff. Glymph and Carlson (1968) estimate an annual loss of phosphorous of 10lb per acre by erosion from cropland in the U.S.A. Quantitative losses in New Zealand from aerial application of superphosphate have yet to be determined, although Hill (1967) has obtained good qualitative evidence. Nitrate can be leached through the soil and Glymph and Carlson (1968) note that lysimeter leachates and tile-line effluents sometimes contain appreciable quantities of nitrogen. The same authors note that in view of the significance of nitrogen and phosphorous in surface waters much more work should be carried out on the type, solubility, placement, elemental ratio, rates, and time of application of fertilisers in relation to rainfall, runoff, and soil loss measurements. O'Connor (1968) notes the difficulty of having fertile lands drained by infertile rivers and suggests that a chronosequence in waters may be expected following their enrichment with phosphate, similar to that observed in land development. He suggests that the initial dominance of the blue-green algae (nitrogen-fixers) could be replaced by a wider range of plant forms when and if enrichment with nitrogen also takes place, in a process parallel to the strong growth in pasture following application of nitrogen fertiliser.

Overseas the most widespread source of chemical pollution from agricultural sources comes from return flows from irrigation carrying salts leached from the soils, together with fertilisers and agricultural chemicals. In forestry, tannin and humic acid complex solutes may be leached from decomposing litter and trimmings. Forest and grassland fires add significant ash to the dissolved load in streams. The pH is usually raised, and phosphorous and potassium generally increase in availability while nitrates tend to be destroyed. The effects of burning are usually greatest in the first season but do not generally persist for more than two or three seasons.

Physical changes - sedimentation is the most important physical parameter in water quality. The consequences of sedimentation are too well known in this country to dwell on. Suffice it to mention its effect on the bulking of flood flows, the siltation of structures, and the aggradation problems in the lower reaches. The other

physical changes apart from turbidity (which with sedimentation reduces light penetration in water) is temperature. Willow clearing presumably raises water temperatures, and irrigation return flows may be expected to be warmer. Logging along streams will also have the same effect. Temperature influences fish habitat and the general ecology of streams. A most important influence is on the oxygen carrying capacity of the water.

Biological changes - Apart from the various biological effects of eutrophication, bacterial contamination is the most important biological change. Every form of land-use and catchment activity can contribute to bacterial contamination and yet if due attention is paid to this factor, its impact can be kept to a minimum. Without letting one's imagination run riot with the possible sources and causes of bacterial contamination, it is useful to have some idea of the 'normal' situation, i.e. the relationship and patterns of bacterial content of waters in their near virgin conditions. Kunkle and Meiman (1967) assessed water quality characteristics at varying natural flow regimes under conditions of limited land-use in a Rocky Mountain catchment. With reference to the bacterial parameter their statistical and graphical analyses indicated that the bacterial groups were closely related to the physical parameters of the stream and were especially dependent on the 'flushing effect' of the runoff from snowmelt and rain, summer storms, or irrigation. The seasonal trend for the coliform, fecal coliforms (FC), and fecal streptococci (FS), groups were similar; (1) low counts prevailed while the water was $0^{\circ}C$ although bacteria from all groups were isolated during winter; (2) high counts appeared during the rising and peak flows caused by June snowmelt and rain; (3) a short 'post flush' lull in counts took place as runoff receded in early July; (4) high counts were found again in the July-August period of warmer temperatures and low flows; and (5) counts declined in September. The FC, FS, and coliforms all clearly defined grazing-irrigation impact; the FC showed the 'highest sensitivity' to such pollution. The coliforms rated slightly less, while the FS were the least sensitive.

Land-use and Water Quality Objectives - Where the waters of catchments have not yet been already affected by land development and use, the primary objective must be to keep these waters in the best condition that is consistent with reasonable and beneficial future development. Where the waters have been adversely affected the objectives should be to restore them to a condition where they are more beneficial. With time, downstream uses of water will increasingly dictate the quality requirements of catchment waters and tolerance levels will have to be set for each use so that land-use and quality parameters are co-ordinated for the benefit of the people. O'Connor (1968) concludes that this will call for new perspectives in plant breeding and management, animal management, water control in irrigation and drainage, and above all in the understanding and management of soil biology. It will also call for new perspectives in land management of the high water-yielding areas where the dollar return per dollar invested is likely to be greatest.

CONCLUSION

Adequate watershed management for water in New Zealand must meet the following objectives:

1. The restoration and maintenance of a hydrologic balance between soil, water and plants to obtain optimum functioning of the catchment.

2. The deliberate promotion of conditions favouring streamflow, especially the seasonal distribution of flow and the reduction of flood discharges.

3. The maximum reduction of sediment loads and stream turbidity together with an associated improvement of the desirable chemical, physical, and biological quality parameters.

4. The restoration and maintenance of improved total water yields where an improvement is required.

The past decade has seen an increasing awareness of the importance of the above objectives. In the tussock grasslands McCaskill (1964) concludes that management for the regulation of water yield is inherently consistent with soil conservation principles and can be consistent with the maintenance and increase of primary production. Holloway (1964) emphasises the broad generalisation that in New Zealand the major function of protection forests is erosion control and not the regulation of water yields, and also states (1968) the national watershed management problem to be the management, the maintenance in or the restoration to, a satisfactory condition of the mountainous upper catchments of the major mountain derived rivers. At the more local level catchment boards are working methodically on practical solutions to catchment restoration and protection and at least one local municipal authority has adopted the principle in a water supply catchment of refraining from planting water-course margins with deep-rooted trees in an effort to reduce transpiration losses from these important areas. The increasing awareness of the importance of land-use in relation to water yields and water quality is also reflected in the elite position given soil and water conservation in the Forestry Sector Report to the National Development Conference (1969).

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LAND MANAGEMENT FOR SOIL STABILITY

Second thoughts about some erosion problems in the South Island hill and high country.

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INTRODUCTION

120 years ago, Strange, the naturalist of the survey ship H.M.S. Ackeron, climbed to the top of the Torlesse Range (Canterbury) and recorded:

> "The site which 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."(1)

Two years ago an article about erosion in New Zealand began: "An Englishman returning from an extensive tour of New Zealand was quoted as saying, 'Egad, what beautiful erosion'." (2)

In the intervening 118 years the "beautiful" erosion has been described as amongst the most spectacular in the world(3), and dismissed by a Royal Commission as a problem of little significance(4).

After a long period of destructive exploitation, an awareness of the need for erosion control developed in the 1930s and 1940s. This concern was based largely on the immorality of waste, and soil conservation was promoted on the grounds that, for example, "... if we are to increase production to meet the needs of the future and to help feed the starving millions in under-developed countries, every square foot of topsoil must be preserved and increased in fertility."(5)

In the 1940s and early 1950s the public gradually became aware of its responsibility to conserve these lands and with the enthusiasm of the recently converted, it was prepared to pay for a variety of action programmes. To the supporters of conservation the issues were clear cut - erosion was a bad thing that had been allowed to go unchecked for years, and therefore soil conservation was a good thing.

However, after twenty years there is now little interest in the argument of whether or not soil conservation is a good thing. Due to the recent economic restrictions on all sectors of the community, the public now want to know how much of a good thing this is. For example, earlier this year an editorial in the "New Zealand Farmer"(6) asked for an assurance that the money voted to soil conservation was being spent to best advantage. Similarly, before the Soil Conservation and Rivers Control Council make a decision about the recommendations of the Waimakariri Report(7) they have set up a committee(8) to estimate the benefits to stream flow and reduction of sediment which may or may not be obtained from land-use measures in the upper catchment.

These indications suggest that we are entering a period of "economic conservation" in which it will become increasingly difficult to justify soil conservation programmes only on the grounds that they are morally right. For the Catchment Authorities, "economic conservation" will be both stimulating and frustrating. Stimulating, because for perhaps the first time professional staff will have to use all their professional skills. Frustrating, because of the complete lack of data from which benefit can be assessed. It seems to be tragic that the organisation, which has done so much to promote action programmes, has done and is doing so little in the fields of economics and soil stability.

No single research programme will give all the information that is needed and no one paper will provide all the answers. This paper is intended to define more closely some of the problems associated with erosion. It is offered in the hope that even without quantitative data, it may be possible to formulate more realistic objects of land management for soil stability. The fact that this paper should have been prepared 25 years ago gives emphasis to the extent

to which erosion research has lagged behind soil conservation practice.

Before a watershed manager can determine his objectives he needs to have a clear understanding of the problems he is trying to solve. What are the problems of soil erosion?

Most writers have implied or stated in general terms that erosion causes a loss of production and an increase in aggradation or flooding, but little reference has been given to specific (quantitative) problems. Some results from the loss of topsoil are:

1. loss of primary production

2. and/or an increase in production costs

3. and/or an accumulation of sediment in stream channels and over farm lands

4. and/or reduction in the storage capacity of dams

5. and/or erosion or silting of drainage systems or irrigation canals

6. and/or increased costs of water purification

7. and/or an increased flood frequency and stream discharge.

Not every case of erosion will be associated with all these problems and it is not possible to discuss them all in one paper. I intend to emphasise the loss of primary production and the increases in aggradation, since I think that these are of the greatest importance in the South Island hill and high country.

EROSION AND THE LOSS OF PRIMARY PRODUCTION

If the prime object of soil conservation is to prevent a loss of primary production, then by definition this objective is limited to productive lands, i.e. the hill

country up to about 3,000-4,000 ft.

Earlier this year a committee of the American Society of Civil Engineers[9] reported that there was little information available about production losses resulting from erosion. One of the four studies quoted was that of Smith et al [10] who recorded that the income from sheet eroded lands after 18 years of farming was about $252/acre less than uneroded land: the loss was about the same as the original land value. A second study was that of Beer[11] who estimated the annual loss from gully erosion in Iowa at $1.12 per acre.

Because there are no comparable data for New Zealand soils the author carried out a pilot trial on the effect of erosion on winter feed choumoullier, in one paddock in the Roseberry district of North Otago. Although the downlands of this area provide some striking examples of reduced crop yields on eroded ridges and upper slopes, this study was made on an area where only moderate differences were expected; the temptation to sample for extreme values was avoided.

The soil was provisionally identified as Timaru silt loam. It was estimated that the upper slopes had lost 25% to 75% of topsoil, while lower slopes had accumulated an additional 25%. Figure 1 shows the differences in crop yields between the upper and lower slopes.

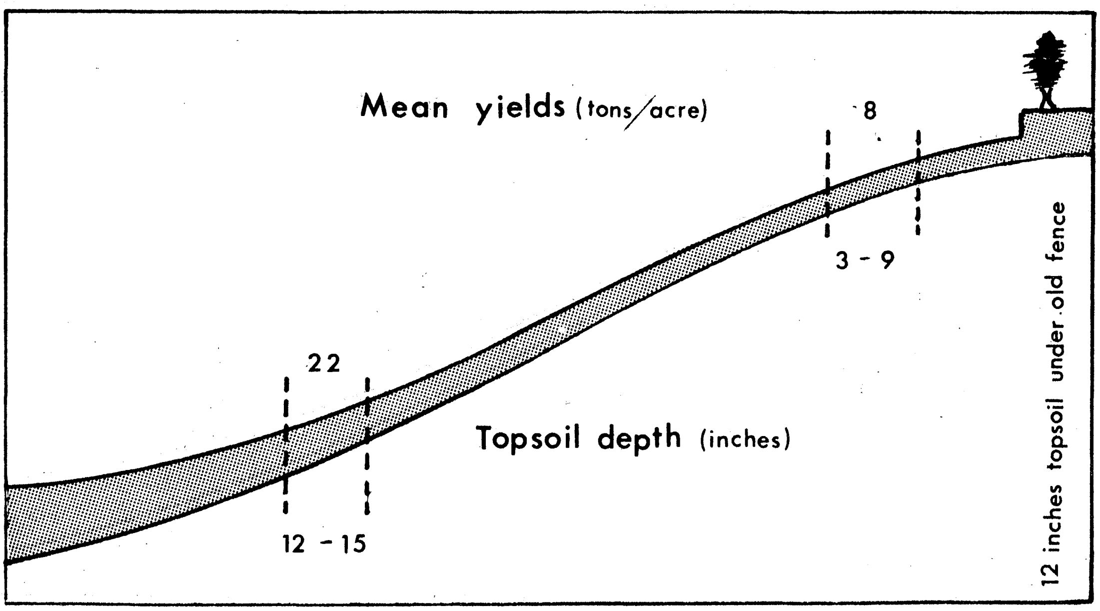

Figure 1

Choumoullier yields on upper eroded slopes and lower uneroded slopes on one paddock in the North Otago area, N.Z.

It must be emphasised that this was a pilot trial and one in which there was no control over a number of important variables such as seeding rate and fertiliser. Within these limits, crop yields on the upper eroded slopes ranged from $3\frac{3}{4}$ to $10\frac{1}{2}$ tons per acre (mean $7\frac{3}{4}$ tons per acre), while yields on the lower slopes ranged from 17 tons to 28 tons per acre (mean $21\frac{1}{2}$ tons per acre).

Although many factors contribute to these yields, soil moisture is probably one of the most important. I suggest that in this 20 to 25 inch rainfall area, the loss of 25% to 75% topsoil will have a significant effect on the soil moisture store and the moisture available for plant production. However, we cannot assume that the upper and lower slopes would ever have produced comparable crops, since greater exposure would almost certainly have resulted in lower yields on the upper slopes. For this example, I have assumed that before erosion the upper slopes could have produced a crop of 15 tons per acre (the mean of present production on upper and lower slopes).

The cash loss of a reduction in crop yield from an assumed 15 tons and a measured 8 tons can be estimated on the basis that 7 tons of choumoullier per acre would have provided grazing for 14 romney ewes for 12 weeks. At 10 cents per grazing week this amounts to an annual cash loss of $16.80 per acre. The accumulated loss through a ten-year rotation might be in the order of $150-$200 per acre.

It should not be assumed that this represents the total cost of erosion. In addition to this cash loss there may also be:

1. The cost of removing the eroded soil from downstream irrigation canals, drainage ditches and farm ponds.

2. Possible increases in the costs of water purification for downstream domestic and industrial users.

3. Possible increases in the costs of cultivating a less friable subsoil.

4. Social costs such as the loss of freight, marketing and processing opportunities. Although these are difficult to assess, a threefold multiplier is not unusual and may in fact be conservative[9].

However, production losses such as these can be reduced. The problem is to determine how much should be spent on reducing erosion.

In this example a combination of techniques would be needed, including control of surface water, conservation methods of cultivation, and crop rotation. The capital and maintenance costs of these treatments can be estimated. Then if the maintenance costs are subtracted from the annual losses, the balance when capitalised would indicate the amount which could be spent as a lump sum investment. For example, if the maintenance costs of the conservation measures are estimated at $5 per acre, then a land manager could afford to spend the capitalised value of $12 per acre ($17 annual loss, minus $5 maintenance cost). At a discount rate of 10% this would amount to $120 per acre. (I would like to emphasise, however, that the validity of this figure depends on the validity of the assumption that the upper slopes could, before erosion, produce a crop of 15 tons per acre.)

Although it is important to prevent erosion, this is the somewhat negative approach to conservation. The more positive approach is the rehabilitation or redevelopment of eroded land.

The Cost of Repairing Erosion

The history of erosion and latterly soil conservation on the Wither Hills Reserve is well known and has been reported by several authors (e.g. Wilkie[12]). Of all the methods used to rehabilitate this Reserve, perhaps the most expensive has been the infilling and reseeding of gully erosion. The costs of 'dozing, levelling, contouring, fertilising and reseeding varied from $30 per acre[13] to $150 per acre[14].

At first glance the sum of $150 per acre to rehabilitate pastoral land may seem high but even at this price, rehabilitation can be an economic proposition. It can be estimated that to service an annual capital charge of 10% (6½% interest, 3½% capital repayment), gullied land after treatment would have to carry an additional 2½-3 ewe equivalents per acre per year. Since the area carried only ½ a dry sheep per acre prior to treatment[12] and can now carry 3-3½ ewe equivalents[15] the increased productivity is sufficient to cover the costs of redevelopment.

Moreover, as the infilling of gullies usually allows a far greater level of production from a larger area (e.g. where it now becomes possible to cultivate a paddock formerly divided by gullies) the profitability of such work is greatly increased.

Both this example and the earlier one are based on inadequate data and rule of thumb methods of calculation and the results as such should be treated with caution. Nevertheless I suggest that in the absence of more exact information, they do indicate that the loss of production following erosion, and the increases in production following redevelopment, may be much higher than has been previously thought.

EROSION CAUSES INCREASED SEDIMENT ACCUMULATION IN CHANNELS

Whereas the effects of land deterioration on production may have been under estimated, their effects on aggradation in stream channels may have been over estimated.

Proposals for soil conservation frequently include the general statement that land management will reduce the rate of aggradation in the river channel and minimise flooding. While this claim may be legitimate in some cases, these benefits may be more often imagined than they are real; especially for the eroded alpine lands.

A major difficulty is that whereas for production studies there are some imperfect data, this topic has no data at all. We are therefore forced to rely on first principles and overseas experience. A second complication

is that the overseas literature on land use and sediment yield has shown quite clearly that the erosion, transport and deposition of sediment is highly complex and little understood; simple answers are rarely found.

One feature to emerge from many independent American studies is that a few infrequent flows transport much of the sediment moved by a stream. For example, Wolman and Miller [16] reported that 90% of the sediment from one 2,000 square mile catchment was moved by flows which were expected to occur about three days each year. Similarly, Staff[17] concluded that about ¾ of the sediment carried downstream in a year is moved during about 1% of the time. From my own observations it is possible that a similar situation exists in the hill and high country.

Therefore if this is so, then reducing sediment yield is closely related to reducing the frequency of the higher values of discharge. Where land management will not significantly alter the frequency of higher discharges, there is unlikely to be much reduction in sediment yield.

Sources of Sediment

A stream's sediment yield is derived either from erosion of the land surface or erosion within the channel system.

Erosion from the Land Surface

Soil loss is governed by the quantity, velocity and depth of the entraining water and the nature of the land slope and plant cover. In the hill and high country of the South Island, sheet erosion is the dominant form of soil loss. The important feature is that overland flow, whether as a sheet or small rivulet, has a limited sediment carrying capacity. In general, it is only the smallest clay-sized and silt-sized particles which are shifted. Further, as catchment size increases, there is a greater opportunity for the sediment entrained in overland flow to be deposited before it reaches the channel system.

This means that land erosion will in general contribute only to the suspended sediment portion of sediment yield, and that this contribution will be greater in small catchments than in large catchments.

Although suspended sediment may account for more than three quarters of total sediment, it cannot be assumed that soil conservation practices will necessarily show a correspondingly spectacular reduction in sediment yield. Unless the channel below a rehabilitated area is stable under the reduced sediment load, the channel itself may erode or degrade and within a short distance the total sediment load in the stream may be similar to that prior to land treatment. Although there is little information about the stability of high-country river channels, limited data[e.g.18] suggest that few may be stable enough for improved land management to cause significant reductions in sediment yield.

Land erosion is obviously a contributor to total sediment in streams. The question really is how much of this sediment comes from land and how much comes from other sources such as the stream banks.

Erosion Within the Channel System

In a study in the Eastern United States on the importance of sheet erosion as a source of sediment, Glymph[19] estimated that sheet erosion accounted for from 11 to 100% of total sediment yield. Expressed the other way, other sources supplied from 0% to 89% of total sediment.

In our hill and high country, slip and slump erosion are not particularly extensive. However, their importance may be far greater than their occurrence would indicate. These forms of movement are most commonly found on riparian land where they deposit unconsolidated detritus in the stream channel. It might well be that most sediment is derived from channel erosion and that this source assumes an even greater importance with distance down stream.

In support of this view, Brune[20] found that as the size of the catchment increased, the upland sources of

sediment, such as sheet and gully erosion, became less important, while the bottom land sources such as stream bank erosion, flood plain scour and valley trenching, became constantly more important. The important feature about this concept of a catchment as a dynamic and not a static system, is that as the distance increases between an area of land erosion and a region of sediment accumulation; there is a lessening likelihood that land use treatments will have a significant effect on the sediment yield.

The study of sedimentation is complex and little understood; whether sediment control is a problem of land management or river management will depend largely on the sources of sediment and their proximity to the area of aggradation. The river manager does not have exclusive rights, but the land manager needs a great deal of information before he can establish the extent of his involvement in this field.

CONCLUSION

Perhaps we have been preoccupied for too long by the problems at the top of the mountain and have paid too little attention to the opportunities on the foothills. Specifically I question the value of spending up to $1,200 per mile to retire high altitude land in areas such as the lakes district of Central Otago. I wonder if this money might not be spent to much greater effect on the redevelopment of eroded lands, or in the control of riparian erosion on lower altitude land. However, the implications of this paper go further than this.

I think that we must abandon the concepts that all erosion is created equal and that one rate of cost sharing can apply from Northland to Southland. Two areas which are eroding in similar fashion may not require similar treatment; slight erosion on one area may be a more important problem than severe erosion on another. Erosion which caused a problem in one area may not cause the same problem in another. The land manager must allow for the uniqueness of each and every case of soil instability.

If we had an economy similar to that of Kuwait then we might be able to afford the luxury of plant cover on each and every square foot of bare soil. However, for the next decade or so economics will determine the feasibility of erosion control, rather than wishful thinking. This implies that work will need to be done to a system of priorities. The Soil Conservation and Rivers Control Council is the only organisation which can establish national priorities. Hence this organisation should replace its present system of support, which assumes that all erosion is equal, with a system of rational priorities. However, such priorities can only be developed from data about the causes and consequences of all forms of erosion. There is an urgent need for the Council to initiate a programme of fact finding which is already 20 years too late. In the absence of this data, all that a soil conservator can do is look critically at each proposal and ask himself, "Why am I doing this?".

DISCUSSION

Q. On what did you base your estimates of the profitability of gully control on the Wither Hills?

A. Gross margins.

Statement: G. A. G. Frengley (Lincoln College)

"This use of the gross margin method is legitmate because overhead costs have not been altered. However, it has been shown that if development involves changes in the overhead costs, then it is difficult to support a debt of more than about $2 per ewe equivalent. Therefore development which costs $150 per acre will in the first place be limited to those areas where the amount of development is small and there are no changes to overhead costs. Under these conditions capitalised gross margins will indicate the upper limits of development costs."

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THE INFLUENCE OF ASPECT UPON THE ALPINE AND SUB-ALPINE ECOSYSTEMS IN THE TWIN STREAM CATCHMENT OF THE EASTERN BEN OHAU RANGE

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ABSTRACT

Temperature and moisture records at two localities on a north and south aspect at 4,100 ft have been analysed. Marked differences between the two aspects have been found in diurnal range of temperatures, saturation deficits and soil moisture levels, the difference in mean monthly temperatures were less distinct. There was a distinct contrast in the pattern of freeze-thaw phenomena in two types of vegetation, a *Raoulia* mat and a *Chionochloa rigida* tussock. The zonation of plant communities and soil types in relation to aspect and the effects on the hydrology in terms of water yield and runoff have been considered.

INTRODUCTION

The various environmental factors which influence a biological system are so closely inter-related that it becomes very difficult to isolate one of these factors as the most significant in controlling or influencing the development of a biocoenosis. In mountainous terrain, however, two factors, namely aspect and altitude, have such an influence upon the distribution of soils and vegetation that they can be used as the basis for defining ecosystematic units.

This paper is in two parts. In the first part, data are presented to indicate the influence of aspect on temperature and moisture. The second part deals with the distribution of soils and vegetation in response to these factors, and their influence upon the hydrology of the sub-alpine and alpine watersheds.

REGION OF STUDY

The Twin Stream catchment is a transverse valley with an E-W axis in the eastern Ben Ohau Range 17 miles south of Mt Cook National Park. The catchment has an area of over 10,000 acres of which 296 acres consist of perennial snow and ice, 3,500 acres are sunlit aspects and 6,700 acres are shaded aspects. According to Wardle's (1963) classification of altitudinal limits, 32.4% lies in the montane zone (1,500 - 3,000 ft), 31.5% in the sub-alpine zone (3,000 - 4,500 ft) and 36.1% in the alpine zone (above 4,500 ft).

The only form of long-term climatological records which were available before this study began was 10 years of rainfall data, which was collected at Glentanner Station. Rainfall values assessed over this period were 80 in. $\pm$ 10 in.

LOCATION OF INSTRUMENTS

The climatological data presented in this paper were obtained from two localities:

Locality I is a steepland site (35° slope) at an altitude of 4,100 ft on a south aspect. The continuous ground cover is mainly *Agrostis tenuis* and *Poa colensoi* with some low shrubs. The instruments consisted of two Lambrecht hygrothermographs installed in Stevensons' screens 12" above ground, with supplementary maximum and minimum thermometers. Coleman fibreglass soil cells were established at 1" and 4" soil depths.

Locality II is a north aspect also at an altitude of 4,100 ft with a 75% vegetation cover consisting of *Chionochloa rigida*, low shrub, and cushion plant communities of *Raoulia* species. The topography is gently undulating with a 5° slope. The instrumentation was similar to the previously described locality with the addition of a three-probe mercury-in-steel Lambrecht thermograph in which the probes were established on bare ground, on a *Roualia* mat within the base of a tussock of *Chionochloa rigida*, and at 2" below ground surface.

INFLUENCE OF ASPECT UPON TEMPERATURE

In mountainous topography one of the major difficulties in comparing air temperatures close to the ground surface on different aspects is the effect of slope upon localised air-flow. The air-flow on the gentle terrain on the upper part of the north face tended to be restricted; in contrast with the rapid air movement on the steep southern face. The relationship between slope and air movement was particularly noticeable during nocturnal cooling when, as a result of the pooling of cold air, the minimum temperatures on the north aspect were lower than those on the south aspect on several occasions.

Screen temperatures of the two aspects have been presented in Fig. 1. The July 1968 records were unreliable and have not been included. Although there is a distinctive seasonal trend on both aspects with well-defined periods of warmth and cold, the cold period on the south aspect is more extended; hence there are greater seasonal contrasts on this aspect. Another distinctive feature about the two apsects is the greater temperature range on the north aspect throughout the seasons. As the temperature range is greatly influenced by the insulating effects of snowpack, this contrast is more clearly seen on the south aspect where snow lies for longer periods of time than on the warmer faces. In 1968, snowpack persisted on the south aspect until mid October which is clearly indicated by the low range of temperature during this period.

The character of diurnal temperatures on the two aspects becomes evident when data from the months of the solstices and equinoxes are enlarged from Fig. 1. In Table 1 the diurnal range of temperatures on the two aspects is presented. It is noticeable that on the north aspect the mean diurnal temperatures are high throughout the solstices and equinoxes, whereas on the south aspect there is a seasonal character which is clearly reflected during the spring and autumn when the extreme diurnal temperature values are recorded.

On the north aspect with the large range of diurnal temperatures plant cover has a considerable influence upon freeze-thaw phenomena. Figs 2a and 2b have been compiled

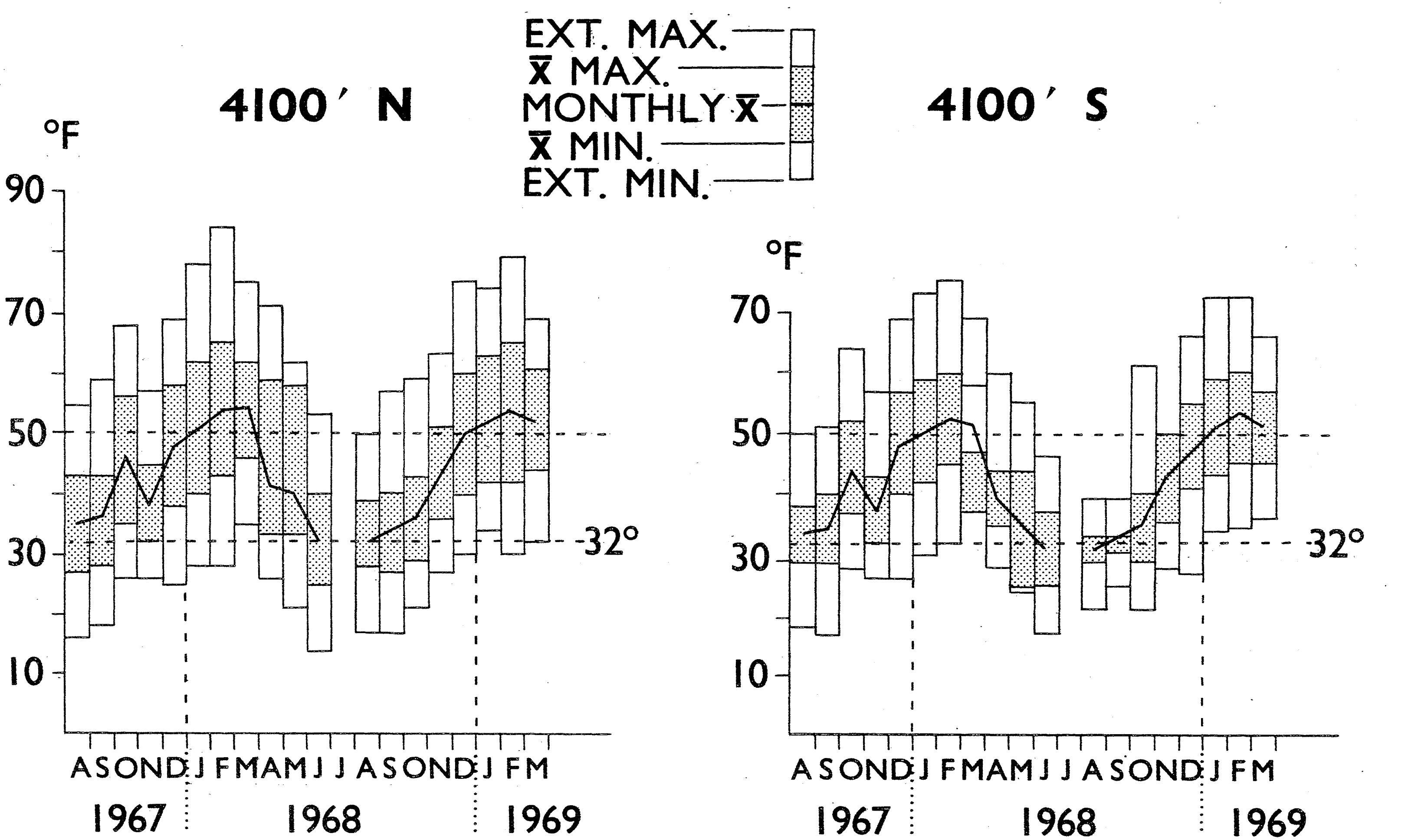

Figure 1

Screen temperatures, 12" above ground on the north and south aspects.

Table 1 MEAN DIURNAL TEMPERATURES (^{o}F) DURING THE SOLTICES OF 1968 AND THE EQUINOXES OF 1968 AND 1969 ON THE NORTH AND SOUTH ASPECTS

DATE	4100(S)	4100 (N)	DIFF	(± S.E.)
June	6.9	14.9	8.0	1.61
December	14.6	20.3	5.7	1.92
September	3.2	13.2	10.0	1.90
March	11.8	19.4	7.6	1.84
Mean	9.1	16.9	7.8	1.82

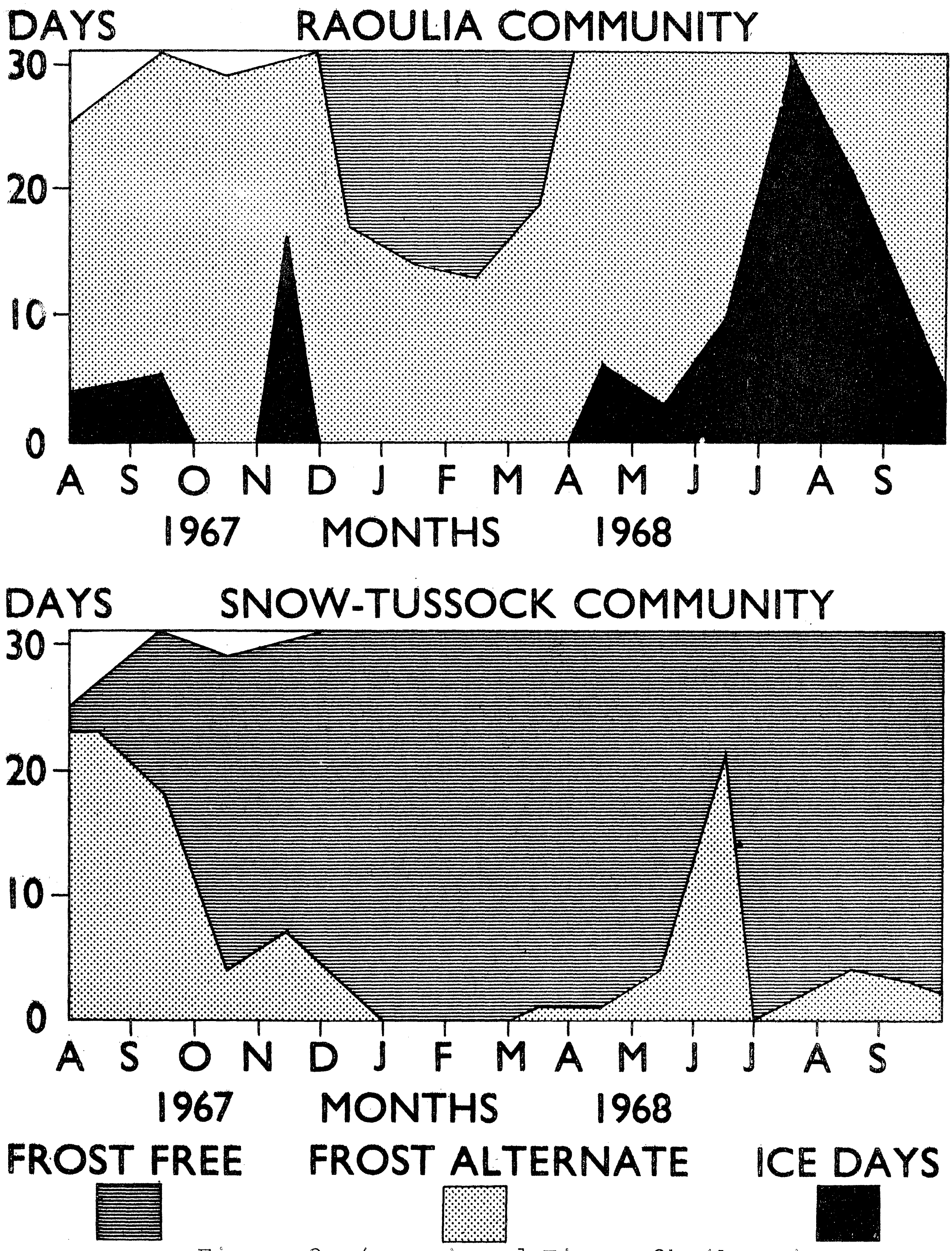

Figure 2a (upper) and Figure 2b (lower)

Effects of vegetation cover on freeze-thaw patterns.

from records taken from mercury-in-steel probes located on the surface of a Raoulia mat, and in leaf litter at the base of a snow-tussock (Chionochloa rigida). The freeze-thaw pattern in the two figures is completely different. The high number of ice-days (Temperature 32°F or below during day) near the surface of the Raoulia mat (fig 2a) is associated with the absence of snow cover, particularly during the winter of 1968. The freeze-thaw cycle, represented by frost-alternate days (freeze-thaw during day), is also very vigorous throughout the year. In the snow-tussock community, the most notable features are the lack of ice-days and the different distribution of frost-alternate days during the winters of 1967 and 1968. In the mild winter of 1967, sporadic falls of snow at 4,100 ft had very little insulating effect at ground surface. If it fell onto the Raoulia mat, it formed a thin cover, but on the tussock the snow was distributed in the foliage and dissipated. In the winter of 1968, however, the combination of a snowpack and leaf litter at the tussock base resulted in a marked increase in the number of frost-free days (temperature above 32°F during day).

INFLUENCE OF ASPECT UPON MOISTURE

As the north aspect bears the full impact of N.W. wind, evaporation on these faces will be considerable. No evaporation data are available, but from the simultaneous records of relative humidity and temperature saturation deficits for the two aspects have been determined. The saturation deficit is the difference between the actual vapour pressure and the maximum vapour pressure at the prevailing temperature and is expressed in millimetres of mercury. It is a useful factor as it assesses the capacity of air for additional moisture retention.

Records of saturation deficits from the north and south aspects in Table 2 indicate that the deficits are significantly higher on the north aspect, particularly during spring and winter months when the south aspect is influenced by snow and is receiving relatively low rates of insolation. During summer and autumn months the difference of saturation deficits between aspects seems to depend upon the precipitation which occurs during those months. For example, in February 1968, over 5.0 in. of rain fell during this period and no significant difference occurred, but in February 1969, only 0.5 in. of rain fell and the difference was marked.

Table 2 MEAN SATURATION DEFICITS (MM) OF THE NORTH AND SOUTH ASPECTS

Date		4100(S)	4100(N)	$\bar{X}$ DIFF	S.E.	t Test
Aug	1967	1.09	1.24	0.133	0.057	2.32 *
Sept	"	1.30	1.68	0.377	0.081	4.64 **
Oct	"	3.05	3.34	0.289	0.092	3.16 **
Nov	"	1.84	1.87	0.114	0.147	N.S.
Dec	"	3.11	3.48	0.615	0.232	2.64 *
Jan	1968	3.60	3.73	0.129	0.116	N.S.
Feb	"	4.54	4.59	0.126	0.171	N.S.
Mar	"	3.06	3.26	0.202	0.111	N.S.
April	"	1.44	2.12	0.546	0.260	N.S.
May	"	1.55	1.84	0.284	0.087	3.26 **
June	"	1.22	1.56	0.329	0.077	4.27 **
July	"					
Aug	"	0.51	1.32	0.702	0.750	3.72 **
Sept	"	0.52	1.13	0.308	0.239	5.15 **
Oct	"	0.79	1.91	1.090	1.090	3.97 **
Nov	"	2.83	2.78			N.S.
Dec	"	1.53	2.25	0.592	0.874	2.66
Jan	1969	2.73	3.37	0.518	1.210	N.S.
Feb	"	2.76	3.54	0.702	0.880	3.19 **
March	"	3.66	3.80	0.265	0.860	N.S.

* P 0.05
** P 0.01
*** N.S. Not significant

In November 1967, conditions were exceptional because of the heavy snowfall which covered both localities.

The high rates of evaporation on the north aspect when compared with the south aspect is clearly reflected in the soil moisture at 1" and 6" below the surface. In Figs. 3 and 4 soil moisture content was determined gravimetrically and expressed as a percentage of dry weight. The moisture content on the south aspect at both 1" and 6" depth is generally high throughout the periods sampled. The peak occurred in September 1968, during the spring thaw when the percentage of moisture was greater than the percentage of soil. Some fluctuation takes place at the 1" depth but the percentage never goes below 50. On the north face, there is no peak period, merely a fluctuation of moisture values with lower moisture content during the summer.

The marked contrast in microclimate between the aspects has a considerable effect upon the hydrology of the shaded and sunlit faces. In winter the shaded aspects, particularly above 4,000 ft where soil and air temperatures are generally low and a persistent snowpack lies from the end of June until the end of October, water yield is low. During summer, water yield would reach a peak as a result of seasonal thaw and decrease as summer progresses. The quality of snow in terms of moisture retention is also greater on the colder faces. Hence runoff associated with intense rain during mild N.W. conditions will be lower when compared with the sunlit aspect. On the sunlit aspects during summer, water yield will be greatly reduced because of the high rate of evaporation equated with insolation and high winds. In the winter months, however, even at altitudes above 4,500 ft, snow melt is rapid and water yield is therefore high.

DISTRIBUTION OF VEGETATION AND SOILS IN RELATION TO ASPECT

At present only a limited number of plots have been analysed, and there are insufficient quantitative data to ascertain the degree of homogeneity of the plant communities. For the purpose of this paper the plant community has been named after the dominant species which has a high frequency in the plant cover, and plants of very low frequency have not been considered. Similarly, the naming of soils is only tentative and has been based upon brief field descriptions.

GRAVIMETRIC DETERMINATION OF SOIL MOISTURE AT 1" DEPTH

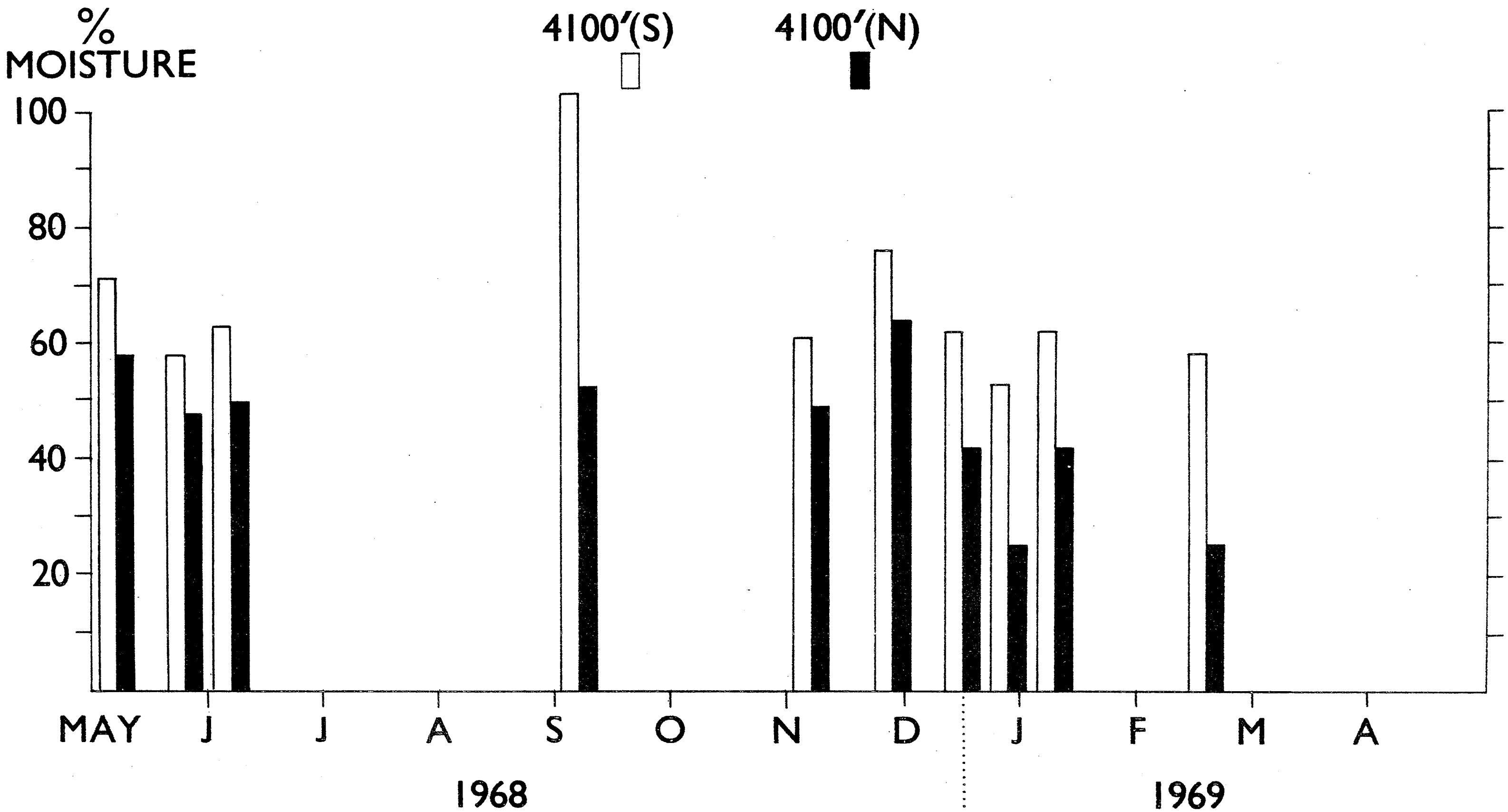

Figure 3

Soil moisture content at 1" depth on the north and south aspects.

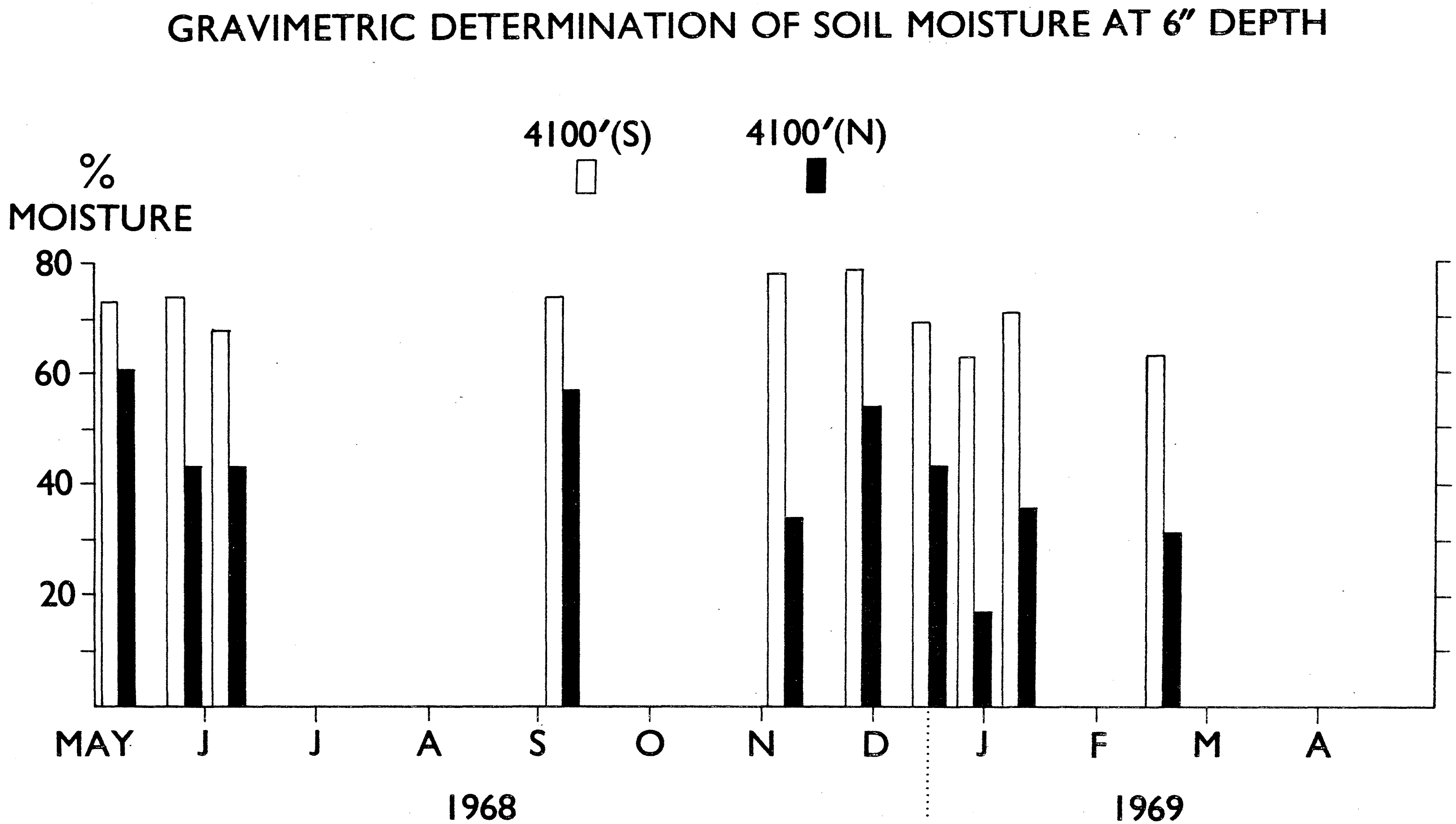

Figure 4

Soil moisture content at 6" depth on the north and south aspects.

Terminology is according to the New Zealand Soil Bureau (1962).

The eldefulvic soils of the north and west aspects, particularly on steepland sites show varying degrees of erosion. In some cases the removal of the A horizon has been partial, in others complete. The vegetation associated with these soils consists largely of a discontinuous cover of snow-tussock (Chionochloa rigida) with low shrubs of Dracophyllum uniflorum, D. kirkii, Cyathodes colensoi and species of Gaultheria and Hebe.

In contrast to the unstable conditions on the sunny apsects, on the dark shaded faces there is a full altitudinal range of soils from the fulvi-eldefulvic intergrades up through the eldefulvic to the elefulvic soils, all of which show a high degree of stability.

Plant succession and pedogenesis on the shaded aspects from an altitude of 4,800 ft to the limit of vegetation at approximately 6,000 ft is closely related to the availability of moisture.

By far the greatest proportion of this moisture during the short growing season is obtained from snow meltwater. In the high basins and formerly glaciated cirques, the vegetation on all but the most recently deglaciated sites is vigorous and more or less continuous. The pioneer colonization on a regolith of frost-shattered rocks consists largely of Celmisia haastii, C. hectori, C. sessiliflora with species of Colobanthus and Phyllachne. As the plant cover becomes more continuous there is an accumulation of organic matter. With high water levels from snow-melt and organic matter accumulation there is a hydric succession of plants characterised by Chionochloa oreophila, Schoenus pauciflorus and species of Carex, Uncinia and Luzula. The typical soil associated with this succession is a fibrous peat of several inches overlying a C horizon of frost shattered debris. In some instances peat may be directly overlying rock pavement. Studies by McGregor (1967) indicate that the last glacial advance (Dun Fiunary) which affected this zone was as recent as 1,700 A.D. Since the gradual retreat of this ice there must have been considerable fluctuation of the perennial snowline and meltwater associated with

seasonal ablation. It is evident that the availability of meltwater has a considerable influence upon plant succession and soil formation because a reduction in meltwater leads to mesic conditions. Plant communities which characterise these conditions are dominated by Poa colensoi and Celmisia lyallii. It is tentatively suggested that the zonal soil in this region is a podi-elefulvic which consists of O (L), O (F) and O (H) horizons with a melanised A and a well-expressed B horizon varying in depth from 15-20 inches.

In the high alpine basins which have a N.E. aspect there is evidence that plant succession followed a similar course as that described for the shaded aspects. The retreat of the snowline, however, has veen very rapid in these N.E. localities and the reduction of meltwater has had condierable influence on their present status. Those plant communities which developed under a high moisture regime are becoming increasingly desiccated and there is evidence that large areas of peaty soils are being rapidly eroded.

Plant succession and pedogenesis has been summarised in Table 3. This table not only summarises plant succession but it also gives us some indication of the effects of these biological systems upon the hydrology of these alpine catchments. Starting at the base of the table, runoff during seasonal thaw will be high in the sketal soils. As the succession progresses, the soils associated with the hydric and mesic succession have high water storage values and appear to be well adapted and stable under high moisture levels. The $O_{(H)}$ horizon of the podi-elefulvic soil has a field capacity of 76.58% and a wilting point of 42.26%. Although such localities have high water yields during summer from snowmelt, the high storage capacity of these humic soils will greatly reduce runoff. On the other hand, runoff is greatly increased if there is a regression of this biological system as a result of erosion of the humus horizon.

In conclusion, although it seems that the present climatic trend is leading to increased desiccation which is having a pronounced effect upon the ecological balance, precautions have already been taken in this particular region to alleviate the present trend. Burning has ceased on the

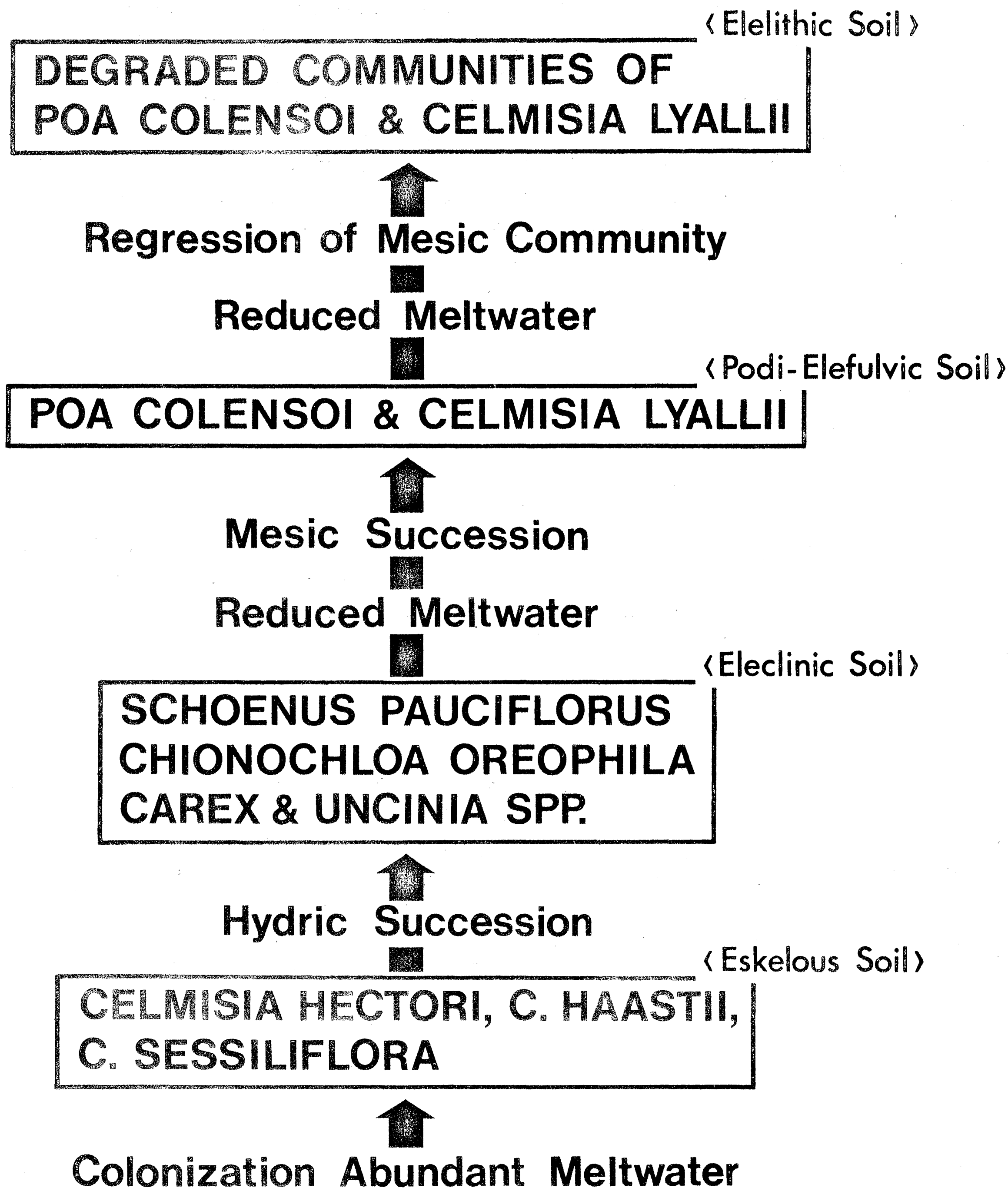

Table 3

Plant succession and associated soils.

drier faces and drastic reduction of the thar population and removal of sheep to more productive localities have reduced some of the grazing pressures. On lower more favourable sites topdressing and oversowing have restored in some instances a vigorous cover of vegetation. We are, however, still left with the problem of the inherently infertile high altitude zone. Whether this region becomes a monument to man's wisdom and foresight or merely a slag heap of unconsolidated shingle will depend largely upon the decisions made in the near future.

ACKNOWLEDGEMENTS

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THE INFLUENCE OF ROCK TYPE AND RELIEF ON WATER SUPPLY IN NORTH ISLAND CRETACEOUS TERTIARY HILL COUNTRY

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INTRODUCTION

Catchments are three dimensional bodies of surface area and depth. Although surface factors such as soils and vegetation are often investigated for their influence on stream flow, the underlying bedrock which stores ground water and provides base flow is rarely considered. This paper looks at some of the more common rock types on the North Island east coast and comments on the influence of their permeability, structure and relief on the water supplies of the region.

Each geographic area has unique rock-soil-water relationships and rock types vary widely in their permeability and storage capacity. However, it seems likely that conclusions regarding flow systems for one area can be extrapolated to other areas of similar environment.

GROUNDWATER MOVEMENT AND STORAGE

Fig. 1 shows the movement of groundwater under homogenous conditions in an idealised flow system[1]. The piezometric surface (or water table) is commonly a subdued replica of surface relief. Where these surfaces intersect, seepages, springs and streams occur. Movement in a groundwater system is along flow paths from areas of high potential* (or inflow zones) to areas of lower potential (or outflow zones)[3]. In an inflow zone, groundwater gradient is downward from the water table whereas in an outflow zone it is up toward the water table and lines of of flow converge. Although a flow system is controlled by

* Potential is water elevation expressed as feet above sea level.

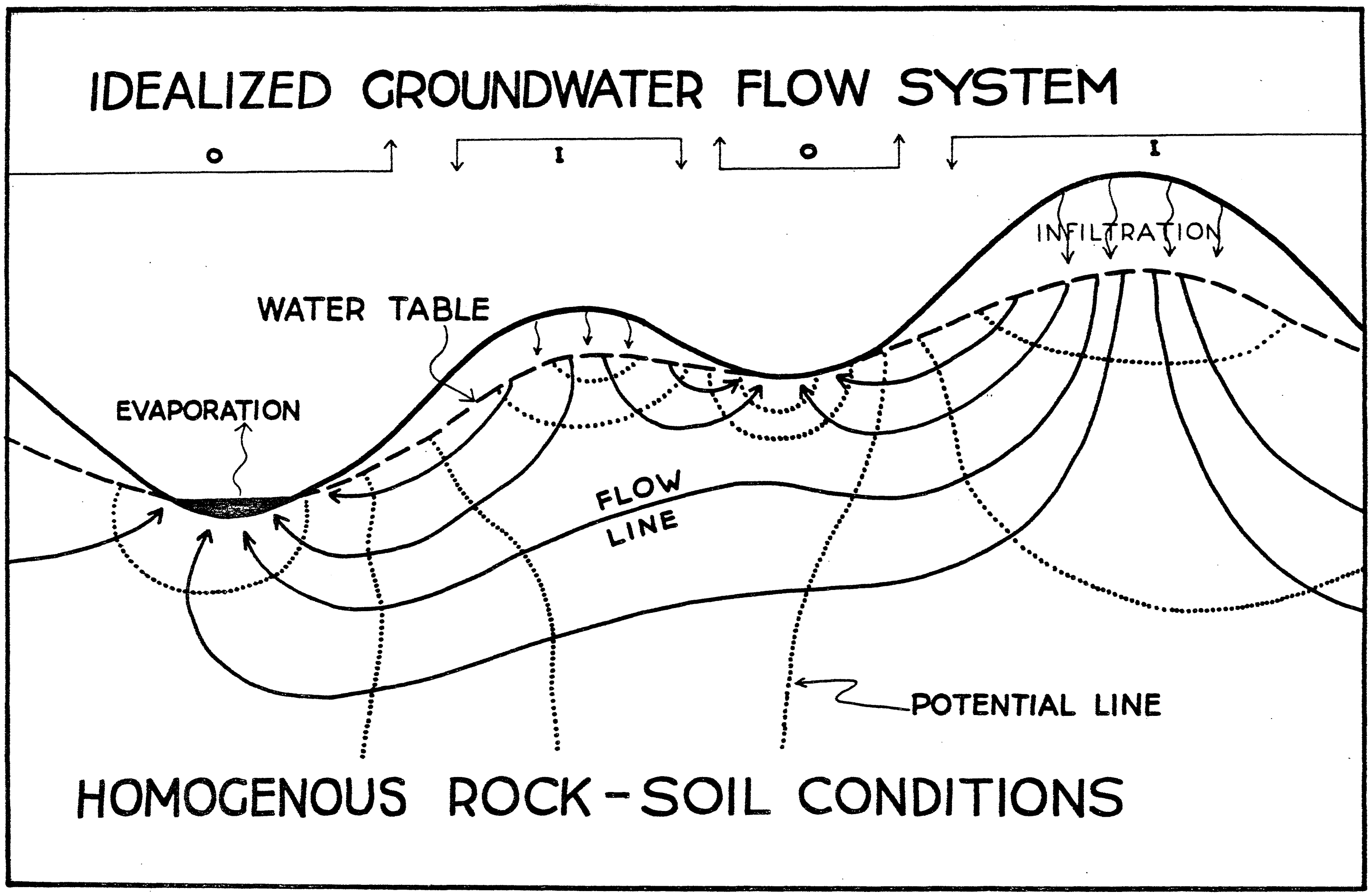

Figure 1

Diagrammatic representation of groundwater flow
in homogenous rock-soil conditions

relief, it is modified in direction and rate by rock-soil conditions along individual flow lines.

INFLUENCE OF ROCK TYPES

In general, rocks become increasingly permeable ranging in order from massive, jointed, banded, shattered and soluble types. Few rocks of Cretaceous-Tertiary age in the North Island are entirely impermeable.

Massive Rocks - e.g. siltstone and silty sandstone are very poorly permeable.

Jointed Rocks - Close jointed mudstone (Fig. 2) though impermeable in itself, is universally finely jointed and water can percolate to several hundred feet below surface. The rock is moderately hard and fragments can only be dislodged with the aid of a geological hammer(7). It is dark blue grey in colour, calcareous and the composition(2) is dominantly clay (89%), silt (7%) and sand (4%). Close jointed mudstone ranges from mid to upper Tertiary in age and it is widespread in the North Island east of the main ranges. The relief is low hills with scalloped slopes separated by narrow ridges, spurs and V-shaped valleys. Soils such as the Pahiatua and Turakina silt loams(8) formed on it, support high fertility hill pasture but compaction has reduced their ability to absorb water quickly and in heavy downpours surface runoff can be considerable. Mineralisation of water (6) is a problem in close jointed mudstone wells but water supplies suitable for single house units are obtainable at shallow depths.

Loose jointed or shattered mudstone(7) is, in fact, close jointed mudstone which occurs adjacent to faulted crush zones and has become incohesive with many shear lines and minor faults. Rock fragments can be picked out by hand and the opening of the joints has allowed water to penetrate to a considerable depth. Deep seated slump and flow movements have deformed the relief at a relatively rapid rate (in geological terms) and scrub has invaded the pastures. The broken landforms have restricted runoff and assisted infiltration. Ponding can occur to some extent on eroded surfaces. Ground water yields should be improved over those of close jointed mudstone but the deeper wells may be too mineralised for direct use(6).

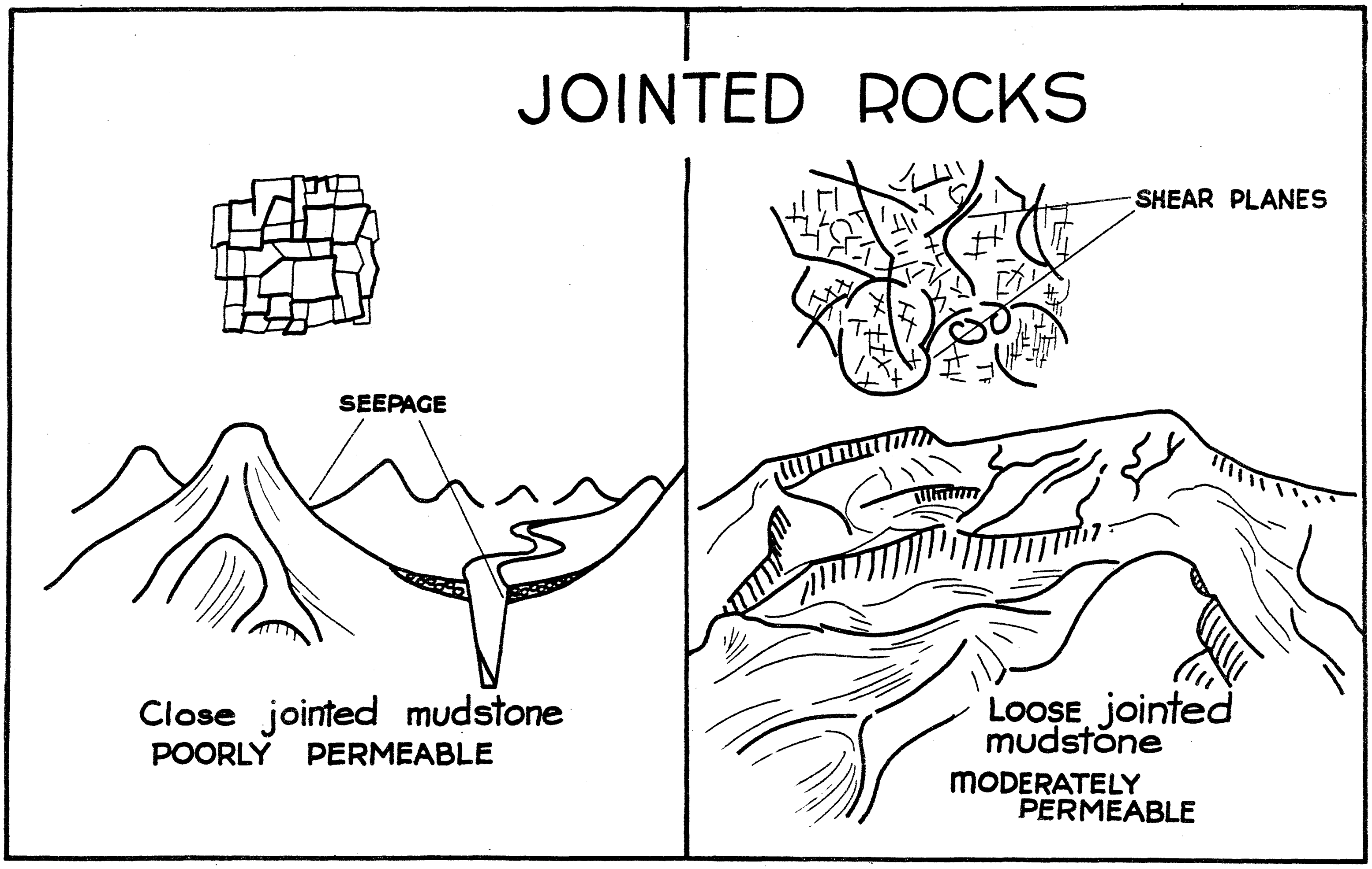

Figure 2

Diagrammatic representation of flow patterns in jointed rocks

Banded Rocks

Banded Mudstone[7] - This consists of narrow sandstone bands alternating with thicker ones of mudstone. At certain levels the sandstone beds may be up to 50 ft thick (Fig. 3). In general the rock strata dips at moderate angles to the west and the formation as a whole is poorly permeable. The medium sized hills have steep slopes, separated by narrow ridges and the Whangamomona silt loam[8] formed on them supports a grass and scrub cover. Although surface runoff rates are high, some water permeates through the thicker sandstone beds and follows the angle of dip of the sediments to outflow zones or springs on the lower hill slopes.

Turbidites - Turbidites appear in the field as narrow alternating bands of mudstone but they are in fact graded beds where texture ranges from medium sand at the base to clay at the top. Results of grain size analysis are shown in Fig. 3. It is evident that sorting in the clay faction of the beds is improved over that of the sand faction and consequently water percolates through the latter more readily. The sediments are Oligocene and Miocene in age and the small quantities of water produced by the sand faction are likely to be high in magnesium salts[6].

The erosion pattern in some turbidites is interesting in that pairs of narrow linear slumps have formed on either side of the streams. These slumps tend to flow in the same direction as the angle of dip of the beds (Fig.3). In adjacent catchments, slump pairs are aligned in a north-south direction along the line of geological strike. This suggests that fracture or crushing by fault movement is the most likely cause. Water yields from fractured turbidite are better than from the undisturbed bedrock.

Banded Sandstone[7] - Banded sandstones are moderately permeable. They consist of thick beds of siliceous sandstone separated by narrow bands of mudstone (Fig. 4). The compact rock is resistant and the attitude of the beds determines the relief. Where they are horizontal the landform is commonly a mesa; homoclines are formed where the beds dip at moderate angles; where the angle of dip is steep, the landform is a hogback. Sandstone soils, e.g. the Ngaumu sandy loam and Moumahaka steepland soil have low fertility and the cover is mainly scrub. Rocky bluffs

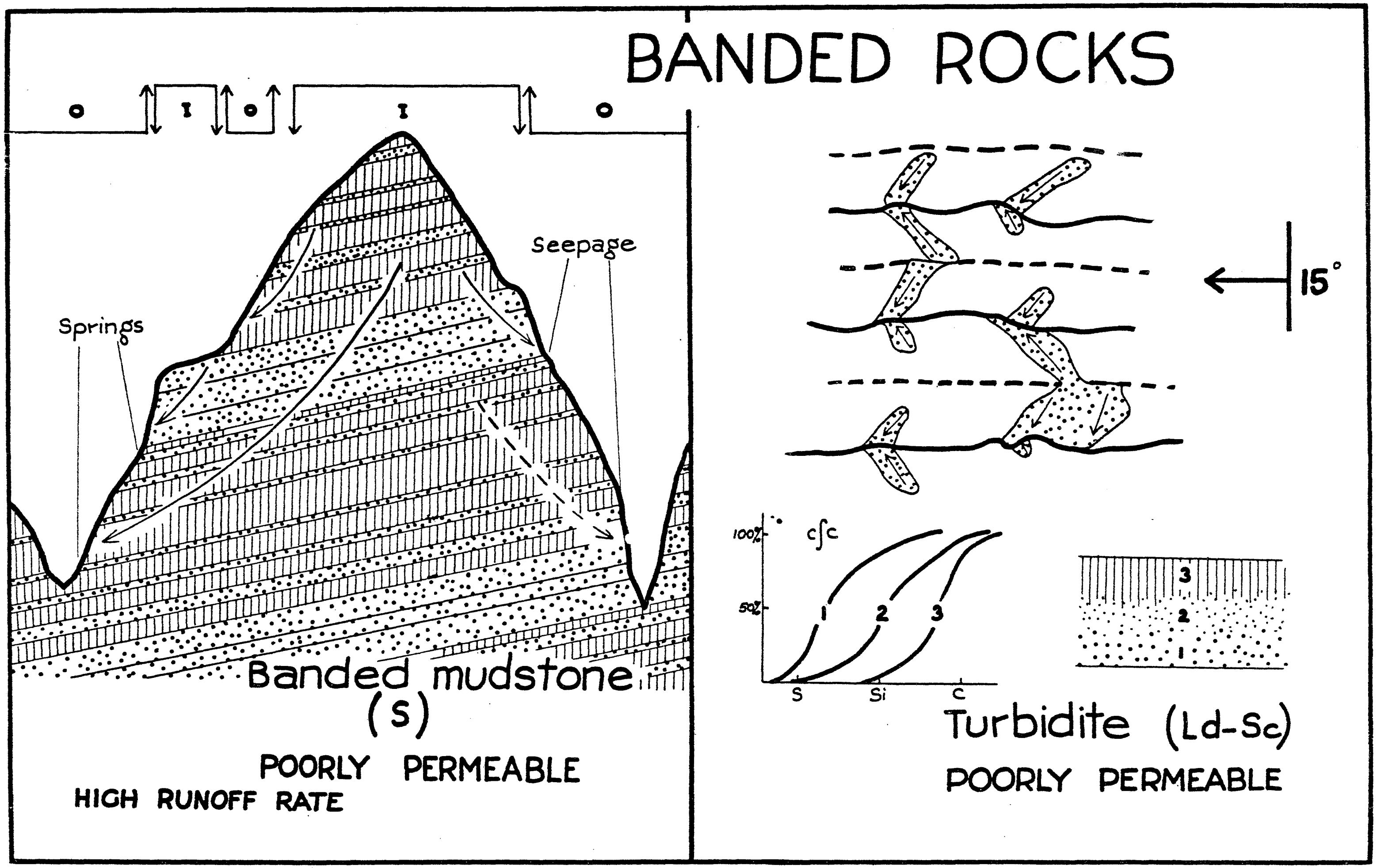

Figure 3

Diagrammatic representation of flow pattern in Banded rocks

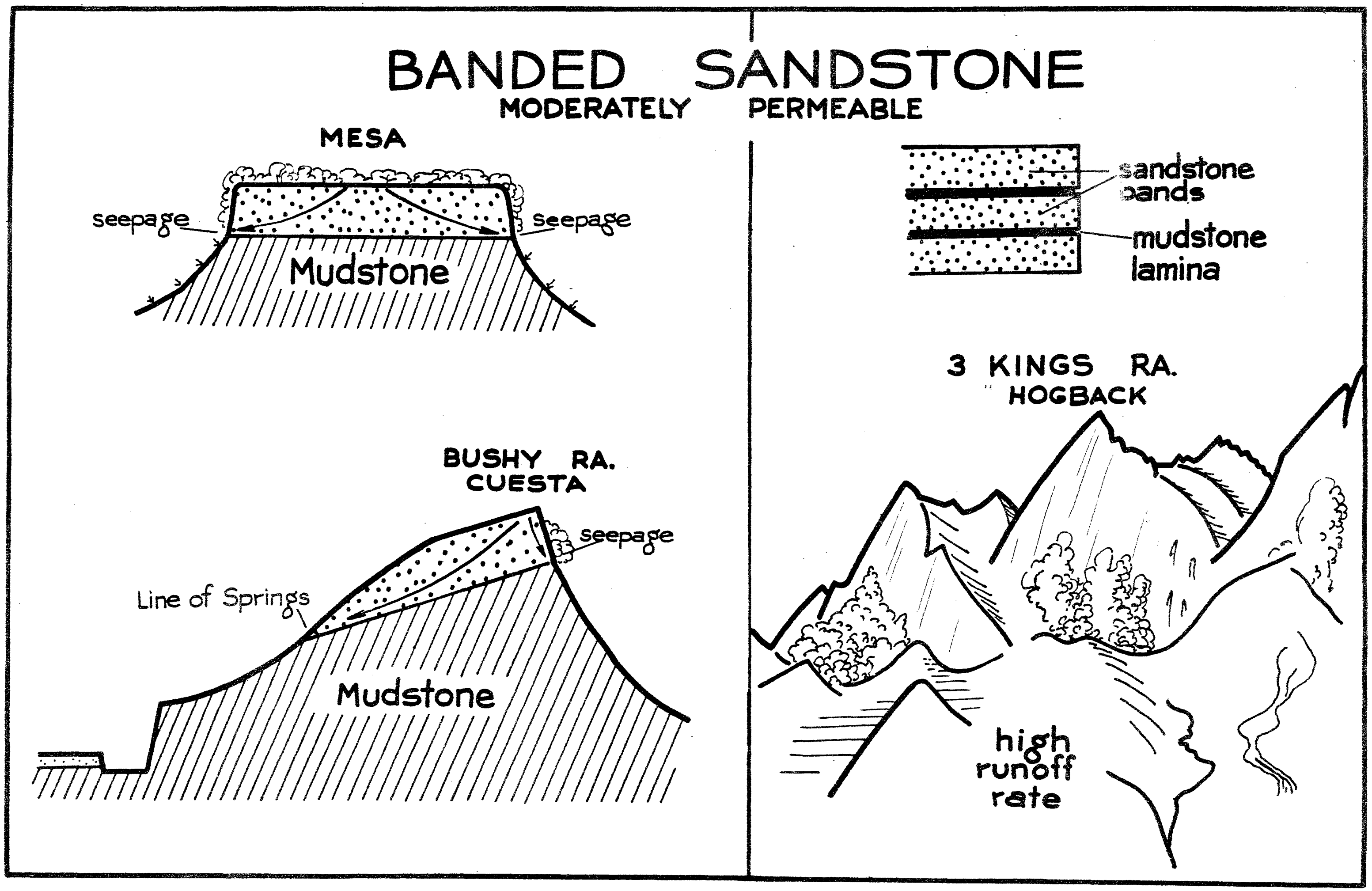

Figure 4

Diagrammatic representation of flow pattern in Banded sandstone

are common. Permeability is partially restricted by the fine grain size of the sand particles and the quantity of silt or clay in the intertices between. The underlying beds are usually mudstone and are even less permeable. Contact springs[9] are common where rock boundaries and the ground surfaces intersect. Runoff is restricted on undulating mesa surfaces, unless they are dissected; moderate on the dipslope of homoclines, and very high on hogbacks. Some parts of the thicker sandstones will yield up to 10,000 gallons per hour[6] but sand screens are needed for the wells.

Shattered Rocks - Fig. 5 is a cross section of a hypothetical landscape underlain by shattered rocks which are highly permeable. Haumurian argillite is flanked on one side by Teurian shale through a transitional boundary and on the other it is separated from the Weber siltstone formation by a normal fault.

Haumurian Argillite (or Whangai shale) is a siliceous rock, badly shattered and contorted, with low specific gravity. It is grey when fresh, but weathers brown to a depth exceeding 20'. The iron content of the rock is 2% but since the extractable iron of unweathered argillite is only half that of the weathered rock[2] the latter is more firmly cemented and less permeable. The formation supports large hills with broad rolling interfluves separating long steep slopes. Runoff rates are high on the associated Mataikona soils[8]. The Tinui soils on the interfluves are light and porous and rainwater percolates through them readily. The cover is mainly inferior grasses and scrub. Argillite outcrops are numerous throughout the east coast of the North Island but the water obtained from them has the undersirable feature of a high iron content[6]. However, this can be reduced by aeration or crude infiltration.

Teurian Shale or claystone is light grey in colour and very calcareous with current-bedded laminations of silts and clays. It has been excessively shattered and the bentonite clay content[7] ranges up to 45% in crush zones. Relief is more subdued than on Haumurian argillite. The associated Ruatoria stony loam soil[8] has medium to high fertility and supports pasture. Only a few outcrops of the claystone

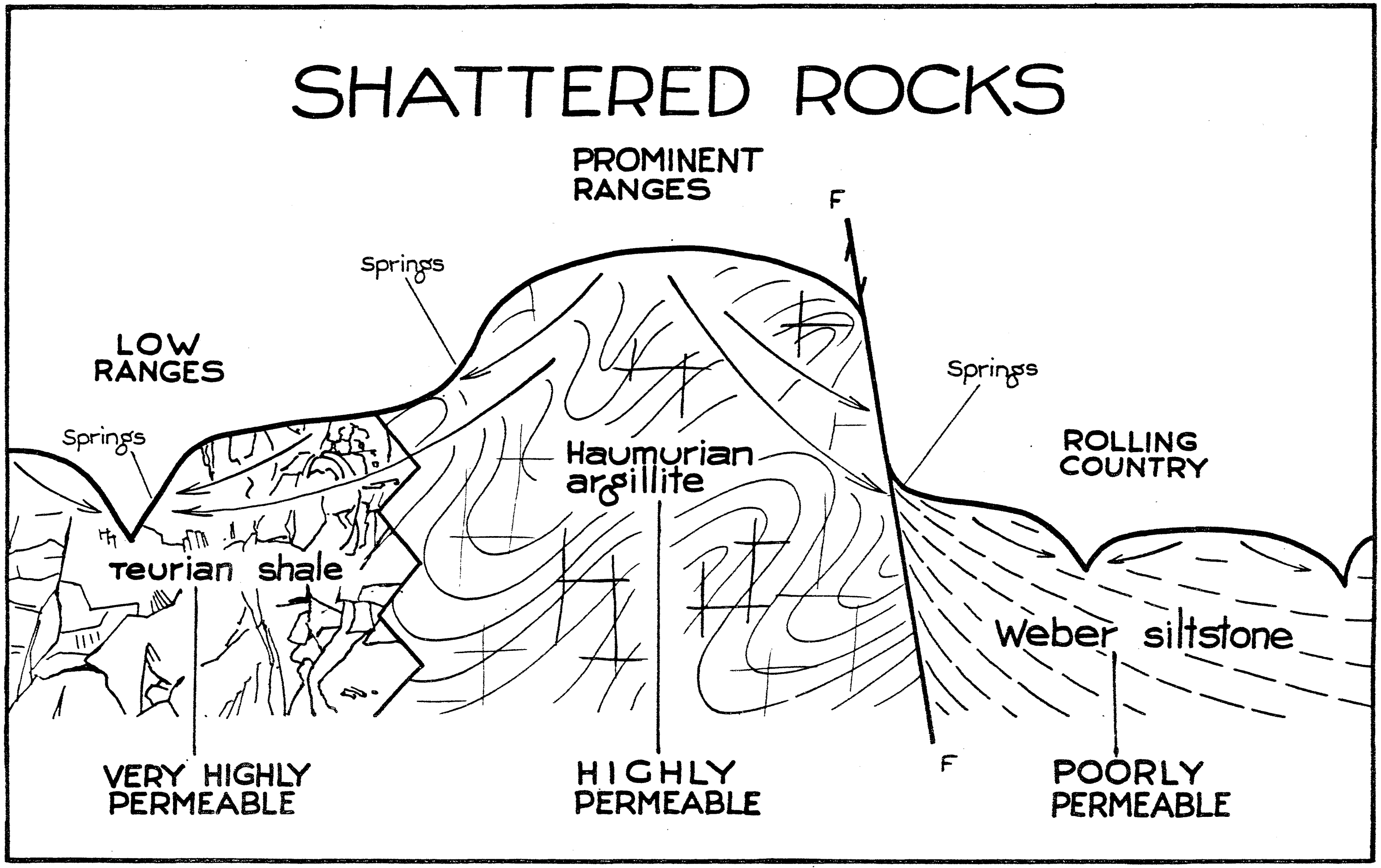

Figure 5

Diagrammatic representation of flow pattern in Shattered rocks

occur near the East Cape where rainfall is high ranging from 60"-90". The prospects for groundwater are very good. Temporary hardness[6] may mar this water of otherwise excellent quality.

The Weber Siltstone[7] of Landon age is a light coloured rock which weathers white. It is moderately hard to hard and extremely calcareous. Normally it is jointed but cementing with calcite has reduced its porosity. Near the fault contact, however, it is commonly distorted or shattered. The low rolling relief has a fertile soil cover formed from a heavy clay which in turn is derived from the weathered bedrock. The clay restricts the movement of both roots and water and pugs easily in wet weather. Both soil and rock are poorly permeable and the small quantity of water that could be derived from it is likely to be hard.

Taitai Greywacke Sandstone - Landforms underlain by Taitai sandstone, a shattered rock, are shown in Fig. 6. This is a dark tough, calcareous rock with muddy fine sandy texture and is lower Cretaceous in age. In the East Coast ranges, south of Hawkes Bay, outcrops support a rugged relief studded with taipos. Slopes are steep to very steep. The associated Pahaoa silt loam is grass covered and remarkably stable. Though the soil and rock are both fairly permeable, the relief is such that most rainwater is shed as runoff. In the Tapuwaeroa Valley, near the East Cape, Taitai sandstone outcrops are small and isolated but resistant. They form high peaks which tower over the low rolling country underlain by the adjoining Mokoiwi argillite, a permeable rock formation. One of them, Mt Hikurangi (5760') is the highest non volcanic peak in the North Island. The mid Cretaceous banded greywacke to the west (Fig. 6) is indurated with wide joints and the beds are commonly warped. It flanks the main ranges and has rugged relief with forest vegetation in an area where rainfall ranges up to 100" or more[4]. These rocks are well watered with many permanent streams[6].

Solution Rocks

Coquina Limestone - Limestones vary widely in density, porosity and permeability depending on the degree of consolidation and development of solution channels after deposition[9]. Coquina, a detrital shell limestone with a

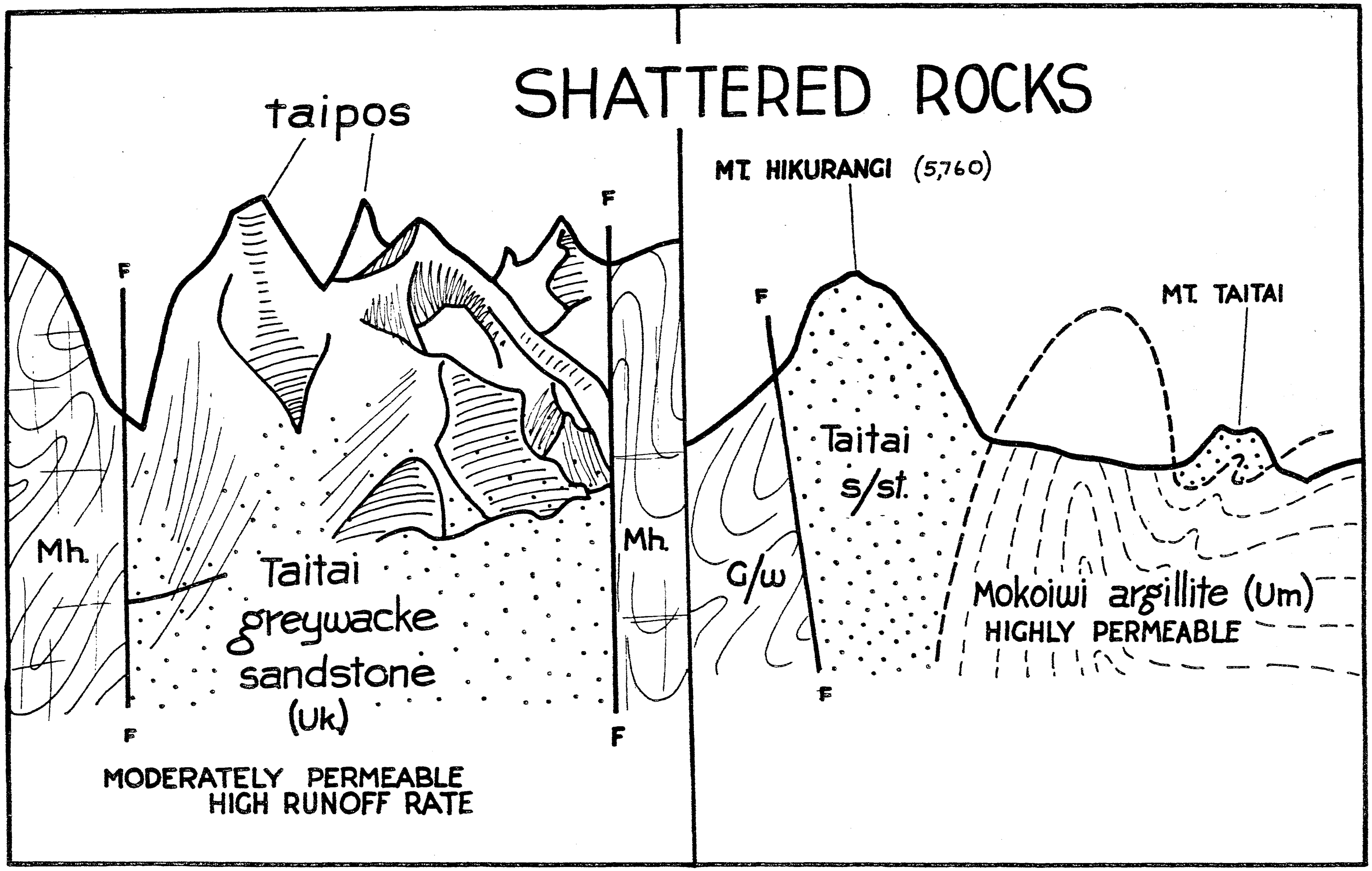

Figure 6

Diagrammatic representation of flow pattern in Shattered rocks

high calcium carbonate content yields considerable quantities of water. The Puketoi Range (Fig. 7) in the Akitio region is aligned in the direction of geological strike (N15°W) and consists of a 100 ft cap of Waitotaran limestone overlying Opoitian muddy sandstone and Tongaporutuan mudstone. The beds dip approximately 15°W forming a homocline with a moderately steep dipslope partially dissected with dolines, solution channels and rocky outcrops[7]. These west facing slopes are grass covered but the steep east facing scarp slopes are covered with indigenous forest. The limestone formation is separated from the forested Waewaepa Range, a Jurassic greywacke horst, by a fault. Although cementing of the limestone is variable water can be produced from any horizon from flow through the pore spaces[6]. Annual rainfall exceeds 60" along the crests of the ranges and even in drought periods there is sufficient water to replenish springs in the outflow zones. The most productive springs are found at the contact of the very highly permeable limestone and the underlying poorly permeable sediments where this is exposed by deeply incised streams. Further springs occur near the fault contact at the Waewaepa Range and some seepage is seen on the scarp slope.

Recent Sediments

Alluvial Gravels - The most productive of the groundwater systems are the alluvial gravels underlying the Poverty Bay, the Hutt Valley flats, and more particularly the Heretaunga Plains. These recent sediments are neither weathered nor, as yet, strongly mineralised[6]. In summer approximately 55% of the water from the Ngaruroro catchment goes to the groundwater of the Heretaunga Plains[5]. The recharge rate is about 150 cusecs. The water flows through capped aquifers of highly permeable gravels which are mainly buried meandering river channels. A population of 75,000 draws water supply from the Heretaunga groundwaters and yields of up to 80,000 gallons per hour have been recorded in free flowing wells at ground level. However this intensive use has greatly disturbed the piezometric surface.

CONCLUSIONS

Except where productive aquifers underly the major river flats, commercial water in the North Island is supplied by surface water.

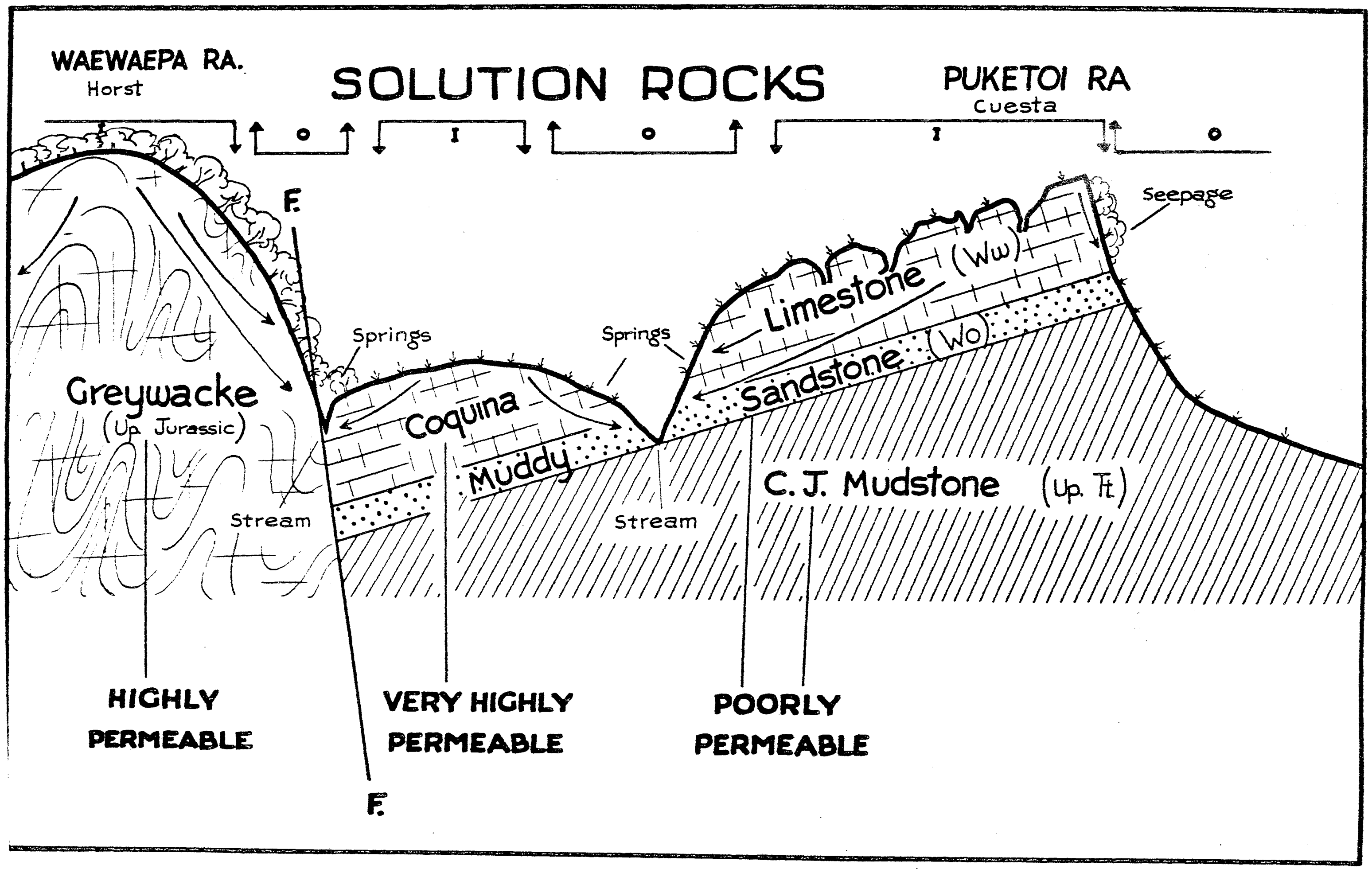

Figure 7

Diagrammatic representation of flow pattern in Solution rocks

The greatest rates of surface water runoff come from the steep and very steep slopes of the banded mudstone hills, sandstone hogbacks and the Taita greywacke taipos. The compaction of close jointed mudstone soils by trampling has led to similar results on low hill country.

Surface water runoff rates are less on the moderately steep slopes of homoclines or permeable limestone and sandstone. They are least on easy rolling interfluves underlain by shattered argillite and shale and the broken surfaces of loose jointed mudstone.

The flow of groundwater depends mainly on the permeability of the bedrock but the direction of movement and the emergence of springs can be influenced by geological structure. Homogenous rocks are relatively uniform throughout and groundwater yields are increasingly improved from the moderately permeable jointed mudstones to the highly permeable shattered argillites and shales.

Heterogenous rock formations are either banded or consist of relatively thick strata of a highly permeable rock such as limestone overlying an impervious sediment. In each case a definite contact separates beds of differing permeabilities. Groundwater movement is directed along the angle of dip of the beds and springs occur where rock contacts intersect the relief surfaces. Further springs are located along fault lines which separate different rock formations but in some cases they are associated with zones of fracture through which water percolates readily.

Although mineralisation is a problem of many areas of North Island groundwater, water quality can be improved by simple methods.

DISCUSSION

Q. Could you comment on the saltwater pollution of underground aquifer in the Hutt Valley?

A. There is often the danger with underground water supplies that if the rate of draw off exceeds the rate of recharge back pressures may be high enough to allow saltwater pollution of the ground water. This problem is not confined to the Hutt Valley but is also found in other areas such as the Heretaunga Plains.

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THE INFLUENCE OF SNOW ON STREAMFLOW

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INTRODUCTION

The New Zealand Forest Service began investigating snow in the Craigieburn Range in 1962 as part of a larger research programme designed to determine the mountain climate of the area. Since 1962 the snow studies have been extended in order to provide information on:

(a) the total winter precipitation at altitudes above 4,000 feet,

(b) The importance of snow avalanches as geomorphological agents,

(c) The importance of snow cover as an environmental factor on various types of high altitude sites,

(d) the importance of snowmelt to stream flow and flooding.

These snow studies have been carried out in the headwater regions of Broken River in the eastern Craigieburn Range. Much of the information on snow has been obtained from regular fortnightly snow surveys on two permanent snow courses sited at 5,700 ft and 4,700 ft respectively. This paper is mainly concerned with snowmelt and its effect on stream flow.

SNOWMELT

The release of stored water in the spring and summer months, particularly from the alpine zone, provides soil moisture for plants over the critical early part of the growing season and helps maintain streamflow during early summer dry periods.

Table 1 - Mean daily thaw rates of Alan's Basin and Camp Stream snowpacks

Location	Measured thaw period	Days	Mean snow loss*	Mean daily thaw rate*	Equivalent runoff rate per 100 ac. cusecs
AB	10/9/63 to 4/11/63	55	17.58	0.32	1.3
CS	9/9/63 to 2/10/63	24	8.20	0.34	1.4
AB	8/10/64 to 25/11/64	48	16.90	0.35	1.5
CS	8/10/64 to 15/11/64	27	9.50	0.35	1.5
AB	14/10/65 to 19/11/65	26	10.90	0.42	1.8
CS	13/10/65 to 27/10/65	15	5.42	0.36	1.5
AB	25/9/66 to 5/11/66	41	13.04	0.32	1.3
CS	—	—	—	—	—
AB	6/10/67 to 25/10/67	19	5.40	0.28	1.2
CS	20/9/67 to 8/10/67	18	5.41	0.30	1.2
AB	16/10/68 to 31/12/68	76	32.60	0.43	1.8
CS	11/10/68 to 26/11/68	46	14.10	0.31	1.3

* Equivalent inches of water

Above 5,000 feet the accumulated snowpack begins to waste between mid September and mid October. Unlike the pack below approximately 5,000 feet, which undergoes appreciable melt throughout the winter months, the alpine snowpack does not usually ablate significantly between June and September except during warm northwest conditions. Figure I showing the changes in mean water content of the snowpack across two permanent snow courses indicates the variation in the magnitude and timing of snowmelt from season to season. In 1968, the heaviest snow year recorded, 4.7 times more water was released from the snowpack than in 1967 at the 5,700 ft snow course. In 1967 the pack at this Alan's Basin course began to thaw in mid September and five weeks later had disappeared. In contrast, the 1968 snowpack in the same area did not begin to thaw until mid October when it melted gradually over a period of 13 weeks until the snow finally disappeared in late January. The timing and length of the snowmelt periods during 1962, 1963, 1964, 1965 and 1966 occurred somewhere in between the extreme 1967 and 1968 melt conditions.

Table I shows the average daily thaw rates for the two snow courses (A.B. 5,700 ft and C.S. 4,700 ft) during the spring-summer melt periods from 1962 to 1968 inclusive. Only those parts of the melt periods during which continuous snow cover persisted on the snow course slopes are included.

Mean thaw rates range from 0.28 inches of equivalent water per day to 0.43 inches per day. Disregarding evaporative losses, thaw rates of this order theoretically release 1.2 cubic feet per second per 100 acres to 1.8 cubic ft per second per 100 acres respectively. The variation in mean melt rates from year to year is due mainly to late season snowfalls which provide an insulating cover of fresh snow causing temporary halts in the thawing of the ripe snowpack. The magnitude of the peak snowpack accumulation is also important. After a heavy snow year the thaw period at higher altitudes continues through December when conditions favour rapid melting.

Photographic sequences taken from permanent photo points show that the snow cover pattern above 5,000 ft in the late stages of the thaw period is closely related to the micro-

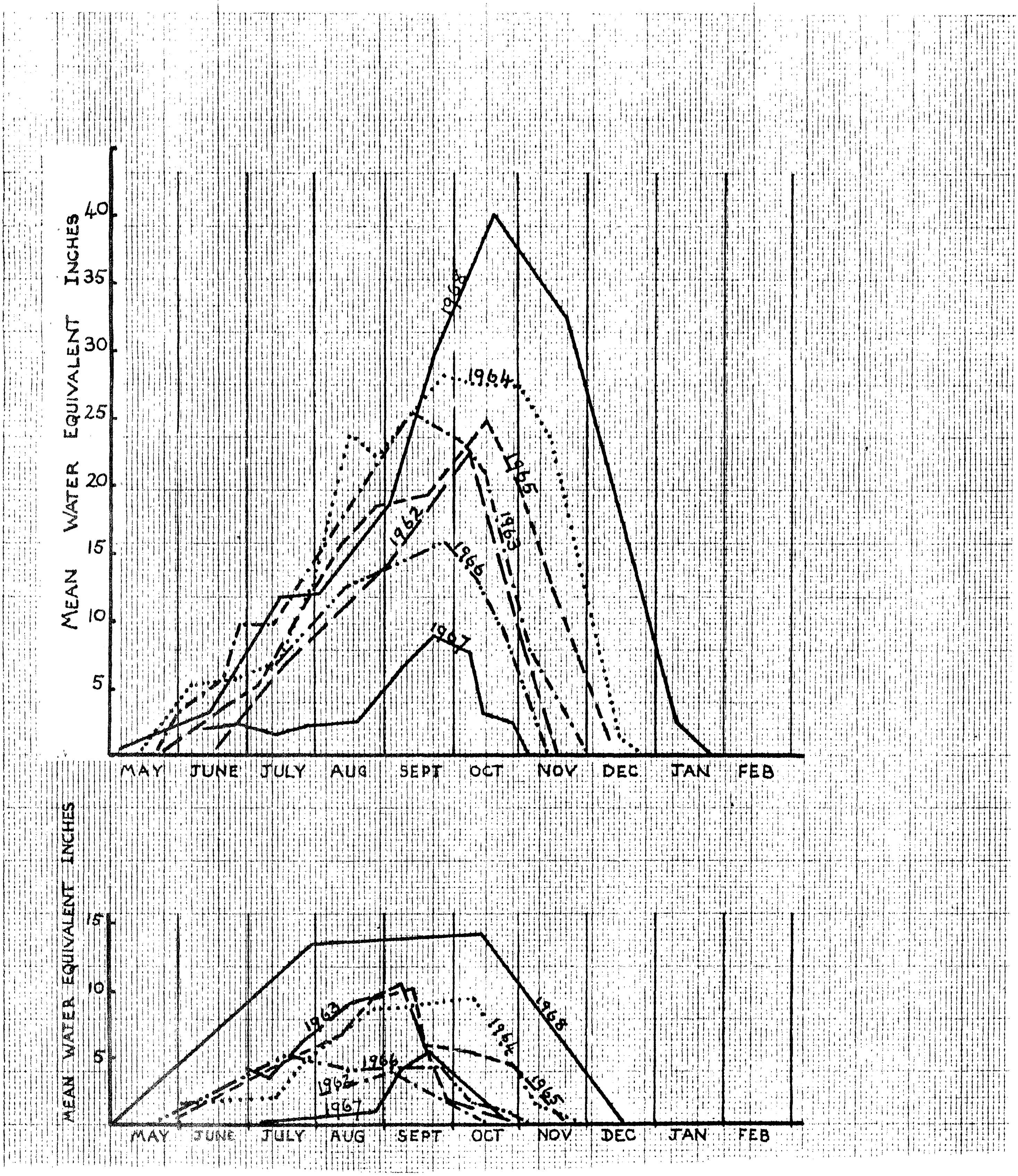


Figure 1
Mean water content of the snowpack at Alan's Basin (above) and Camp Stream (below) over the duration of seven snow seasons. Note the marked seasonal variations in the magnitude of the snowpack.

topography. This pattern is duplicated each year although the same stage of snow cover disappearance occurs at different times of the year from snow season to snow season. For instance, photographs of the eastern Craigieburn Range show that the snow cover pattern in late December, 1968 was almost identical to the pattern occurring in early December 1965 and late October 1967.

MELTING FACTORS

The physical aspects of snowmelt have received much attention in North America, Japan, and Europe and a brief mention of these studies is warranted. Theoretically 750 B.t.u./ft^2 or 203 cal./cm^2 are required to melt one inch of water from snow or ice.

Wilson (1941) in a study of the thermodynamics of snowmelt outlined the relative magnitude of heat transfer by the various means (Table 2).

Table 2 - The Theoretical Heat Balance of a Snowpack (after Wilson, 1941)

Means of heat gain	Extreme Conditions	Approx. cal/cm^2/day
Air convection (turbulent exchange)	70^{o}F D.B: 20 mph wind	600
Condensation (heat of vapourization)	60^{o}F D.P: 20 mph wind	600
Net radiation gain	Very moist air, cloudy at night	200
Warm rain	4" at 50^{o}F W.B.	100
Underlying soil	New snow	20
Means of heat loss		
Outgoing radiation	Dry air, clear sky	200
Evaporation (heat of	10^{0}F D.P. 45^{o}F D.B. 20 mph wind, high convection gain	150

Means of heat loss	Extreme Conditions	Approx. cal/ cm^2/day
Convection (turbulent exchange)	Air colder than snow	20
Underlying soil	Frozen soil	20

This heat balance summary indicates that significant snowmelt takes place only at the surface of the snow exposed to the air. That raindrops falling onto a snowpack can cause rapid melting is a common misconception. Rather it is the condensation, convection and net long-wave radiation accompanying warm, rain-producing air masses which are important factors (Garstka in Chow, 1964; Bruce and Clark, 1966; Wilson, 1941). Miller (1950) concluded that one important source of heat for snowmelt was the heat relayed to the snow from the forest canopy. This source of heat may be very important at altitudes below 5,000 ft in the Craigieburn Range. It may also be partly responsible for the differences in melt rate between Alan's Basin and Camp Stream. Another important source of heat in a region such as New Zealand where warm, moist, maritime air masses are common in the spring months is the heat gained from condensation of water on the snow surface. For each gram of water condensed about 7 grams of ice can be melted.

SNOWPACK QUALITY

The quality often referred to as the thermal quality of a snowpack is a measure of the percentage by weight of the snowpack's water equivalent which is in the form of ice. Because the latent heat of fusion of ice is 80 calories per gram, the quality of snow may be expressed as the ratio of the heat required for melting the snow (in calories per gram) to the 80 calories per gram for melting ice. For instance, snow consisting of 70 percent ice and 30 percent liquid water has a quality of 70% and a melting heat of 0.70 x 80 = 56 calories per gram.

Probably no other physical property of the snowpack influences the discharge of water by the snowmantle more than quality. Early season snow and fresh powder snow of relatively light density normally possess a thermal quality of 100%.

A period of warm weather may result in very little melting from this type of snow. On the other hand high density, wet snow containing a large quantity of stored liquid water may produce disproportionately large quantities of melt water during a similar warm period.

Snowpack quality determinations were made during September and October 1968 using a calorimetric procedure described by Bernard and Wilson (1941). A large calibrated thermos flask (5,000 cc capacity) equipped with a mercury column thermometer was used as a calorimeter. Horizontal core samples of the snowpack, obtained at various depths from the vertical faces of snow pits, were placed in the calorimeter which contained a known volume of hot water. The thermal quality (Qt) of the snow was determined using the equation:

$$Qt = 100 \left[\left[(T_I - T_2)(W_w - k) W_s \right] - T_2 \right] \Big/ 80$$

where T_I = initial hot water temperature °C

T_2 = final temperature after addition of snow °C

W_w = weight of hot water (grams)

W_s = weight of snow sample (grams)

k = calorimeter constant (grams)

The pits were dug in the snow at 5,000 ft. Density and temperature measurements were made at different levels in conjunction with quality measurements. The results are shown in Figure 2.

These snow quality measurements indicate that compacted powder snow can retain a liquid water content of up to 10% by weight of the snow. Gerdel (1945) maintained that the capillary tension within a deep snowpack appears to be insufficient to support a liquid water content much greater than 10% by weight of the snow. The liquid water content measured on the 8th August 1968 near the top of the snowpack can be regarded as a maximum possible value under the existing snow conditions as very heavy rain was falling onto the snow surface and the upper layers were saturated.

These findings indicate that a 4 ft deep pack with a mean density of 30% and a quality of 100% could theoretically absorb about 1.5 inches of rainfall.

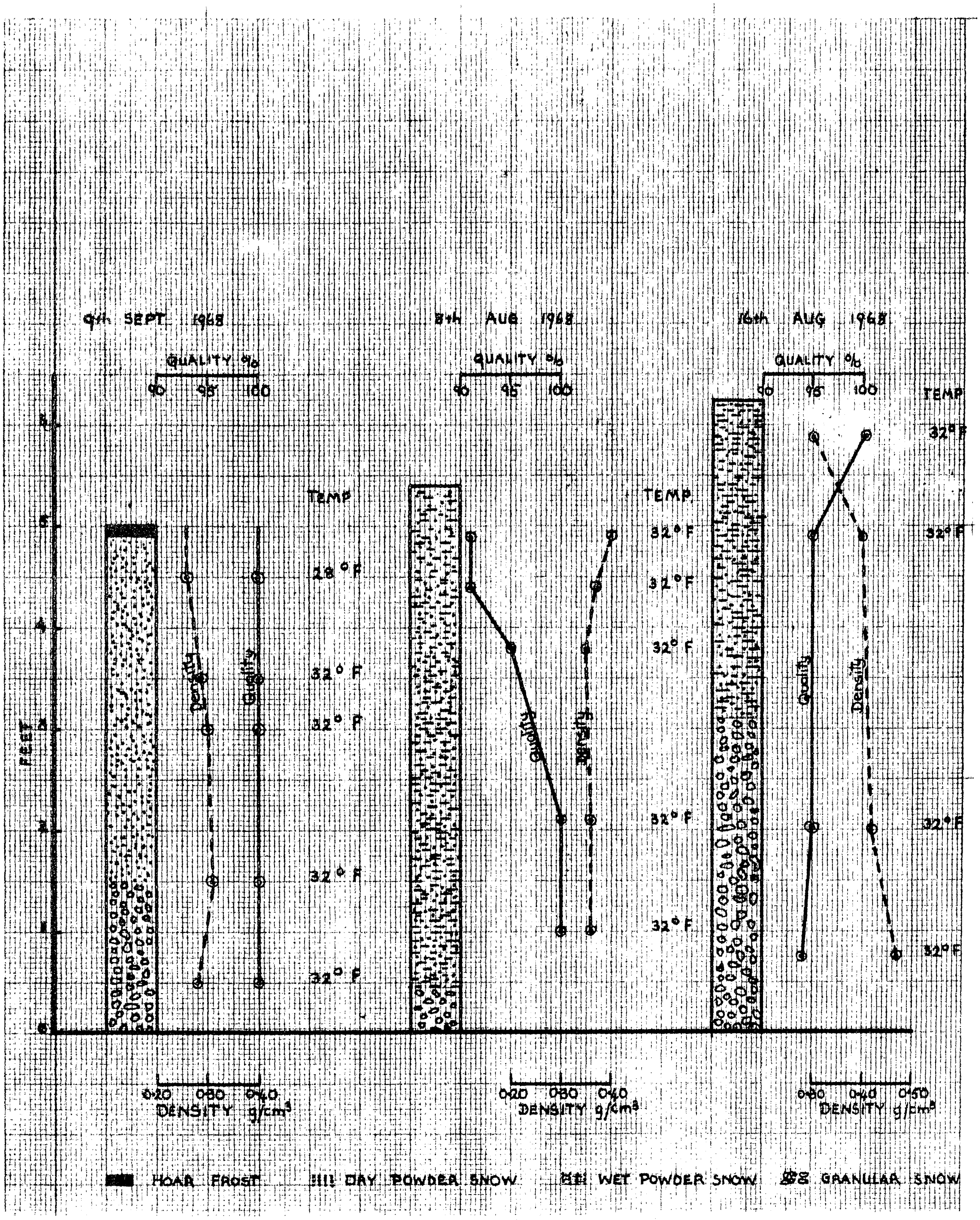


Figure 2

Vertical profiles of the snowpack at Ski Basin 5,000 feet showing the variation of snow quality, density and temperature.

TRANSMISSION OF WATER THROUGH SNOW

Unfortunately,reliable data has not been collected on water transmission rates through snow in New Zealand alpine areas. Gerdel (1945, 1954) measured a water transmission rate of 0.44 inches per foot per hour through a ripe snow-pack and a maximum percolation rate of 24 inches per minute. A preliminary experiment conducted at 5,000 ft in the upper Broken River Basin, which involved the application of a solution of carbol fuschin (red dye solution) to a ripe snowpack surface, indicated that percolation rates ranged between 0.5 inches and 12 inches per minute.

The liquid holding capacity and the water transmission rates of late season snowpacks are extremely important aspects of snow hydrology and the influence of these properties on the flood behaviour of snow mantled catch-ments requires evaluation.

SNOWMELT AND STREAMFLOW

The effect of snow and snowmelt on the discharge of Camp Stream, the only high altitude basin equipped with a stream gauging station in the upper Broken River area, is illustrated in Figures 3 and 4. Approximately half the 230 acre Camp Stream catchment lies above 4,000 ft and nearly all the spring snowmelt water comes from this area.

In 1968,snow surveys in Camp stream showed that rapid melt began in mid October, although the pack below 5,000 ft had been wasting slowly throughout the winter. Most of the snow was gone from the catchment by early December. A detailed snowmelt hydrograph analysis has not been attempted, partly because a stage-discharge relationship for the gauging station is not yet firmly established for high flows, and partly because the 1968 October and November streamflow records are complicated by a series of rain storms. These records are the only records available during a snowmelt period.

Figure 3 broadly illustrates the effects of snowmelt on streamflow in Camp Stream basin. Streamflow did not fall below 2 cubic feet per second from mid October to the end

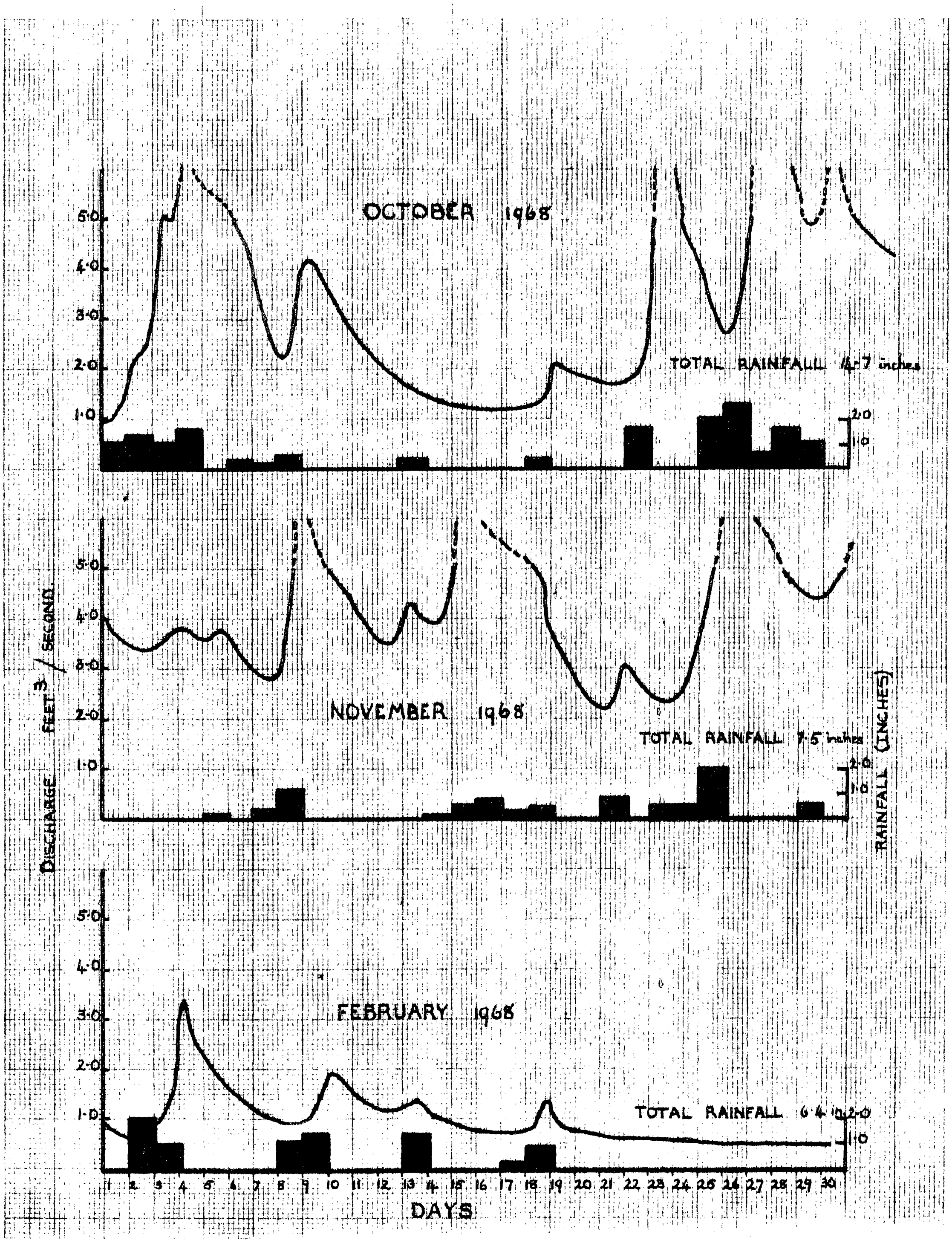


Figure 3

Discharge hydrographs and rainfall hyetographs for Camp Stream catchment, during October, November and February 1968.

of November, the period over which rapid snowmelt occurred. However, in February 1968, a month during which the catchment was snow free but received about the same rainfall as in November 1968, the hydrograph only exceeded 2cubic feet per second for a brief period during a high intensity storm.

Approximations of the total precipitation input and stream output in acre feet are shown in Table 3 for October, November and February 1968, and for the main snowmelt period (15th October - 31st November).

Table 3 - Summary of Monthly Runoff/Rainfall relationships, Camp Stream

Period	Total Runoff(Q) Acre Feet	Total Precip.(P) Acre Feet	Q/P
1 Oct - 31 Oct	208	276	0.75
1 Nov - 30 Nov	257	142	1.81
15 Oct - 30 Nov	377	308	1.22
1 Feb - 28 Feb	55	124	0.44

Taking base flow into account, the ratio of runoff to precipitation during the snowmelt period is more than double the ratio calculated for February. This indicates that at least half the stream flow during late October and November is derived from snowmelt. These estimations are very approximate and no consideration has been given to the seasonal changes in catchment loss rates which effect the runoff/ rainfall relationship.

It is significant that the maximum mean daily snowmelt rates recorded in Camp Stream by depth-density measurements of the pack (0.36 inches of equivalent water per day) produce a theoretical daily flow of 1.50 cubic feet per second per 100 acres. The maximum short term snow melt rate, measured after the November 1967 snow storms in Camp Stream (0.05 inches of equivalent water per hour) theoretically would produce 5.20 cubic ft per second per 100 acres. Assuming that all of Camp Stream catchment was contributing snowmelt directly to stream flow at the one time (a most unlikely situation) melt rates of this order would not produce a discharge of more than 10 cubic feet per second in Camp Stream. It is unlikely that these melt rates produce surface runoff,

but rather that snowmelt reaches the main streams as subsurface runoff.

The four examples of individual hydrological events shown in Figs 4A to 4D further emphasise the relatively complicated functioning of steep mountain catchments compared to lowland catchments not influenced by snow. In the case of 4A, 1.4 inches of warm rain fell at a mean intensity of 0.1 inches per hour on a ripe, melting snowpack to produce a flash flood at the Camp Stream gauging station. In contrast Figure 4B shows that when 3.3 inches of warm rain fell at a mean intensity of 0.3 inches per hour on a dry snowfree catchment, peak discharges were less than 7 cubic feet per second. Figure 4C shows a broadly rounded rise in the hydrograph as a result of snowmelt on a warm November day when temperatures climbed to the mid sixties (^{o}F). The shape of this snowmelt hydrograph indicates that surface runoff or quick subsurface runoff was not involved. Finally, Figure 4D shows a case where heavy winter precipitation in the form of snow, falling onto a snow-mantled catchment, failed to produce even a bump in the hydrograph.

These large variations in mountain catchment sensitivity, which largely depend on the antecedent snow conditions, indicate that if accurate flood forecasting techniques of catchment behaviour models are to be developed in the future, the relationships existing between snowmelt and streamflow must be properly understood. More specifically, the following avenues of investigation require most urgent attention:

(a) Development of simple but accurate techniques for assessing a catchment's total snow storage at the beginning of the spring thaw period.

(b) Establishment of the relationships existing between certain climate indices such as maximum daily air temperatures and snowmelt for a range of topographic and vegetation conditions.

(c) Establishment of the relationships existing between measured snowpack ablation and streamflow.

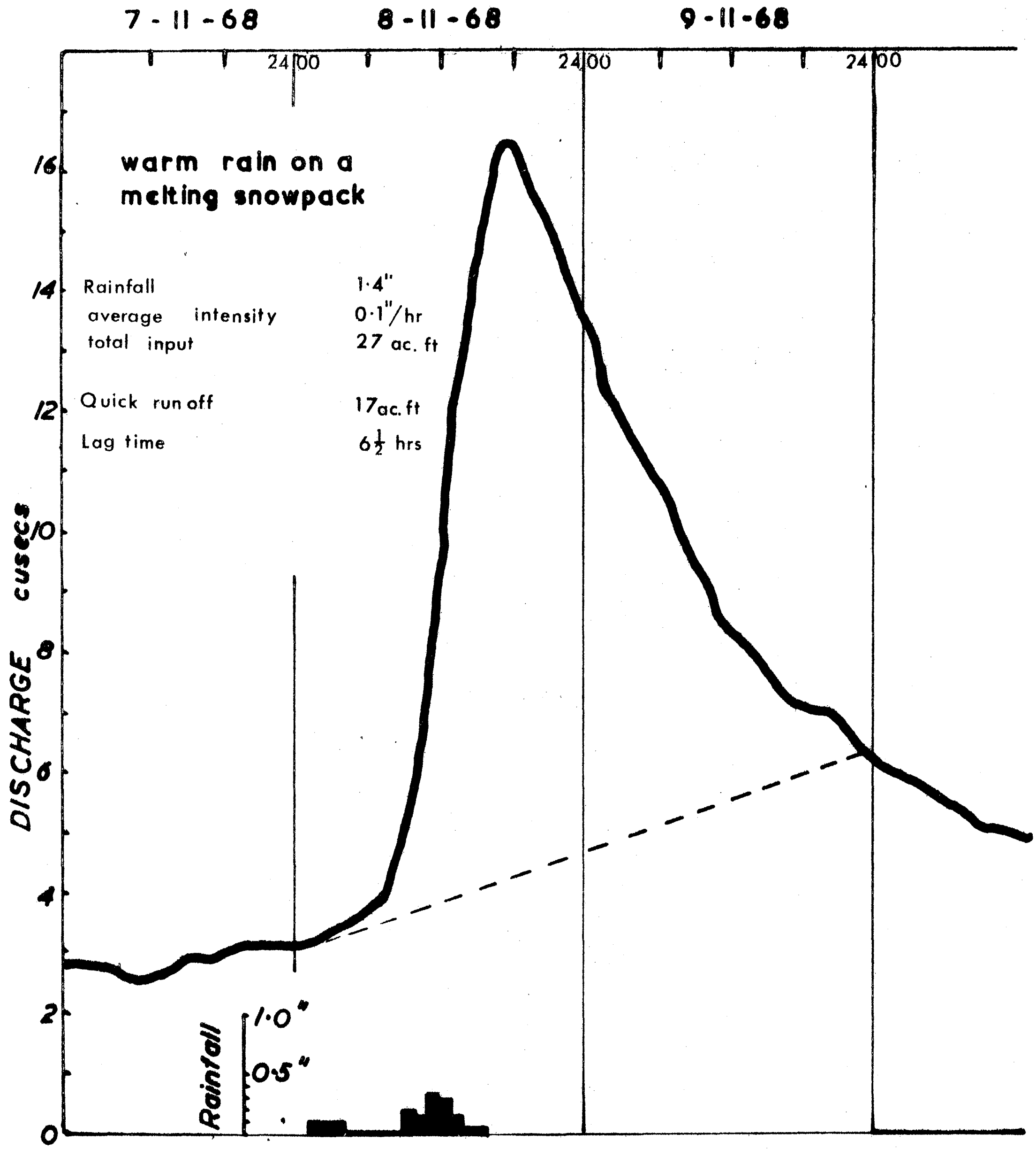


Figure 4A

Discharge Camp Stream Gauging Station

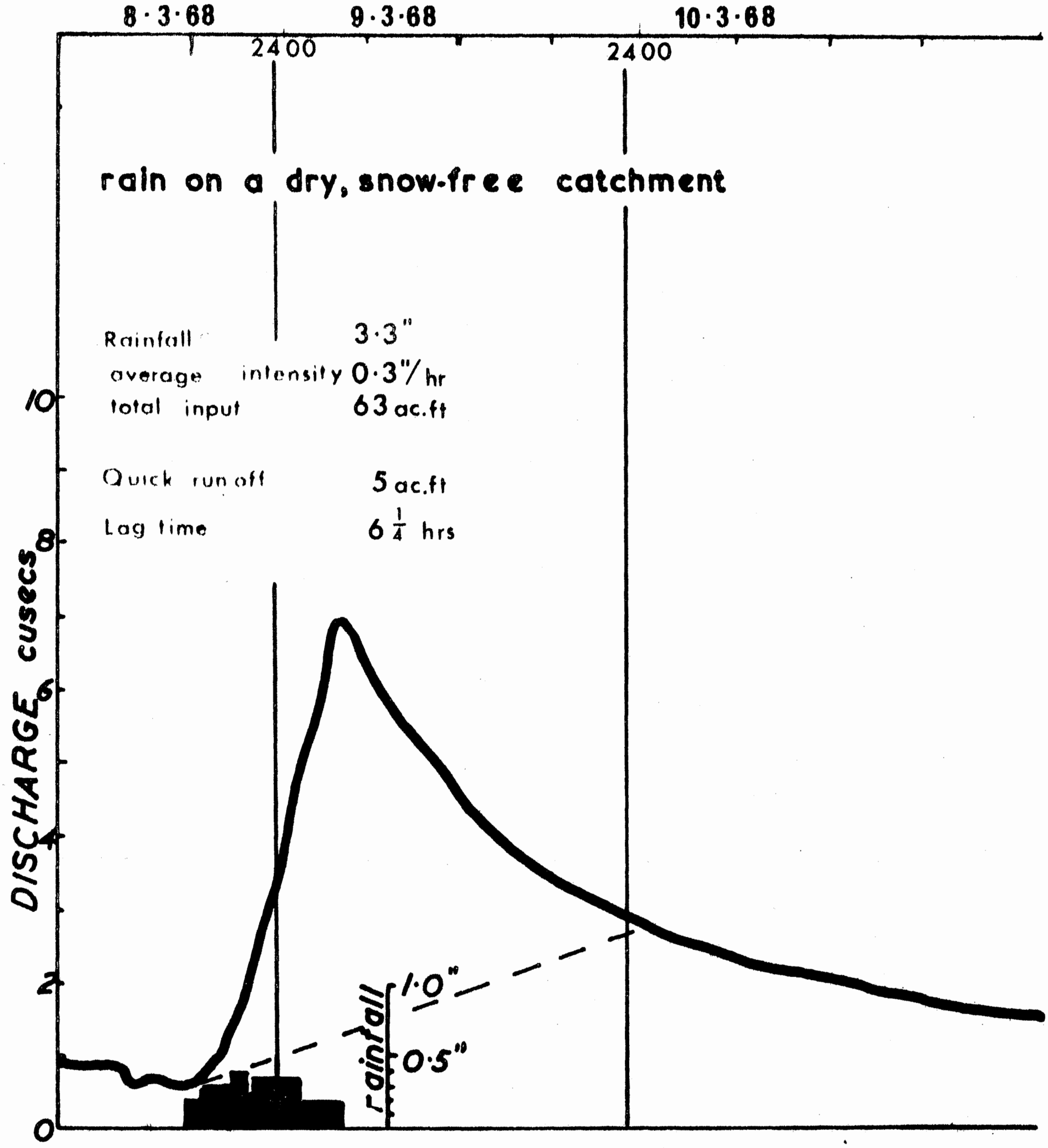
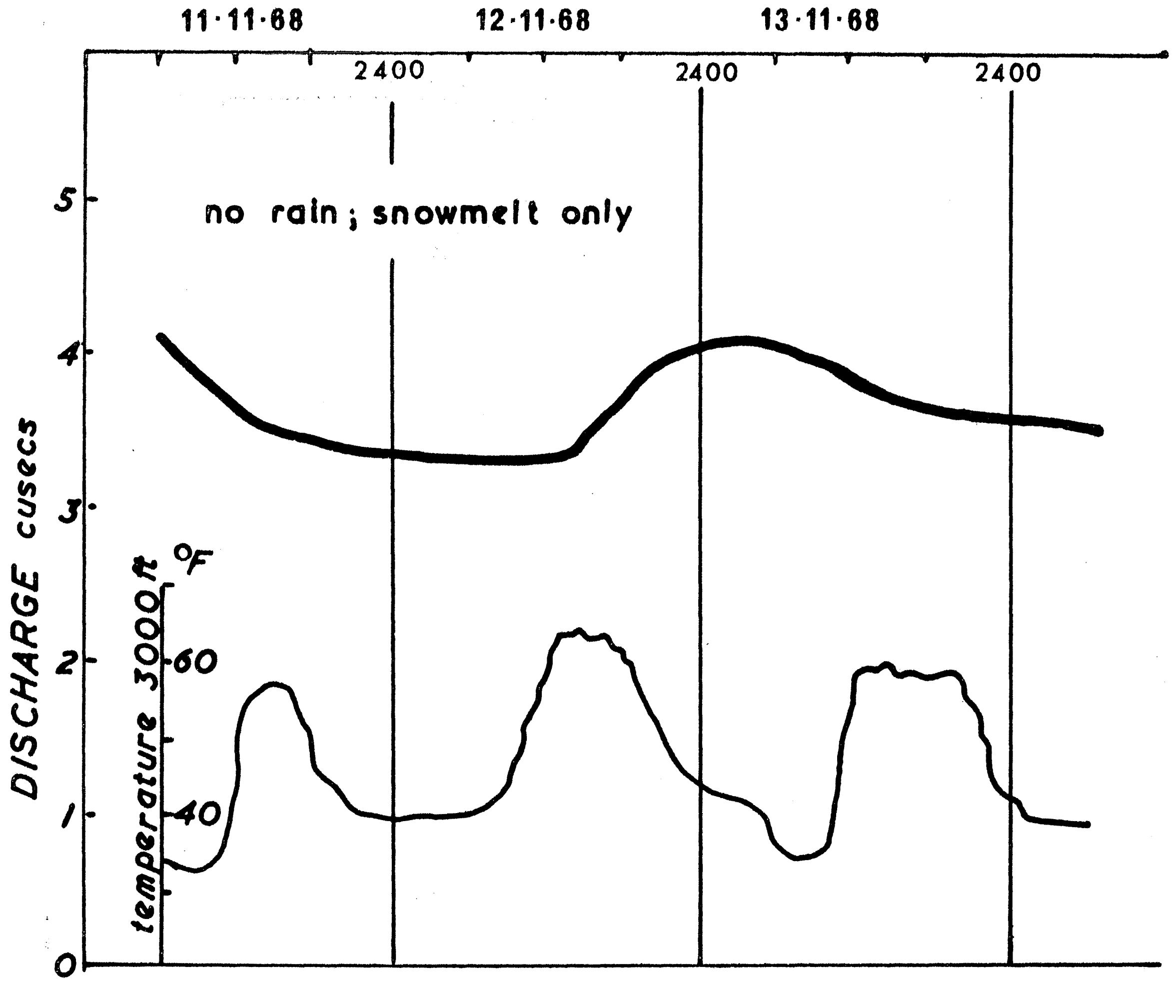


Figure 4B

Discharge Camp Stream Gauging Station



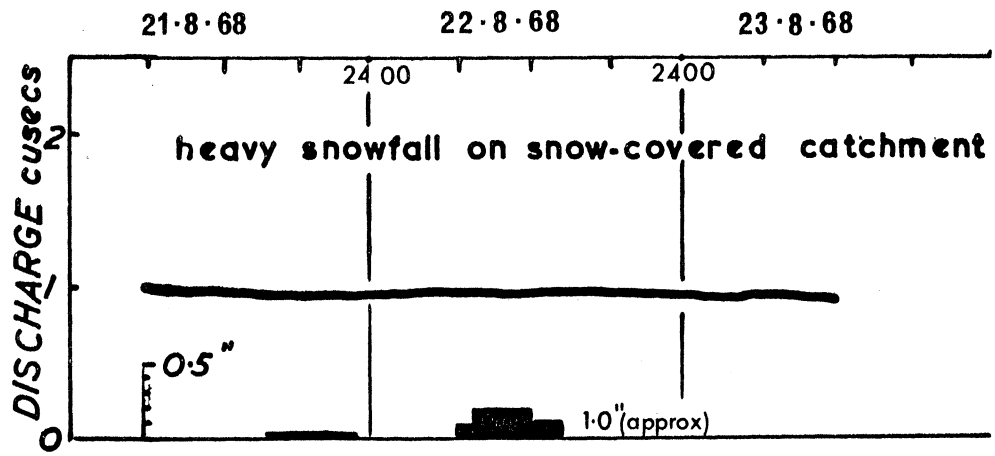


Figure 4C (upper) Figure 4D (lower)

Discharge Camp Stream Gauging Station

DISCUSSION

Q. How much of a snowpack is lost by evaporation?

A. Although there are no New Zealand data, overseas values suggest that these losses are insignificant and within the accuracy of measurement in our studies. It may be that evaporation losses are compensated by the gains from condensation onto the snowpack.

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SOME INFLUENCES OF RAINFALL ON STREAM FLOW AND LAND MANAGEMENT

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ABSTRACT

The influences of long-range variations of different rainfall parameters are discussed, with particular reference to the East Coast, North Island. These variations have probably affected other areas in the North Island.

As annual runoff and rainfall are closely related, long-range patterns of rainfall reliably indicate long-term runoff patterns. For eastern Hawke's Bay the annual pattern of rainfall, representing runoff, since 1870 is presented. Annual runoffs were at their highest average level during 1890-1910. The subsequent decrease in average runoff is sufficient to account for the diminution or drying up of numerous streams.

Broad patterns of storminess are presented. Storm and flood regimes have fluctuated markedly on a decadal basis; since 1890 the 1890s were the stormiest decade. The period 1930-60 had a higher average level of storminess than 1901-30. Changes, since the 1930s, of river regime, flooding and the incidence of deep-seated erosion are primarily the result of changes of the storm rainfall regime.

Seasonal drought patterns since 1890 show that major and sometimes abrupt, changes in drought severity have occurred. Compared with 1890-1929, the period 1930-69 had more days of partial drought, 26% more drought years, and a greater number of occurrences of three or more consecutive drought years. These changes have adversely influenced streamflow, pasture and crop production, tree growth, the dairying industry and some facets of sheep and cattle farming.

A general rise in atmospheric temperatures since the early part of this century has accentuated the effects of drought in lowland areas by increasing the length of the growing season for plants by at least 20%. At high altitudes snow and ice budgets have been altered; some implications of this change are discussed.

Some concepts and principles are outlined to aid in the interpretation and application of parametric time series changes.

INTRODUCTION

After precipitation, and before it finally reaches stream channels, water is subjected to numerous physical processes including evaporation, transpiration, infiltration and absorption, passage through soil and rock media and surface runoff. Stream flow is truly the residue of precipitation. Therefore it is not surprising to find some degree of relationship between streamflow and precipitation. Except where stated otherwise, these notes concern only rainfall, and catchments where the streamflow regime is not influenced by either major artificial or natural storages (reservoirs, lakes, ice and snow). The source area for most of the information presented is the East Coast of the North Island (Fig. 1).

The amount of streamflow that will result from a given quantity of rainfall on a catchment is determined by the many factors of (a) climate, (b) geology, (c) morphology, (d) soil, (e) vegetation and (f) cultural activity. Some idea of the complexity of rainfall/streamflow relations may be gained from the following generalisations. Compared with light rains a higher proportion of heavy rains will become streamflow. Larger and more sustained dry-weather flows can be expected from limestones than from sandstones or siltstones. A denser drainage network is likely to produce a greater annual water yield. Very deep soils should buffer flood peaks better and sustain larger dry-weather flows than shallow soils. Water yields will probably be smaller from forested than from grassed catchments. A flatter catchment should yield less water than a steeper one, whereas urban development will increase the total water yield.

Within limits imposed by climate and catchment geology and morphology on the one hand, and economics on the other, man can modify streamflow regimes. In the former category fall the effects of replacing forest by grass, and the results of different types of pastoral management (Toebes,

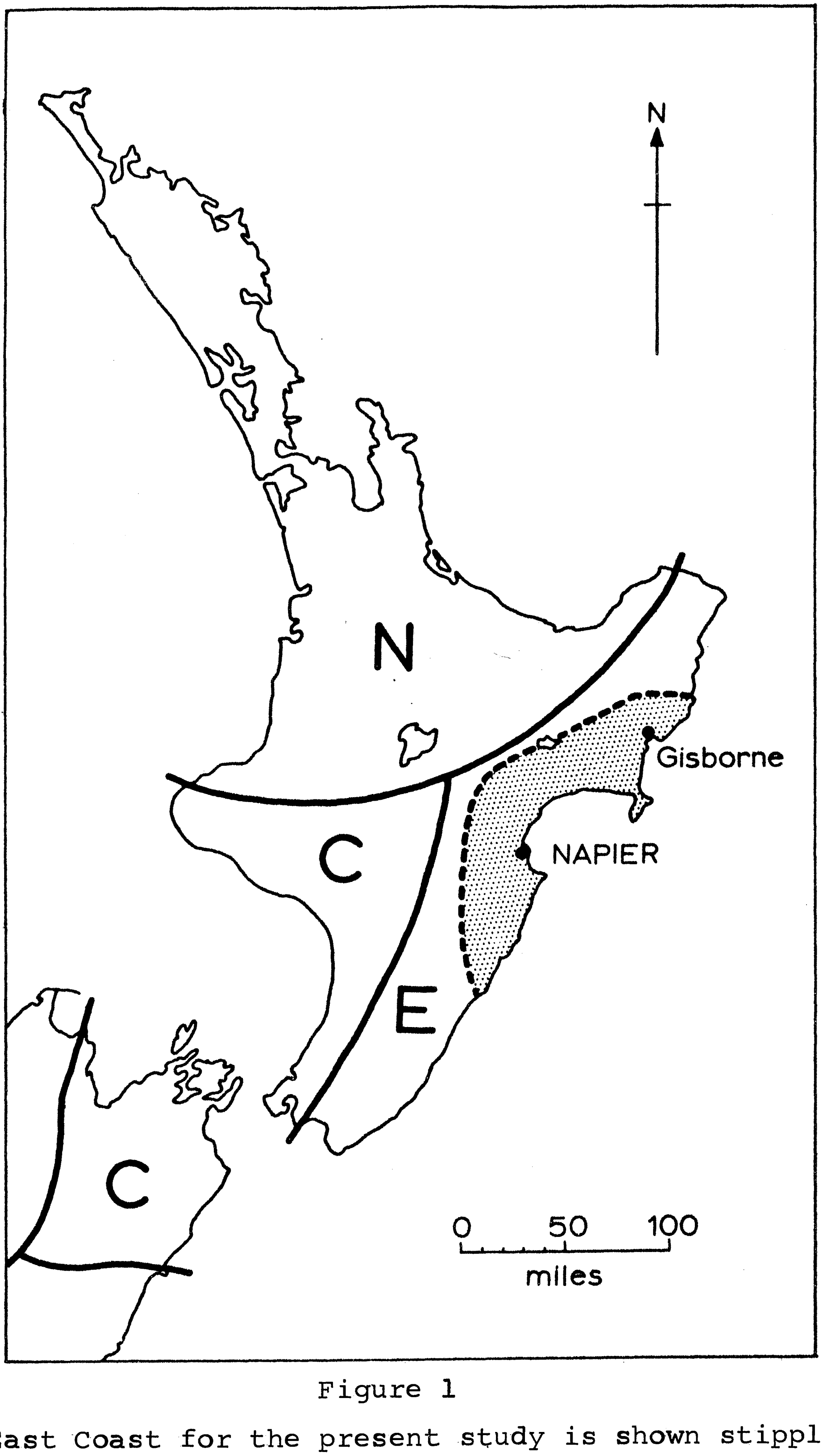

Figure 1

The East Coast for the present study is shown stippled and bounded by the broken line. The unbroken lines define the areas of de Lisle (1961). These are: (N) Northern, (C) Central and (E) East Coast.

Scarf and Yates, 1968). In the latter class are the effects of introducing storage, diversion and protection structures. But in an insular climate, such as New Zealand's, man cannot influence to any measurable degree the rainfall factor itself, because this is geared to the prevailing global atmospheric circulation patterns. (A distinction is made between insular and continental regions because in some semi-arid areas of the latter there are indications that man may be responsible for modifying the local rainfall regime.) However, because of the obvious rainfall/runoff relation, study of rainfall should give us some help in our study of streamflow.

Change, not constancy, is the universal norm. On any drainage area there are two complex sets of variables that can change. On the one hand man is largely responsible; on the other, climate is the controlling influence. Man seeks to assess the impact of his own activities on biological and physical systems; but obviously this is not possible until he has determined the effects of changes in climatic factors. And of these rainfall is probably the most powerful variable that influences water yield and with which land management has to contend.

This treatise considers mainly the long-range variations of rainfall and some of their influences on streamflow and land management. Certain aspects only have been selected and they are treated very broadly; the primary aim being to draw attention to the practical significance of many of the changes. If we appreciate these independent background changes and their influences, we are in a better position to assess the effects of cultural changes. Also, we will have gained the necessary requirement for placing short-term events and variations in better perspective, thereby establishing a sounder basis for prediction and planning.

ANNUAL RAINFALL AND RUNOFF

On both small and large catchments, whether forested or pastoral, close relations exist on the East Coast between annual rainfall and runoff amounts. Flows from the forested catchment of Lake Waikaremoana for 1925-60, the

longest flow record available, correlate very significantly with annual rainfalls at Onepoto. The regression of annual runoff (in inches) (Y) on rainfall (X) is:

$$Y = 0.72X - 7.5\ (\pm\ 4.4)^{*} \quad (r = 0.89,\ p \quad .001)$$

Runoff values have a standard deviation of 7.1 inches rather larger than the standard error of estimate of 4.4 inches - therefore the long-term rainfall pattern is a fairly reliable indicator of the long-term runoff pattern.

Equally close relations have been obtained for numerous catchments. Of importance is that when such close relations exist between annual rainfall and runoff, the former can be used to demonstrate the probable annual flow pattern for a period as long as the rainfall records. Annual rainfalls at Napier are known to be reliable indicators of annual runoff for catchments of eastern Hawke's Bay, therefore the rainfall record affords us a pattern of annual runoff from these catchments since 1870. Figure 2A shows the unsmoothed year to year variations of runoff while the broken line is an approximate indication of the longer-range variations. It is interesting that these broad coastal changes harmonise with those for flow at Lake Waikaremoana (Fig. 2B) some 50-60 miles north of Napier, with a catchment altitude range of 2,000-4,500 ft. A minor anomaly in the 1930s occurs because the years 1935, 1936 and 1938 had a greater influence nearer the coast, but overall this period yielded relatively low runoffs in both regions. Explanation of such short-term anomalies on a spatial basis, and they are the rule, is best stated by the principle: the longer the period of change the larger is the area affected in the same way; conversely, the shorter the period of change the smaller is the area likewise affected. Hence, we must be cautious in the extent to which we apply records that are restricted in space or time. One useful indication given

* Although this relation is not in keeping with the water balance equation Y = X-E (where E represents evapotranspiration losses) it is objectively determined and therefore valuable for prediction purposes.

by a comparison of Figs. 2A and 2B is that runoff at Lake Waikaremoana was probably greater during the 1890s and the 1900s than it has been during the recorded period - perhaps by about 20 percent.

If we now examine the coastal rainfall and runoff pattern (Fig 2A) we note that annual flows were generally high during the mid 1870s, the 1890s and the 1900s. They reached their lowest levels during the late 1870s to 1880s, and since 1910. With respect to the last two very low runoff years of 1945 and 1964, flow observations and records confirm that the annual runoff and minimum water yield values in 1964 were the lowest since 1945.

In passing we could note that the range of variation between high and low water yield years has been smaller since 1940 than during the preceding recorded period.

We may view and utilise such a pattern in many different ways. One important approach relates to the frequency of an event of known practical significance. Firstly, a limit or threshold value must be determined for the event. By way of example we could adopt the 80% level (Fig 2A) as the threshold below which annual runoff, without storage, is inadequate for local-area power generation (such as the old Havelock North plant). We find the numbers of years when power output was inadequate to be:

	No. of Years
1870-1889	6
1890-1909	-
1910-1929	5
1930-1949	3
1950-1968	2

Clearly, a plant designed for and established during 1890-1909 would face many difficulties in subsequent years, and furthermore, there is no reason why the conditions of 1870-1889 could not recur. If they did, what would we blame? Perhaps the destruction of the forests, land development, nuclear explosions and rocketry could share the blame!

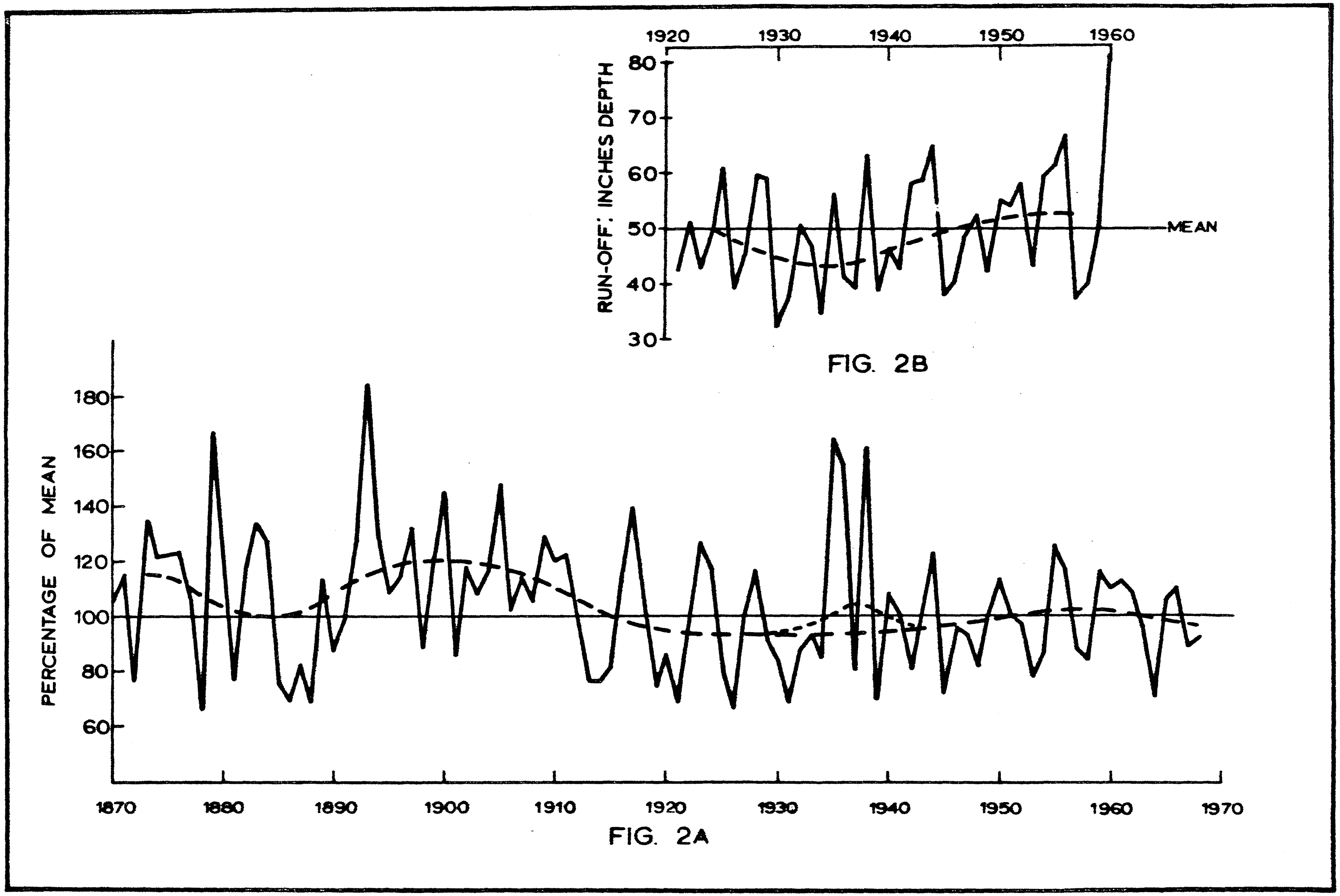

Figure 2A (lower)

Napier annual rainfalls since 1870, as percentage of the mean, representing variations of annual run-off in coastal Hawke's Bay. The broken line indicates the long-term pattern.

Figure 2B (upper)

Lake Waikaremoana catchment annual run-offs; the broken line indicates the long-term pattern.

If from experience we judge that the 120% rainfall level is the threshold above which deep-seated erosion tends to occur on steep coastal mudstones, and that above 140% severe erosion is initiated on easy slopes then we can assess the erosion potential of different periods. This approach can present us with a more accurate history of serious erosion than can be obtained in any other single way, from the limited available records. It may not be feasible to plan for the extremely rare events such as in 1879, 1893, 1935 and 1938, but we should recognise two features. The first is that they occur and therefore can recur. Secondly, their influence may be long lasting because once initiated the physical processes of erosion may be perpetuated, and further deterioration result from smaller events of higher frequency. Consequently it is often difficult to relate effect to the correct causal events. However, the above are illustrative examples only; it is the concepts demonstrated by them that are important.

Regional rainfall indices and patterns were presented by de Lisle (1961) for 1890-1956 for six areas. The three North Island areas are shown by Fig. 1. Napier rainfall indices (Fig 2A) correlate significantly ($r = 0.84$) with the East Coast indices of de Lisle who found that in the three northern areas the long-period annual fluctuations are correlated. Therefore the long-period variations of rainfall, and runoff, of Fig. 2A reasonably illustrate the qualitative long-period variations that have affected the North Island.

Broad references have been made at times to streams drying up since the early part of the century. Walsh (1910) records that smaller streams about Okaihau, Northland, dried up after the forest was destroyed "for want of protection at their sources". On the other hand, the drying up of streams has occurred also after exotic reforestation on a large scale. In terms of the effects of land management these two sets of observations - and there is no reason to doubt them - are contradictory. But there remains the common feature that since some early period of the century small streams have tended to dry up more. It is probably not coincidental that annual rainfalls, and therefore water yields, have been lower on the average

since about 1910 than they were in the preceding 20 years. At intervals of time since about 1900 threshold limits for flow must have been crossed for numerous formerly perennial streams causing their flow regimes to change and at times to become zero. This would appear to be an adequate answer to Archdeacon Walsh. Where reforestation has been undertaken it has merely accentuated the effects of a climatic change. The "red herring" has been that the marked background rainfall change during 1900-1930 coincided with the phase of rapid and more drastic land development.

STORMS AND FLOODS

Strom (1962) noted, "There has arisen some tendency to ascribe all floods to human action; to assume that flooding is due to deforestation, soil erosion, fires, or wrong land use, and to think that all floods can be controlled by reafforestation, soil conservation, correct agricultural practices, and so forth. This idea should be treated with great caution, because it has an element of truth in it." (p.29) He then goes on to say (p.31) that proper land use and soil conservation methods, while all to the good in reducing floods, cannot abolish them. History indicates the correctness of the above.

Because we know that flow is a residue of rainfall, we are aware that floods result from rainstorms. The physical effects of large rainstorms are well known but the magnitude and frequency of storms is not constant from period to period and naturally floods follow the same general pattern. Although there may be cumulative effects from either one major storm or from a series of moderate storms, it would be broadly true that the history of major river regime changes, particularly if the rate of change is considered, closely mirrors the history of storminess and flooding.

On the Tukituki River, studies of major regime changes helped to determine (Grant, 1965) that, prior to European settlement in the 1840s, the tempo of change had accelerated. Since European settlement, and its influences on the catchment, marked fluctuations in the

rate of channel change are discernible. These do not harmonise in direction with the likely effects of replacing forest and scrub by grass but they do agree closely with rainfall regime changes since this factor was measured. The last major river regime change was initiated in the 1930s, had become pronounced by the late 1940s, and in upper catchments in particular, is still continuing. It was postulated (Grant, 1965) that small-area rain storms had increased in intensity since the 1930s. This postulate was later examined (Grant, 1966) using maximum daily rainfalls since 1900 for 16 rainfall stations having a coverage of about 2,500 square miles.

Since 1900 the four decades of greatest regional storminess and erosion potential, in descending order of greatness were:

1. 1931-40
2. 1911-20
3. 1951-60
4. 1961-

In addition, if the 60-year period 1901-60 is divided equally the latter 30-year period, 1931-60 was significantly stormier than the preceding one. If the original postulate was to be qualified at this stage it would be to state that the frequency of effective rainstorms has increased since the 1930s.

Storm and flood damage have been recorded in recent years from many areas of indigenous forest (e.g. Pain, 1968) but the dilemma was stated by Cunningham and Arnott (1964) for the Rimutuka Range: ".... one of the most alarming features of this case is the discovery that such rains can cause serious erosion under forest conditions which we at present regard as reasonably satisfactory". Along the Eastern Ruahine Range there are reliable indications that the number of erosion scars is now greater than prior to _ca_ 1920. Many new debris avalanches occurred during heavy storms in the 1930s, 1950s and 1960s. It was suggested (Grant, 1965) that a great deal of erosion on a portion of the Ruahine Range is primarily due to rainstorms. It could now be positively stated that

rainstorms are a primary cause of erosion in forested areas. They exert an influence that outweighs the influence of animals; slip areas similar to those known to occur during heavy rain have occurred in "virgin" forest long before the advent of exotic feral animals. Backing for this view comes from F. P. Wallis and I. L. James, N.Z. Forest Service (pers comm, July 1969), who related most new debris avalanches in the northern Urewera forests to exceptional storms of the past decade, and who stated that it was not possible to associate such deep seated soil movements with animals. It is of value to note the conclusion reached by Zeleney (Nemec et al, 1967) in Czechoslovakia, "that with extremely heavy rainfall, no forest is able to prevent catastrophic events from developing even in entirely forested watersheds." We may conclude that changes of river regime, intensity and frequency of flooding and the incidence of deep seated erosion both on forested and pastoral land can be related to changes of the storm rainfall regime.

Variations of rainfall in relation to erosion in eastern Hawke's Bay have been outlined in the foregoing, and the broad changes of erosion potential have been presented on a seasonal basis (Grant, 1966). Figure 3 shows a series of annual patterns based on the ranking of the average severity of storminess or flooding in each decade. Storminess was at its highest level, since 1890, during the 1890s. Regular flood records were not kept before 1920 but records of major floods confirm the high level of storminess in the 1890s. Since 1920 there is agreement among the four data sources (Fig. 3) that the 1930s were very stormy and that the current level of storminess is high relative to some earlier periods. We must recall the principle that the longer the period of change the larger is the area affected, and its converse. This explains minor differences among the patterns. Overall the level of storminess has been higher since about 1930 than during the preceding 30 years and this concerns flooding, channel regime changes and erosion. This long term change undoubtedly has affected most, if not all, of the North Island. It can easily explain the history of erosion and channel changes about the Kaimai Range outlined by Griffiths (1969) and accounted for by

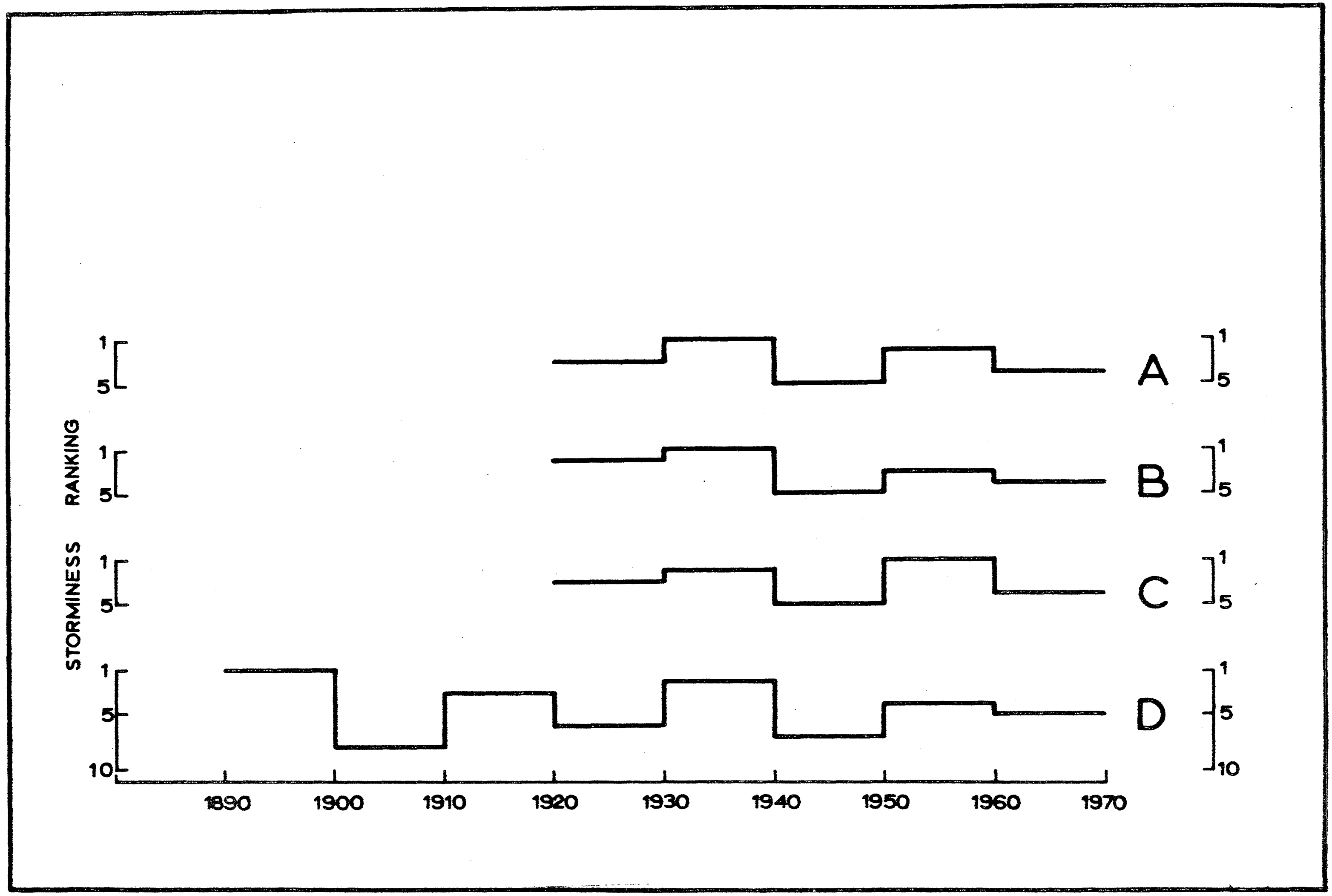

Figure 3

Storminess ratings for Hawke's Bay, by decades, for: (A) Ngaruroro River floods, (B) Tutaekuri River floods, (C) Tukituki River floods, and (D) Storm rainfalls for eastern Hawke's Bay.

land development. In fact the increase in storminess is the only factor that can account for a similar trend throughout the North Island. Certainly the fluctuations in the overall storminess pattern cannot be matched by the general pattern of land development.

The concept of threshold levels is valuable in aiding understanding of cause and effect. For example, in relation to deep-seated erosion there must be a storm threshold level above which movement results. It is probable that this primary, or controlling, threshold depends on the integrated effect of the secondary factors such as slope, aspect, soil depth etc., each with its own threshold. A change of any one secondary threshold means that the primary threshold for rainfall must change. This explains, in principle, why two more or less comparable storms may affect the same land area to different degrees.

There have always been floods (which is a relative term) and always will be, no matter how efficiently man conserves the soil and vegetation. But by conservation he can ameliorate some of the side effects of floods, especially those concerning sediment. Even so, he is more likely to be successful on small catchments.

DROUGHT

Droughts result primarily from a deficiency of effective rainfall. But wind, temperature and humidity during the drought, plus the meteorological and soil moisture characteristics of the antecedent period may either accentuate or alleviate the effects of rainfall deficiency. On the East Coast, where droughts are frequent, daily rainfall frequencies were analysed by season and patterns of mean periodic rainfall effectiveness (R.E.) since 1890 were presented (Grant, 1968). It was indicated that changes similar to those demonstrated have probably affected the North Island and possibly the N.E. portion of the South Island (Fig. 1). Drought patterns are shown by Fig. 4; the lower is the R.E. index the more severe is the drought level.

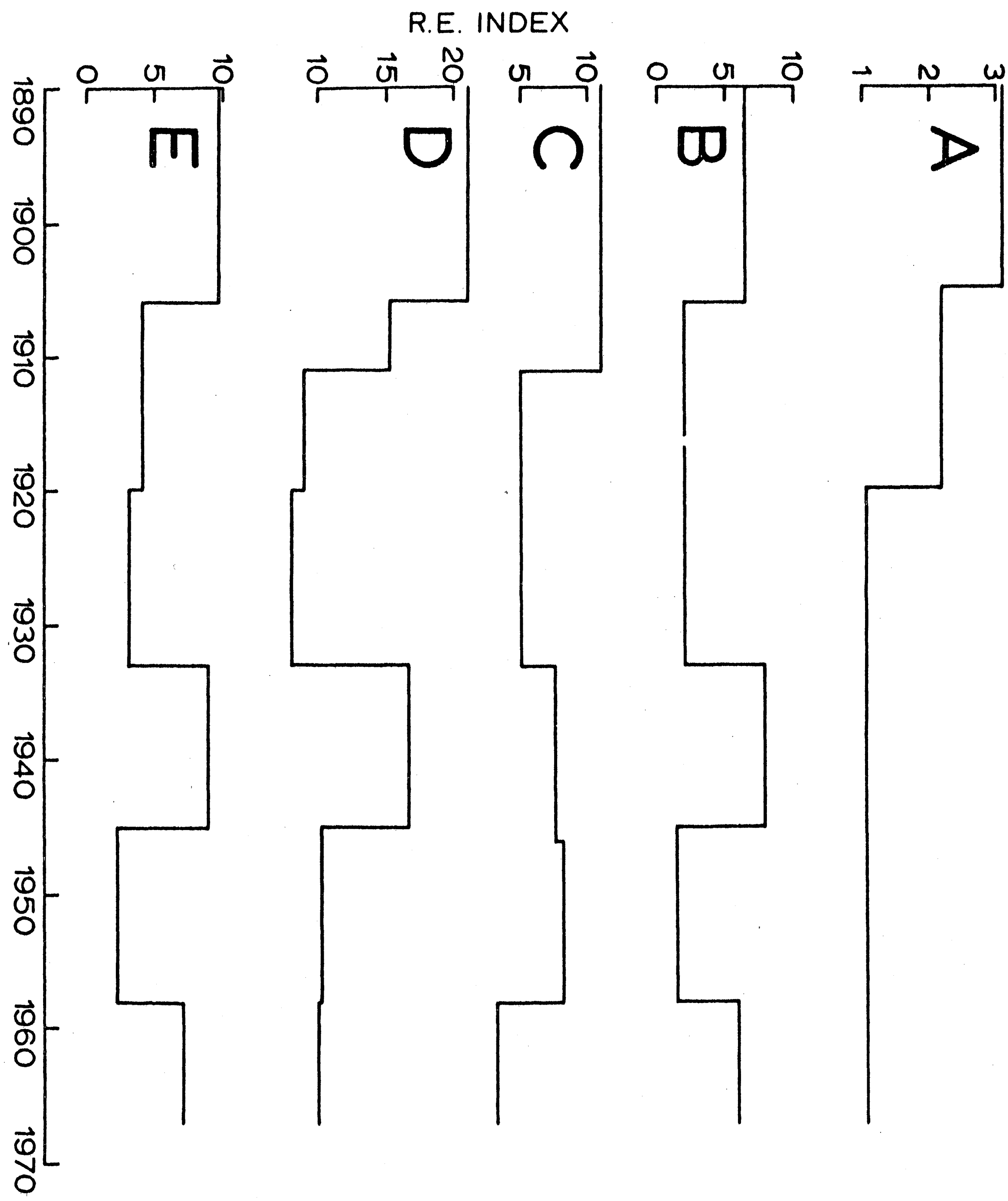

Figure 4 - Drought intensity changes on the East Coast since 1890 for: (A) spring, (B) summer, (C) autumn, (D) summation of spring, summer and autumn, (E) summation of spring and summer. The lower the rainfall effectiveness (R.E.) index, the more intense is the drought level.

Spring - Spring drought became more severe after 1905 and further intensified after 1920 since when it has remained about the same level, viz around 60% below the 1890-1905 regime (Fig. 4, curve A). Compared with pre-1920, especially pre-1905, the present drier phase must affect seed germination and subsequent early growth and is likely to result in reduced final yields. Of course, on flat areas such as Heretaunga Plains and Canterbury Plains such a marked seasonal moisture change can be readily offset by irrigation. It is now common to see irrigation sprinklers operating on Heretaunga Plains in spring. It is almost certain that during 1890-1920, for the same land use, this practice would have been unnecessary.

It is worth referring to Rickard and Fitzgerald (1969) who noted that the 32-day agricultural drought during October-November 1961 in mid-Canterbury was the only occasion since 1929 at least, that a substantial drought occurred in spring. This may be an indication that some long-range change has occurred in Canterbury also.

Summer - Fluctuations in drought intensity have occurred in summer (Fig. 4, curve B). There was a marked increase in drought severity during 1906-33 followed by the least droughty summer period of this century, 1934-45. This terminated abruptly with the widespread major drought of 1945-46 which introduced the most droughty summer period 1946-58. The fact that the wettest run of summers was immediately followed by the most droughty period must have had many practical implications in relation to pasture and stock management. From 1958 to the present, East Coast summers have again been moister. Runs of moist summers are probably beneficial for pasture growth and some crops; however, increased moisture at a time of high temperatures means increased humidity which permits many diseases, of fungal and insect origin, to increase. A series of more humid summers such as the East Coast is now experiencing could produce a cumulative effect in relation to both plant and animal diseases; the end level of disease being related to the frequency of the causal conditions rather than to the circumstances of any one year.

Autumn - After about 1911 the autumn drought level became more severe and following a long period of amelioration (1934-58), the intensity increased to make the last period, 1959-69, the most droughty since 1890. On pastoral hill country this last change has produced increased management and economic difficulties as a result of shortages of stock water and feed, the increased need to buy in supplementary feed and the fact that capital stock sometimes either have to be sold or grazed out of the district. Drier autumns are also likely to have a delayed unfavourable effect on lambing and in many years they also result in land management difficulties in winter because of inadequate pasture growth for cattle.

Effect on Production - Rickard and Fitzgerald (1969) write that even brief periods of drought can decrease agricultural production significantly, and prolonged periods can have a very severe effect. Using pasture production data at Winchmore and the numbers of days of agricultural drought, they determined the relations:

$$\text{(a)} \quad P = 6884 - 43.0\,D \qquad r = -0.82^{**}$$

$$\text{(b)} \quad P = 6139 - 35.9\,D \qquad r = -0.94^{**}$$

Where P = annual production of pounds dry matter per acre, D = number of days of agricultural drought. Equation (a) was based on a 28-day sampling interval and (b) on a 14-day sampling interval. They state that in an average season of 40 drought days pasture production is approximately 25% less than in a season without drought.

Pasture production efficiency on the East Coast must have varied greatly in harmony with the drought changes discussed. The average production efficiency level since the 1930s for hill country has been lower than that of the early decades of the century.

Influence on Streamflow - In harmony with the spring, summer and autumn moisture regimes of the last decade it has been common for streamflow to fall to a low level by late spring, and then to increase during the summer before diminishing greatly during late summer to

late autumn. Minimum annual streamflows now commonly occur in autumn. In a drought period the rate of streamflow from different basins is related largely to basin geology and morphology and to major spatial differences of average rainfall amount. While on a given basin, differences of minimum flow values at the end of different droughts are related to the amount and effectiveness of antecedent rainfall.

It is probable that flow duration patterns in the lower discharge ranges and also minimal flow values have followed the general pattern of curve D (Fig. 4). Certainly the major East Coast droughts of the century, viz, 1913-14, 1914-15, 1930-31, 1945-46, 1947-48 and 1949-50 and the two series of five consecutive drought years, viz, 1927-31 and 1961-65, conform with the pattern of curve D. By the winter of 1964 the accumulated widespread effect of preceding low river runoffs and inflows to storage reservoirs was having an effect on power generation.

Influence on Trees - The 1945-46 dry period constituted a physiological drought on many forest sites in the central and eastern North Island at least. Hocking (1946) commented on this in Hawke's Bay and recorded mortality of rimu, browning off of totara and some permanent damage to black (?) beech. Elder (1956) related large numbers of dead mountain beech to the 1946 drought. Grant (1963) demonstrated that in the same year the Urewera forests were affected and suggested that some damage must have resulted to many major tree species.

In the autumn of 1964 many indigenous tree species, including totara, growing on heavy mudstone soils, were showing browning-off, and die-back. And this was clearly related to moisture deficiency because ground water storage was at its lowest level since 1946. The 1964 drought duration was short compared with that of 1945-46 but there had been a consecutive run of annual droughts since 1961 and the effect was cumulative. Actually, during the current decade, there has been only one season, 1966-67, when drought did not occur.

While small daily rains will sustain grass and benefit some crops, frequent large rains are necessary to replenish deep soil moisture and ground water for the benefit of trees and streamflow. In spring, large daily rains are now rare; in summer they are rather more frequent that in the previous period, but they are more than offset by the driest autumns of this century. In other words, the current decade must rank with the 1920s and 1940s as one of the most droughty of this century. And perhaps because of the effects of the 1920s and 1940s plus those of the individual extreme droughts that have gone before, we are witnessing in the 1960s an accumulated adverse effect on some indigenous species such as totara and tawa (Beveridge, 1968).

It was suggested (Grant, 1968) that tree growth is likely to be related either to spring and summer combined (curve E, Fig. 4) or to the pattern of spring, summer and autumn combined, (curve D). The relationship may vary but probably curve D will more closely mirror the long-term pattern of tree growth. However, it does not reflect the accumulation effect discussed above.

Partial Droughts - A partial drought is a period of at least 29 consecutive days during which the mean daily rainfall does not exceed 0.01 in. It is a conservative measure of agricultural drought but is an objective means of assessing long-term changes of the drought factor.

Considering, for the East Coast, the two 40-year periods, 1890-1929 and 1930-69: the latter period had more days of partial drought and 26% more drought years, it also had a larger number of occurrences of three or more years of consecutive drought. It can be concluded that the period 1930-69 was more droughty than the preceding 40 years.

Comparing the same periods, partial drought frequency during 1930-69 increased slightly in spring, remained about the same level in summer and increased markedly in autumn by about 65%. These patterns are essentially the same as those given by the drought patterns of Fig. 4, excepting that the latter specify the natural periods of change.

The average drought severity rating is now higher than it was during the early decades of this century and undoubtedly this change has adversely influenced streamflow, pasture and crop production, tree growth and health, the dairying industry and some facets of sheep and cattle farming.

TEMPERATURE INFLUENCES

At first sight this section would appear to be out of place in a discussion of rainfall changes; but even though it is merely a brief reference its practical importance will become apparent.

In the North Island temperatures started to rise soon after the turn of this century; warming developed further during the 1930s and increased markedly in the 1940s and 1950s to reach a peak in the early 1960s. All seasons were affected in the same direction; perhaps spring warming was the most pronounced showing an increase of the order of 1.5^{o}F at some localities.

In relation to the water balance, the greatest effect of these changes appears to have been in the lengthening of the growing season and consequent increase in total evapotranspiration losses, especially by trees. It is estimated that by the 1950s the onset of spring growth was 2 to 3 weeks earlier than it was prior to 1920. With some extension of growth at the end of the season, it is likely that the growing season had been extended by at least four weeks on average, or about 20%. In lowland forested areas this feature hastened the depletion of available ground water in the root zone and thus further accentuated an existing high drought level which resulted from rainfall changes. It is obvious that drought levels of recent decades based on rainfall alone, seriously underestimate the real drought intensities in relation to tree growth, streamflow and land management. A similar effect operated also in pastoral areas but quantitatively the negative influence on stream flow is likely to have been less marked than that under forest.

During the early part of the century, warming in the

southern portion of the South Island was less pronounced than in the north, but by the 1930s warming in the south was increasing and the 1940s marked a phase of rapid warming. Since the early 1960s there has been a general cooling. The net changes in temperature (^{o}F) from 1900-19 to 1940-59 taken from Mitchell (1963) were:

	Annual	Winter
Northern New Zealand	+ 1.4	+ 0.3
Southern New Zealand	+ 0.9	+ 0.6

At higher altitudes, at least since the 1930s, warming must have altered snow and ice budgets. It is probable that permanent snow lines have ascended and that below these the warming has resulted in reduced durations of snow cover; tendencies for snow cover to develop later and to thaw earlier and for overall snow regimes to be more variable both in space and time. The implications of the temperature change are many and the wasting of glaciers bears testimony to its significance (see Skinner, 1964).

Flow regimes from snow and ice storages must have changed. Since the 1930s perennial storages have probably yielded greater annual runoffs, while small areas where storages were more variable possibly now yield reduced runoffs.

Below permanent snow lines the present warmer regime must permit animals to graze on native vegetation for longer thaw periods than previously - perhaps to the detriment of the plant cover. Furthermore, herbivorous insects would be permitted to exert a greater depletive influence, and to higher altitudes than formerly, in a warmer climate.

Quite apart from an increase in the weight of biotic influences are the increased physiological problems that montane plants must cope with, or perish, in a warmer but more variable climate. Protection forestry throughout New Zealand and management of much South Island tussock grassland has been made more difficult by the recent temperature changes.

FURTHER DISCUSSION

Change, not constancy, is the norm. Rainfall regime changes large enough to have practical significance have taken place this century. Sweeping generalisations are not possible. Changes of different rainfall parameters, and in different seasons, have often commenced at different times and trended in opposite directions.

In relation to a problem, it is essential **firstly**, to determine the specific parameter(s) likely to be concerned in long-term change. It is then necessary to assess the critical level or threshold of each parameter beyond which it is likely to exert a marked practical influence. At times, as in relation to land instability, the primary or controlling threshold (of rainfall) may depend on the integrated effect of numerous secondary parameters, each with its own threshold level in relation to its sphere of influence.

When the threshold of the parameter is assessed, it is then possible to determine changes of frequency, consecutive runs, times of extremes etc. Sound interpretation, particularly of single, or of short-period records, must be based on the principle that the longer the period of change the larger is the area affected in the same way; the shorter the period of change the smaller is the area likewise affected. Major short-term variations and the likelihood that opposite changes occur on a spatial basis may warrant consideration. This was discussed for a remote mountain region by Grant (1969).

It must be remembered that the effects of one extreme event can be sustained for a long time by a series of smaller, even sub-critical, events, e.g. storm effects. And in some problems, e.g., fungal disease, the cumulative effect of a high frequency of moderate contributing events (moist summers), will probably exceed the effect of one extremely wet summer.

Long-range changes of rainfall regimes, and of temperature, can satisfactorily explain many practical difficulties that have arisen this century, especially since the 1930s, but for many the blame has been placed

on land development. This is absurd, because the detailed histories of land development seldom, if ever, closely match the history of problem development. Furthermore, the latter has a comparable history over a large area, if not all the North Island; but local histories of land development differ greatly in time. In forested wilderness areas land development as such has not existed, but the same problems have developed; and exotic feral animals are not the causal agents. However, because the level of natural erosion is now high it is probably fitting, at least in certain regions, that some measure of animal control be exercised to facilitate the revegetation of damaged areas.

Likewise, although normal land development has not been the primary cause of episodes of massive erosion and of major channel regime changes, there is no doubt that many cultural activities accentuate the problems which result from natural changes. Therefore , in a climatically more difficult period, such as the present, it is desirable that land development and management be based on the best conservation practices for a region.

Since the 1930s the drought factor has become more severe and the level of storminess has risen. In other words, compared with 1900-30, the period since 1930 has, on average, been more variable. Variability itself is often a potent factor in terms of land management problems. On the East Coast where droughts are often terminated by large storms, with serious damaging effects, the current climatic regime means that the chances of this combination occurring have increased since 1930. Moreover, this increase in the range between drought and storm probably also means that with regard to land instability the increase in the intensity of drought has resulted in storms being effective beyond a lower threshold than formerly.

The application of standard frequency analyses to time series of data, such as heavy rainfalls or floods, assumes that no non-random long-term changes exist in the data. But if long-term changes do exist in the data, and they certainly do in most North Island climatic parameters, the frequency values obtained will differ for different periods

as found for floods by Raudkivi (1963). It is usually considered that the longer the time series the more reliable is the estimate of frequency values but this is not necessarily the case. Reliability is dependent on the duration, magnitude and direction of any long-range change(s) that the data reflect, in relation to the critical design requirements. Long data records may seriously underestimate the current frequencies of certain events (e.g. storms, floods, droughts). Actually, a long time-series of data is more valuable than a short one, as long as it is first tested for homogeneity, and then for long-range non-random variations. Any pattern of change should then be interpreted in the light of the foregoing discussions.

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FOREST INFLUENCES

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INTRODUCTION

In the opening sentences of the preface to his book "Forest Influences", Joseph Kitteridge (1948), more than twenty years ago, made a statement which is still valid today:

> "Forests and rainfall, forests and streamflow, and forests and floods have been subjects of intermittent controversy between foresters and others for many years. Yet many foresters today have only a hazy conception of what is meant by forest influences, watershed management and protection forests."

This still holds in 1969 and it is not necessary to confine these remarks to foresters. Indeed, Kitteridge could well have used the term biologists for foresters, and engineers for others, for it is between these two groups that argument occurs, and even if the lunatic fringes of each have retreated from their extreme positions of two to three decades ago, there are still large enough areas of disagreement to make for difficulty in watershed planning. Without going too deeply into the reasons for this, it would appear that a fundamental cause has been the lack of training in hydrology as such, with the result that much experimental work in the forest influences field has been poorly planned, and as a consequence has yielded results of doubtful validity. This tendency to regard hydrological training as merely a useful adjunct to a biological or engineering qualification must be overcome before watershed managers can hope to make progress in the field.

To return to the title however, a definition of forest influences could be made to last the time available for this address. In the widest sense forest influences could be defined as including all the effects of forest on climate, soil moisture, runoff, streamflow, floods and erosion. The field could be divided into a large number of compartments each of which, although important in itself, is but part of an integrated whole. For instance, with regard to the effect of forest on precipitation alone, there are a bewildering number of facets to be examined from the effect on vapour pressure of the atmosphere, through interception to evaporation from the soil surface. None would dispute that each of these was of importance in determining a catchment water balance, but it is with the overall effect that we are most concerned. In other words, what matters is how much water is left for streamflow after these various processes have had their effect. To see how forests influence this,we could do worse than to return to Kitteridge's preface and consider the field under the three headings of, forests and rainfall, forests and streamflow, and forests and floods.

FORESTS AND PRECIPITATION

This section should be considered under two headings: the effect of forest on gross precipitation,and the effect on the distribution of such precipitation.

At the turn of the century there was a lively controversy as to whether or not forest had any effect on gross precipitation. A European school championed in the United States by Raphael Zon contended that forests increased both the frequency and abundance of local precipitation over the areas they occupied and that this increase could be as much as 25%. In his work, "Forests and Water in the Light of Scientific Investigation",Zon (1927) produces much evidence to support the argument. However, later analyses of many of the results shows that the discrepancies could be accounted for by normal variation in gauge catches. This is further emphasised when it is considered that many of the early experiments were carried out in mountainous terrain - country in which it is extremely difficult to accurately gauge rainfall without

the added complication of a forest cover. There is some evidence that where a high proportion of the annual precipitation occurs as fog or drizzle as is the case in many coastal regions of the world, then the presence of forest does add to the amount of precipitation reaching the ground. This occurs as condensation or drip and is of course quite a different effect from that attributed to forests by proponents of the increased rainfall theory. In this case it was supposed that the forest was the source of atmospheric humidity which was then condensed and fell again as rain. In other words the forest was supposed to actually make rain. Although there are still those who believe that the world's deserts can be made fruitful again by large scale tree plantings, there is little support for the theory that forests make rain.

If there is any doubt concerning the effect of forest on gross precipitation, there can be no doubt as to its importance in the redistribution of precipitation. Interception by vegetation has been the object of many studies in various parts of the world and it is generally agreed that interception losses can have serious consequences. Delfs (1967) quotes some interesting figures for areas of high population density in West Germany. In the highly industrialised Ruhr area where population density exceeds 1500 per sq. km, water use rose by 70% between 1960-65. Obviously the difference in interception loss between areas under spruce forest (26%) and beech forest (8%) is an important one.

Kitteridge lists values for interception and stemflow in a number of North American species and more recently, studies in the United States have been reviewed by Zinke (1967). These results indicate that substantial amounts of precipitation are involved in the interception process with the greatest effect occurring, naturally enough, with rainfall of low intensity. Whether or not the intercepted precipitation should be regarded as a loss to basin water yield is open to question. While it seems that most intercepted water is re-evaporated from the plant surface, there is evidence to show that some of it can be taken up by the plant. Zinke in fact suggests that sizeable amounts of intercepted water are taken up by the plant and thus modify

transpiration conditions. Even if intercepted water is not absorbed by the plant the fact that water is being evaporated from the leaf surface must mean a lowering of transpiration rate because of the build up of atmospheric humidity around stomatal openings. This can only result in reduced soil water depletion so that the interception process can hardly be regarded as a total loss. Very little research has been carried out on this damping down effect and it is usually considered that it is unimportant.

FORESTS AND STREAMFLOW

Pliny, who died in A.D.79, was one of the first recorded observers in the field of forest influence. In noting that grass grew under sycomore trees but not under pines he was drawing attention to the fact that the type of forest cover had some effect on soil conditions underneath. In the particular instance noted, it was thought that light was the limiting factor for grass growth but it could equally well have been soil moisture deficiency.

A close relationship between forests and water has been recognised for centuries and most people are familiar with the early French and Swiss ordinances of the 13th and 14th centuries. The literature is rich in examples of the effects of deforestation on erosion, floods and streamflow but unfortunately much of this evidence is purely circumstantial. In what Kitteridge calls the "period of propaganda" in North America, from 1877 to 1912, a flood of emotional writing stressed the evil effects of deforestation. Conservation was the catchword of the times and the preservation of large forest tracts to regulate water flow caught the public imagination. Many of the claims made in support of beneficial forest influences were exaggerated but difficult to disprove. Eventually, as in all cases of excess, reaction set in and counter-claims became as bad as the originals. The period of controversy had begun. Fortunately, this argument stimulated researchers and lead to the initiation of experiments to gain a better idea of physical processes involved. While many of the early experiments were not particularly well planned and yielded results which must be considered inconclusive, they did serve as a foundation on which later, more successful work could be built.

Consideration of the role of the forest and its effect on streamflow leads to a study of the processes of evaporation and transpiration. The distinction is somewhat false, for transpiration is essentially an evaporation process dependent to a large extent on prevailing atmospheric conditions and a process over which the plant has little control. As Kramer (1949) has pointed out, "the stomatal structure of leaves is designed to permit uptake of CO_2, and as a stoma is neither a valve nor a semi-permeable membrane, it cannot prevent outward movement of water vapour while it is open". The transpiration rate then is dependent mainly on the availability of soil moisture, and on atmospheric conditions prevailing at the least surface, although resistances to conductivity along the path from soil to atmosphere play a part as well. It will be seen then that a source of energy is necessary for these evaporation processes to take place, as each gram of water evaporated requires the supply of 590 calories as heat of vaporisation. This use of the energy balance concept has led to the development of purely physical formulae for the estimation of 'evapotranspiration'. In other words, it is argued by many that because the amount of incoming evergy is independent of the vegetation type, then water use on an areal basis will be the same regardless of vegetation. In other words trees and grass use the same amount of water. This of course is not the case, as any number of field experiments have shown. Neither is the interpretation of the energy concept generally placed upon it, that intended by those most intimately connected with its development. Many who find it convenient to advocate the "equal water use independent of vegetation" idea have lost sight of a condition of fundamental importance. This is that water supply should be non-limiting - a condition not easily satisfied in many climates. If vegetation is adequately supplied with water, <u>and</u> the vegetation covers the total soil surface, <u>and</u> the roots permeate the total soil mass, <u>then</u>, because of energy considerations it is likely that water use will be independent of vegetation type. As any biologist will realise, however, these are conditions which are seldom met with in nature and the differences in rooting depth between a forest stand and a grass cover are considerable. A further complication is introduced when the availability of soil moisture is considered. It was

long advocated and generally accepted that soil moisture was equally available to the plant throughout the range from field capacity to permanent wilting point - a range from 0.5 atmospheres to 15 atmospheres suction tension. Proponents of this theory produced evidence (mostly from field trials) purporting to show that plant processes were not affected by water shortage within this range and that serious reductions in both photosynthesis and transpiration occur at low suction tensions. Obviously this puts a different complexion on the "non-limiting water supply" and shows that there are limitations to the universal application of a purely physical formula to estimate water loss from areas under different vegetation.

Hibbert (1967) has recently reviewed results from 39 studies of the effect of altering forest cover on water yield. This represents the most up to date assessment generally available and covers experiments in Japan and Africa as well as in North America. Hibbert concludes that the following generalisations can be made:

1. Reduction of forest cover increases water yield.

2. Establishment of forest cover on sparsely vegetated land decreases water yield.

3. Response to treatment is highly variable and for the most part, unpredictable.

In a comprehensive table Hibbert lists the response of individual catchments to alteration of the cover, and it is obvious from a study of the table that the magnitude of response varies considerably. For example, "complete cutting and burning of scrub aspen forest high in the Colorado Rockies caused streamflow to increase only 34 mm during the first year after cutting, whereas in the mountains of East Africa, complete cutting and removal of high bamboo forest increased water yield by 457 mm.

Without doubt the most interesting result quoted by Hibbert is that for Watershed 13 at Coweeta, for this is the first recorded instance of a cutting experiment being repeated after forest regrowth. Here, the original cutting

of hardwood forest on the 40 acre catchment increased water yield by 370 mm in the year following cutting. This increase declined progressively as regrowth occurred, but when the cutting was repeated 23 years later, the increase in streamflow was almost identical with that resulting from the first cutting. South African experience quoted by Wicht (1949) indicates that afforestation of scrub-covered catchments with Radiata pine resulted in decreased streamflow <u>after four years</u> although Ryecroft (1952) could detect no significant effect on stream discharge 12 years after afforestation of a scrub-covered area with the same species. By and large the results quoted by Hibbert support Wicht. Closer to home there is the well known but unmeasured case of Stony Creek in the Ashley district where streamflow has been reduced by the establishment of Radiata pine in its headwaters.

There appears to be little doubt that under conditions experienced in most temperate regions of the world, removal of forest results in an increase in streamflow and a practical upper limit of 4.5 mm per year for each percent reduction in forest cover has been suggested by Hibbert. He also points out that in most of the experiments studied by him the figure was less than half this amount. Maximum gains will be experienced where the full evaporation potential is reached throughout the year. Where moisture supply is a limiting factor then increases following forest removal will be less obvious.

FORESTS AND FLOODS

This is without doubt the area in which the most extreme arguments have been held. The history of the flood control controversy is long and often boring, and has been adequately described by Leopold and Maddock (1954). Suffice it to say that often the two sides were arguing about different issues and that most extreme and emotional statements were made.

Moderate elements have never contended that land management practices would have very significant effects on major floods in the main river valleys. The position is not the same in small catchments where there is a considerable

body of evidence to show that forest vegetation can have a very significant effect on runoff <u>from small storms</u>. At this stage too it might be appropriate to ask what is a small catchment. It has been defined by Chow (1964) as,

> "one that is so small that its sensitivities to high intensity rainfall of short durations and to land-use are not suppressed by the channel storage characteristics. It may be up to 50 square miles in area."

How does the forest cover influence such runoff? An understanding of this will indicate also the limitations of a forest cover in retarding runoff in other than small storms. Forest vegetation, partly by the action of the extensive root systems involved, greatly increases pore space in the soil. The infiltration capacity of a soil under forest is usually greater than that of the same soil bare; Kitteridge lists a number of infiltration values for the same soils under different vegetation. Added to the increased pore space in forest soils is the effect of litter on the forest floor which is capable of absorbing considerable quantities of water. Various figures have been given for this retention capacity - they range from one to five times the dry weight of litter with a maximum retention of 1" of water. The combined effect is the creation of a storage capacity in forest soils which, in forest in a relatively undisturbed state at least, is usually significantly higher than in the same soil bare or under grass. It is only when this storage capacity is exceeded during prolonged rainfall, or when the infiltration capacity is temporarily exceeded during short period high intensity rain, that overland flow and flooding are likely to occur.

Forest further affects runoff by its action in preventing soil freezing and in retarding snowmelt. This latter is of some importance in regions where snow makes up a substantial proportion of the annual precipitation. Perhaps it would be appropriate to end this discussion on flood control effects by quoting an example from Kitteridge (1948). He lists (pp 269-270) the likely effects consequent on the presence of a forest cover in a storm of 10" The decreases in depth of water available for flood flow are listed as:

Interception (10%)	=	1 inch
Depression Storage	=	0.1 inch
Litter on forest floor	=	0.6 inch
Organic matter in mineral soil	=	1.5 inches
Total	=	3.2 inches

Some work has been done in North America on the relationship of decreased runoff to flood heights. It has been shown for the Ivy river in North Carolina for example that a reduction in runoff of 0.67 inches would reduce peak gauge height by 2.24 feet in a storm of 4.92 inches in one day. While this is not flood prevention is is a useful reduction in flood peak.

To summarise the flood situation, the influence of forest in reducing flood peaks is greatest in small catchments. Where total storage capacity of a basin is exceeded during major storms, forest, by increasing storage capacity and retarding runoff has only a limited influence.

There are many aspects of forest influences which have not been touched upon in this paper. The obvious one is the influence of forest on erosion, but this can be accepted as self evident. The aim of this paper has been to attempt to present an assessment of those facets of forest influences which have been least understood (or should it be said most generally misunderstood) and of most direct interest in a symposium on watershed management.

DISCUSSION

Statement: Dr D. Scott (D.S.I.R.)

As well as differences between forest and non-forest vegetation, there are also quite spectacular differences between different types of herbaceous vegetation, even when water is freely available. Mitchell and Kerr (1966) at Palmerston North have shown that under conditions of freely available soil moisture, evapotranspiration rates from tall ryegrass may be up to or even more than double

that from tall white clover.

Reference: Mitchell, K.J.; Kerr, J.P. 1966: Agron. J. 58: 5-8.

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IS PASTORAL FARMING COMPATIBLE WITH WATERSHED MANAGEMENT?

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INTRODUCTION

Watershed management is defined for this symposium as, "the management of land for the optimum production of high-quality water, for the regulation of water yield, and for maximum soil stability, along with other products and uses of the land."

The important words to the hydrologists and soil conservator are, "high quality water", "regulated water yield" and "soil stability".

The important words to the grazier are "other products and uses of the land".

The community prefers the full definition with no one part excluded - no single-purpose use by hydraulic engineers or by farmers, unless either has a sound case for special rights. In other words it prefers multiple use of its land resources.

In this paper I discuss one factor in multiple use. It is a factor over which man has quick and critical control; a factor whose presence in our tussock grasslands, and the land-use practices associated with whose presence, has caused argument in this country for a century - it is the grazing animal.

MULTIPLE USE

What is Multiple Use?

The land in a catchment is mostly classified by its principal use. It may be primarily industrial or commercial land, residential land, arable farmland, grazing, forest or barren land. Of course although it may be best

suited to one of these uses, such as grazing, it might instead be given some other special use, such as recreation (e.g. a National Park); Or commercial forest land may be pre-empted as a service area for water-supply protection.

Again, although land is labelled with a type name because of some principal use, it can simultaneously have other uses. In fact rarely is only one use made of it. For instance, high-country grazing land is often also used for recreation and as a source of water for electric-power generation.

And even within the principle use there may be smaller associated uses such as local areas of a grazing run sown to crop for winter forage.

A true multiple-use system aims to perpetuate the maximum safe production of all the naturally-renewed resources of a watershed - be they water, timber, forage for grazing animals, or herbaceous crops. Also, less substantial products such as the aesthetic pleasures of scenery, and public recreation, have their own value.

What Determines How Land is Used?

At any given time and for any given level of technology, land will be used for the purpose which produces the highest net returns in terms of money or of individual or community satisfaction. "Highest net returns" reflect any comparative advantage which this unit of land might have over another unit of land for a certain purpose, because of its climate, location, soils or topography. They also reflect how much demand there is for its best potential use. For example, some land in the upper Waimakariri catchment could grow cash crops or even support an industrial community, but until markets or population pressures create a demand for this use it is grazed.

And why grazed? Because the community believes that at present it gets most benefit or satisfaction from leasing this land to a farmer. This farmer has in turn reasoned that his highest net returns will be made by grazing domestic animals on it.

Even within the whole area of land leased (or sold) to this farmer there will be many small units of land divided by differences of topography, soil fertility, location etc. The farmer will then use each of these units in the particular way it will best contribute to his making the highest practicable net return from his property as a whole.

But even though it has leased its land for a principal use - grazing - the community retains its interest. It retains it as an owner who does not want to see his asset waste away for someone elses personal gain. It retains it because the land gives other products besides the meat and wool of the grazier. There is positive value in the quality and quantity of the water it yields. And there is negative value in the erosion by-products of misuse. Unfortunately it always seems that the farmer's prime, even exclusive interest, is in maximum net return from farming, while the community's sole concern is with other values.

There are no arguments when both the individual occupier and the community are happy with the single objective of highest net <u>monetary</u> return. But when "best use" involves <u>non-monetary</u> factors, such as setting aside land for national parks or reducing stock numbers for long-term conservation benefits, disputes can arise - disputes often seen as graziers' profits versus a community concern for soil conservation, even if that concern has only slowly been aroused.

<u>The Farmer's Quandary</u>

The question the community poses to the rational farmer is at what intensity can he use the soil and biological resources at his command? How best can he make full use of their productive capacity to earn a maximum net return, while yet not drawing down this fund in which he too has a share? Barlowe (1958) answers it thus:

> "The wise use of biological, soil and man-made resources calls for practices that yield the highest possible net return throughout each operator's planning period, while at the same time maintaining or possibly even improving their expected productive capacity."

The late Professor Garrett of Lincoln College said it in another way: "Good farm management is maximising net profit while maintaining or improving the asset".

Now, here in a nutshell you have the principles for good land use. But how much a grazier will chase maximum profits at the expense of maintaining or improving the asset will vary from man to man according:

i. The level of income he wants

ii. How concerned he is for his own and his family's future welfare

iii. How concerned he is for the welfare of his land and animals

iv. What alternative management opportunities he has.

The Community's Quandary

It seems to be now accepted that catchment management should aim at reducing the amount of sediment entering rivers, rather than at regulating flood flows, If water yield can at the same time be kept high and even, then this is desirable too. Therefore, our concern is whether, or at what intensity, pastoral use causes a drawing-down or erosive use of the protective plant and soil resource fund, and by doing so increases the opportunity for soil to enter stream channels, lower water quality and aggravate problems of flood control. We must also consider whether animal residues or chemicals associated with animal management could cause a fall in water quality sufficient to warrant retirement of a catchment from grazing.

PASTORAL FARMING AND SOIL STABILITY

Plant cover and soil stability are the most responsive facets of watershed management to pastoral farming practices. Each is within the powers of the grazier to vary in degree in so far as his domesticated stock are responsible for them. Where the stock are non-domesticated "game"

animals the responsibility for control lies with the Crown.

I will now deal with the specific pastoral farming practices which may influence plant cover and soil stability for better or for worse.

1. Burning - The burning of forests and scrub for access or agriculture was a practice well-established before Europeans came to New Zealand. By that time much forest, particularly in the South Island, had been destroyed in its original form and had either reverted to a changed association of tree species or become scrubland of grassland (Holloway, 1964; Molloy, 1967). The first Europeans seeking grazing for their sheep and cattle found these scrublands or grasslands unattractive or inaccessible to the stock they wished to introduce. They burnt them. Where forest remained and the climate, topography and distance from markets made farming worthwhile, it too was burnt. Since then, except where farming proved futile and land was abandoned, graziers have kept scrub at bay by putting a match to it. Also, burning was a regular management practice to remove roughage - mainly the unpalatable tussock - and encourage edible regrowth.

Generally, burning of grazing land decreased as the decades passed, although some individuals did their best to reverse the trend, either from necessity or a genuine love of the sport. However, it was really only in the late 1940s with the advent of the catchment authorities that the practice decreased sharply on areas considered vulnerable to erosion.

Burning of tussock grassland has long been accused of leading to accelerated soil erosion. Hot fires in dry conditions can cause the outright death of tussocks, although in wetter areas they will recover, but there is evidence to show that the greatest risk to their survival is by burning and repeated grazing. (O'Connor, 1963; O'Connor and Lambrechtsen, 1964: O'Connor and Powell, 1963; Mark, 1965, 1966).

On yellow-grey earths and those transitional to yellow-brown earths, other adventive plants will frequently replace the dead tussocks. But during this period of

replacement the soil surface is open to the erosive effects of frost, wind and high-intensity rain. The same risks prevail while a tussock canopy is recovering, or for much longer if the tussocks on yellow-brown earths or alpine soils have been killed without replacement by other plants.

Suffice to say that if vegetation can recover after burning, the risk of soil loss is temporary. But if it cannot, or it is killed by later grazing, soil loss may well continue until the fund of soil resources in the area has gone. The grazier may have gained a temporary increase in income at little cost but both he and the community have lost in the long run. Burning of rough forage and scrub can have some vegetational advantage, such as killing scrub or permitting new grass growth to develop earlier without old straw of low nutritive value causing suppression by shading (Harlan, 1956). But generally the risks exceed the benefits. Unfortunately tall, dense tussock vegetation, while providing excellent ground cover, is not attractive to livestock and a condition of partial depletion of tall tussock grassland can often best suit the grazier.

Therefore, in my opinion, there are sites where carefully controlled burning can cause little harm to soil stability, while at the same time increasing the productive usefulness of an area. However, if the risk of soil loss is significant, even if burning is essential for continued pastoral use, then better no stock than less soil.

2. Trampling - Trampling by stock may reduce the amount of plant litter, damage plants, cause compaction of the soil or physical displacement.

(a) Litter - some graziers argue that litter, particularly snow tussock litter, has a smothering affect on other plants or their seedlings and therefore should be burnt. The observation, if not the drastic remedy, has some scientific support, particularly in wetter regions (Dyksterhuis and Schmutz, 1967). Some would even burn to reduce the alleged fire risk which litter causes.

However, litter has some important virtues, particularly in drier grasslands. Although it will intercept small amounts of precipitation, it has a much more significant role as a dissipator of raindrop energy and insulator of soil from frost lift or sun heat. Admittedly vegetation does this too where it provides a complete ground cover but there are many areas of depleted vegetation where it does not. Litter, or at least dry litter, is destroyed by burning but can also be removed or disturbed by grazing animals causing desiccation and wind removal and leaving usually an unprotected soil surface. Only on wetter sites is litter beneficially trampled into the soil to increase organic matter.

(b) <u>Plant Damage</u> - both seedling trees and herbs can be damaged by trampling stock, particularly where they concentrate. Adult plants may be so damaged as to die - for instance, tussocks when uprooted by cattle. There must be a high level of grazing pressure before there is significant damage. On unimproved native pasture, the food supply has usually gone long before widespread trampling damage is possible. Thus the risk here is low. On improved pasture, although the risk of plant damage by trampling is higher, the denser and more actively growing vegetation is better able to bind the soil and replace plant losses.

(c) <u>Compaction</u> - several studies of soil with a moisture content close to field capacity have shown increased bulk density and decreased infiltration due to animal treading. In some experiments this has led to reduced pasture growth (Edmond, 1964; Scott, 1963). However, on drier soils and particularly on those with low bulk densities, high macroporosity values, and free-draining characteristics, the effects of animal treading are minimal (Gillingham, 1964). The ability of clays in many weakly-weathered high-country soils to resume their former position when compressed is also a factor which makes them able

to resist compaction (D. Ives, per com). On the evidence, it seems that the treading of grazing animals can affect the compaction and hence opportunity for soil loss by runoff from more strongly weathered or damp soils, but is of less importance on drier soils.

(d) Physical Displacement - Although most soil displacement by stock is insidious, everyone is familiar with the terracettes formed in steep grazed pastures on damper soils. This phenomen, although not serious erosion in itself, can lead to it if concentration of water in foot-track channels causes scouring. More noticeable is the skid or cut damage caused by animals, particularly by cattle. Their point load is about 50 lbs per square inch compared to about 9 lbs per square inch for sheep (Lull, 1959; O'Connor, 1956). Again this erosion is more significant on damp soil, particularly steep damp soil. Cattle can slip off contour tracks and break away the ground below, or plough out strips of turf with their hoofs when skidding down a wet spur. In fact one runholder concerned by the damage done by cattle to high snow tussock blocks has now made the interesting decision to graze only sheep on steep damp country.

3. Grazing Vegetation - To the grazier, vegetation is of interest only as food for his stock. How good that food is, how many stock he can feed on it, depends on: (a) the proportions of various plant species, (b) its state of maturity and (c) the environment in which it grows, that is the effect on it of the surrounding climate and soil.

His aim is to provide enough edible herbage at the right time to satisfy the varying seasonal requirements for growth, health and high producitivity of as many stock as possible.

(a) Unimproved Pastures - grazing artificially improved vegetation generally carries less risk of causing enough plant damage to disturb

soil stability than grazing unimproved native vegetation. How many animals a grazier turns out onto an area depends on his estimate of the nutritive value of the vegetation and of its palatability. Some animals prefer one kind of vegetation, some another. There are many factors affecting the individual attractiveness of plants to stock, such as succulence, taste and height.

Obviously in a mixed sward some plants will be grazed heavier than others. With heavy grazing and depending on the season, the class of stock and the intensity of use, some plants may even be grazed to exhaustion (Petrie, 1912) or to death from competition by less palatable competitors. Occasionally this can be turned to agricultural advantage when short-term, high-intensity grazing and trampling is used deliberately to check undesirable plants such as bracken fern. With prolonged higher grazing intensities, an increase in less palatable plants can be expected, although at lower levels even preferred plants can often survive or multiply. However, in general, heavy grazing of native swards decreases the nutritive value of the forage (Cook, Harris and Stoddart, 1948) and at the same time leads to depletion, opening up, and the risk of consequent soil loss.

Moderately-grazed country often appears to have more healthy and vigorous vegetation than ungrazed. Not only could it be partly due to a reduction in the smothering effect of litter, as already mentioned (Weaver and Rowland, 1952), but some plants actually respond with increased growth to cutting or grazing (Canfield, 1939). Soil moisture status appears to be important. Plants in sub-humid and humid climates seem to respond better to grazing than those in semi-arid climates. Depletion of plants on dry lands may actually reduce their capacity to grow rather than enhance it, although stock can even here be of use by creating a seedbed of disturbed soil and trampling in seed.

Light grazing often gives spectacular recovery in dry areas but may mean too few stock can be carried to be economic.

Alternate grazing and spelling is generally accepted as the best way to get maximum productivity from native grasslands while the American range adage of "take half (of the palatable species) leave half" is a rough and ready guide to intensity (Blackmore, 1962).

(b) Improved Pasture - the difficulty in persuading a pastoralist to improve his vegetation with fertiliser or seed is because low-cost, low-intensity natural grazing usually gives the highest net returns. However, the greatest benefit to plants is when a farmer, to increase the nutritional value and productive capacity of his land, corrects mineral deficiencies with fertilisers and probably at the same time adds new species. Some may compete for scarce minerals with the existing grasses (Jackman, 1960) but other plants such as clover may actually enhance the production of the natives. The fertilising and seeding, besides increasing the producitivity of the land may well have a real effect in reducing soil loss the increasing water storage. There may be more complete surface cover by the plant canopy; more organic matter added to the soil to improve its water holding capacity (Sears and Evans 1953); plant roots living or decayed may open up soil channels improving infiltration (Semple, 1952); and the sward may reduce soil compaction by animal trampling (O'Connor, 1956).

When new plants are introduced and fertiliser applications continued, the vegetation will be much less vulnerable to overgrazing. There is one exception to this. Sometimes in severe droughts, when plant growth fails, the higher numbers of stock once carried on the improved pasture may, if not removed, cause severe damage to the vegetation, perhaps prolonged in its

effect. However, wise management should be ready to cope with such emergency by feeding stored forage reserves or bought-in concentrates.

(c) Animal Management - different species and classes, even different age groups of stock, can have different preferences for grazing sites, and proper management of extensively grazed catchments must make allowances for this to avoid undesirable concentration of numbers. Stock grazing-pressure distribution by fencing is almost always advisable to control the intensity of grazing of any particular unit of land. The species of animal grazed does not seem to matter so much as the numbers of animals on a given area (Hughes, McClatchy, Hayward, in prep.).

The plant and soil conditions in a catchment are influenced by such a maze of factors that all relevant ones must be considered when planning its grazing:

i. plant growth and maintenance
ii. nutritional needs of plants and animals
iii. the animals' grazing habits
iv. the number and location of edible plants
v. risk of soil erosion.

Unfortunately, the difficulty of balancing animal needs and numbers with plant production and survival can sometimes be the rock on which animal performance of soil stability founders.

However, although grazing will alter the vegetation of a watershed from its virgin state of non-use, a level of grazing can often be found which preserves the productive level of the plant sector of the biological resources (Heady, 1967).

The concensus of opinion seems to be that intelligently controlled grazing can be an advantage to the sward rather than a disadvantage (Heady, 1967). The sward will not necessarily retain the same botanical composition but a new balance need not necessarily be any less productive nor less protective than the old ungrazed or lightly grazed one.

4. Fertiliser Application - In unimproved grassland the actual fertiliser value of animal droppings would be little. The stocking rate is usually so light that the amount of manure deposited per acre over any period would be very small.

It seems probable, however, that the elements of plant organic material would be made more readily available to the plant again when voided after decomposition by animal digestion, than when plant tissue merely falls to the ground and decays.

This cycling of nutrients becomes more important when soil mineral deficiencies are satisfied and new highly productive plants are introduced by the farmer so that he can graze more stock on a given area. The more stock that are grazed, the faster the nutrients cycle, the greater the increase in plant growth and the higher the net producitivity of the area.

Obviously there will be losses of nutrients in animals and wool sold off any area (Sears, 1951). On reasonably stocked native grazing this does not seem to be significant since animals have grown, lived and died on unimproved grazing elsewhere for far longer than the 130 years of New Zealand's pastoral history. At artificially-enhanced stock levels a sensible fertiliser programme will make an attempt at reasonable, albeit haphazard, mineral replacement.

PASTORAL FARMING AND WATER YIELD

The water yielded by a stream or catchment is what remains of the total precipitation from rain, hail, snow, fog and condensation after reduction by evaporation, transpiration, soil moisture and non-recoverable deep percolation. (Sharp, Owen and Gibbs 1959). In other words it is the runoff from the catchment measured at some point in the stream channel draining it.

Yield becomes significant where the water from a catchment is put to some use such as irrigation, hydro-electric generation, city water supply or industrial processing.

Yield can be affected by the parameters of precipitation, infiltration, percolation, evapotranspiration, depression and surface storage, temperature, soils and subsoils, land use and treatments, vegetation, geology and topography.

Some of these can be influenced by grazing use, some not. The problems of evaluating the effect of any particular land-use treatment are extraordinarily difficult. In this complex field the answers are few, the questions many. However, it seems that agricultural land-use treatments have a relatively small affect on water yield - an effect masked by more important variables such as precipitation, soil moisture and season (Ackerman, undated)

The difference between grazing use and no-grazing use is not, in general, a drastic change of land treatment, although the consequences of continued overgrazing and burning of vegetation can lead in time to significant changes in catchment condition. The affect on yield of simply grazing or not grazing a catchment is not really capable of measurement separately from the other parameters mentioned above. However, possible ways in which animals might influence water yield are:

i. <u>Infiltration</u> - it has already been pointed out that treading by grazing animals can compact and hence reduce capacity for infiltration of moist and strongly-weathered soils. Also that treading has little compacting effect on dry soils, free-draining soils of weakly-weathered high-country soils. But compaction of the surface soil layer can be caused by raindrop impact which standing vegetation or litter will prevent.

Good infiltration does not necessarily increase the water yield from a catchment. In fact it may reduce it by encouraging loss by percolation. It does, however, improve ground-water storage and helps to sustain stream flow between storms. Conversely, compacted soil favours high peak flows and low base flows.

Infiltration is one of the few factors influencing water yield which is itself significantly influenced by land treatment. But it is a question of degree.

It is doubtful whether grazing in an unimproved catchment will greatly affect compaction. However, where land improvement in humid areas has led to high stock numbers being carried per acre, the resulting lesser infiltration, in spite of a more organically active soil, has caused measureable changes in stream flow characteristics. Mr Yates will discuss this elsewhere in the symposium.

In some humid areas, it has been observed that increased infiltration of water (due to better plant cover or more litter) into certain types of steepland soils can lead to mass soil slumping. Here non-use could be a disadvantage.

ii. Evapotranspiration - stock, by heavy grazing, could remove a transpiring plant cover. They could also, by exposing the soil surface to sunlight, cause drying or an increase in the reflective insulation value of the surface and hence lower evaporation of soil water. In other words, stock could conceivably reduce this water loss. On a different scale Lewis and Burgy (1967) found that the lower consumptive use of grassland compared to the forest it replaced increased yield by 4.5 inches and Rothacher (1965) cited other examples showing in general a yield increase with timber felling.

Scrub or forest is of no special value to the water yield of a catchment compared to a good grass cover. In fact it is likely to increase transpiration losses of soil moisture and intercept rainfall leading to its evaporation (Semple 1952). On certain sites, however, it can have great virtue as a soil stabiliser.

I suggest that long before grazing stock significantly increased the yield of a catchment by reducing evapotranspiration, widespread soil erosion would have led to their removal.

iii. Depression and Surface Storage - stock ponds and animal tracks may be artificial or natural changes associated with grazing which increase the depression storage of a catchment. But evaporation from ponds, local increases in runoff and reduction in evapotrans-

piration due to extra stock concentrating near them, may counteract the physical storage of the pond.

Stock destroy vegetative litter and may reduce thick growing vegetation enough to speed up overland flow and reduce surface storage. Again, grazing stock at high concentration may actually smooth out imperfections in the ground surface, decreasing its roughness, or on the other hand increasing depression storage by their hoof marks.

This further shows the complex nature of the influence of grazing stock on yield.

Sharp et al (1959) hypothesised after a thorough but inconclusive study of the subject, that the more arid the climate, the greater should be the influence of land use treatment on water yield, since conservation measures would have an increasing effect on soil and plant condition and hence greater infiltration and less yield. Conversely, the more humid the climate the less should be the influence of land use (and thus grazing) on water yield. However, as Professor Burton will explain elsewhere in this symposium, any influence is likely to be more significant in small catchments than in large.

PASTORAL FARMING AND WATER QUALITY

The presence of animals in a catchment raises questions about potential water pollution by materials other than soil particles.

Fertiliser, insecticides and weedicides are all part of modern farming, for the most part used increasingly as the type of farming intensifies. Either alone, or abetted by decaying animal carcases and animal effluents, they can contaminate water supplies and conflict with the watershed management aim of good water quality.

How important are these pollutants and what remedies might reduce their harm to an acceptable level?

Mineral Pollution - O'Connor (1968) has reviewed New Zealand and overseas studies of raised phosphate and nitrogen levels in water draining agricultural land. He notes that these minerals may be lost by surface wash (particularly from steep slopes), by erosion of soil and the minerals in it, or from leaching by movement of water through the soil profile.

Losses of these minerals may be small from unimproved infertile land (unless it is actively eroding) but greater from younger more fertile soils. However, if either has been stimulated to high organic activity by the addition of seed and fertiliser and by the depasturing of enough animals on it to devour most of the new plant growth, then the process of loss of minerals such as phosphates, nitrates and sulphates will change with the higher nutrient uptake of plants, soon to be eaten and the residue of digestion and metabolic wastes returned to the soil.

Many unimproved soils, especially those of open structure and high organic matter, may hold most of the newly-added phosphate and prevent its removal by leaching. Sulphates, however, can be readily leached through open soils, and as the nitrogen level of the soil increases due to atmospheric nitrogen "fixed" by clover rhizobia, and from dung and urine returned to it, the amount of nitrate lost from the soil by leaching can be expected to increase, particularly in higher rainfall areas. Minerals such as potash, magnesium, calcium and sodium will be leached out also.

The result will be that rivers draining catchments on which these changes are taking place can become especially enriched with nitrogen and phosphorous and other plant nutrients leading to increases in all levels of plant life from algae upwards. The effects of this plant growth are becoming apparent in several central North Island rivers and lakes.

Matthews and Manson (1969) say that this increased plant growth from mineral and organic sources has caused:

- impeded water movement in streams and drains with consequent flooding.

- blocking of screens at hydro-electric stations thereby reducing or stopping power generation

- reduction of aesthetic values and actual swimming dangers at recreation spots.

- likelihood of direct pollution by weedicides when control measures are taken, and even more from the decaying sprayed weed

- need for costly clearing measures

- higher chlorination requirements to give potable drinking water.

The present level of knowledge about fertiliser requirements leads to rather haphazard estimates of the amount to be spread. One-stage application is common, two-stage rare, and gross top-dressing all too frequent. While this is the case, any real decrease in the opportunity for minerals to enter water draining farmland seems unlikely.

Our hope for the future is that precise amounts of fertiliser may be spread accurately at reasonably frequent intervals. This should cut down the risk of surface wash particularly if the fertiliser could be sprayed on instead of spread as particles. On arable land, sub-surface introduction could be more accurate and less wasteful.

The problem of leaching is unlikely to be overcome. The best that can be done is to encourage rapid and continuous plant growth with extensive rooting systems and a healthy appetite for soil-borne nutrients.

<u>Organic Pollution</u> - to the pollution caused by the drainage of water through and over pastures must be added the direct contamination of water with organic waste caused by effluents from pig styes, cow sheds, sheepyards, cattleyards, saleyards, loafing barns, silage pads, freezing works and all places where animals are concentrated. Stock-truck cleanings add to the effluent.

Bacterial pollution of water supplies is also a steadily increasing and associated problem.

Solid wastes may not now be deliberately let into a water course. But this does not stop enriched fluid entering rivers nor the seepage of dissolved nitrogenous solvents into a drainage system. Neither does it prevent the occasional catastrophe when storm water runoff overloads a settling basin.

Prevention of concentrated overland flow from manure accumulations is a rational first step to reducing organic pollution but it must be followed by increased acceptance of the principle of spreading such wastes back onto agricultural ground - mechanically expensive though this may be. Many dairy farmers are already sprinkler-irrigating their pastures with milking-shed effluent.

The principle of this must be extended to the stage where all concentrated organic waste is spread onto pasture or crop land rather than allowed to move into a catchment drainage system.

Again, where border-dyke or wild-flooding irrigation is practised, every effort will be needed to see that there is enough flow control to prevent excess water reaching the tail race. Similarly, irrigation above the water-holding capacity of the soil is unwise and leads to mineral loss by leaching.

Degree of pollution - some streams and lakes suffer now from pollution due to pastoral farming, and their number will increase. But at least in the near future many streams, particularly fast-flowing ones draining mainly to the sea, are unlikely to show adverse affects.

Indeed, where water from some streams is used for irrigation, enrichment might be no bad thing, for instance on the Canterbury Plains.

But obviously where clear water from a catchment is its most important product, strong measures to prevent pollution by pastoral use are warranted. Exclusion of all stock is not unrealistic in some cases

such as catchments around city water reservoirs.

Chemicals - the greatest risk from the chemicals associated with pastoral farming occurs when sheep dip is released into a stream or even into a normally dry gully from whence the chemicals can later be carried on by flood flow. The general risk of pollution by insecticides such as DDT, diazinon and trichlorfon or weedicides such as picloram is present, but with greater awareness now of the risk should not get worse.

THE VALUE OF PASTORAL PRODUCTION

The principal, in fact almost the only reason why stock are grazed, is to produce an income for their owner. He chooses between the various management practices which will maximise his net return without (we hope) depleting his land resources. There can be a community benefit from controlled grazing too.

Most people, even ardent conservationists, would agree that some use of potentially grazeable land is better than the economic and social waste of non-use - as long as it can be made consistent with the maintenance or preferably the improvement, of its productive capacity.

And the export of stock products benefits the community by the funds it earns.

Generally, if the grazier can be persuaded by price differentials that producing high-quality sale stock and stock products is better than concentrating on larger amounts of lower quality products, the catchment condition will benefit. Although this may conflict with research-based recommendations for maximum production of animal products per acre from highly-improved pastures in sub-humid and humid regions, skilled land managers can still strike a fair balance between the productive and protective functions of the sward. Real managerial skill is needed, for stock productivity often remains high long after serious plant cover depletion has set in.

THE BENEFITS OF MULTIPLE USE - An Example

For the agricultural year 1966/67, the value of sales of pastoral products from the grazing runs in the upper Waitaki catchment above the Waitaki dam (based on actual sales at estimated prices) was $1,730,000. (Hughes - in prep.)

On the other hand, the annual revenue paid to the N.Z. Electricity Department by power-supply authorities for bulk power from Tekapo, Benmore and Waitaki generating stations was $17,500,000 (Inter-Departmental Committee 1966). That is, the gross return to the Electricity Department for electric power from water draining the catchment was about ten times the gross return to the runholders for the stock and produce sold off the grazeable area.

Furthermore, some 95% of the water feeding the generators came from the higher rainfall area of more than 40 inches of precipitation (Inter-Departmental Committee 1966) which produced only $50,000 worth of meat and wool. That is, the revenue from water for electric power from this region returned 33 times the revenue from meat and wool. Or if these figures are looked at another way, the remainder of the catchment - the drier area - produced $1,230,000 of pastoral products and only $875,000 worth of electricity.

Although these figures have all the faults of approximation they serve to highlight an important point, namely:

<u>All parts of a catchment are not equally valuable as sources of water or as sources of pastoral products</u>

Clearly the best use of the semi-aris and sub-humid part of the Mackenzie country is as farmland first and as a source of water second. In the higher humid regions the prime use is for water first and pastoral products second. To this balance it is well suited by climate and topography.

The obvious question is how much does one enterprise adversely affect the other? How much do the sheep and cattle grazing in the upper rainfall areas affect the water yield and quality? If they were removed would there be a more than compensatory increase in revenue from electric power or from irrigation?

In this case the answer to me is clear. The grazing stock would have no significant affect on the quantity or quality of water reaching the turbines due to the buffering effect of the natural artificial lakes. Even were these not present it has already been argued that in a humid environment the effect of catchment conditions on the water yield is small. In this catchment, although soil erosion may be a waste of a capital asset, although it may cause local problems of stream control, water supply and road engineering, it has no effect on hydro-electric generation. Two prime multiple uses are here compatible. The revenue from each serves to maximise the net returns from the catchment.

However, no two catchments are similar. In this case the uses seem complementary. But if they competed for the same resource, as irrigation and power supply can do for water, then multiple use may be a more doubtful goal.

Before permitting pastoral farming in an area where the quality of water was important I would have to be satisfied that the pastoralist tangibly recognised the importance of other uses besides his own. Often he would have to be willing to set aside present use of his resources in favour of future use perhaps by his heirs or successors or even by the community at large. In areas where water yield and quality are important, such as catchments serving hydro-electric, irrigation, water supply or industrial schemes, he would have to be willing to recognise that catchment conditions can affect silt pollution of water supply and the time distribution of streamflow.

CONCLUSION

There is no doubt in my mind that responsible pastoral farming is compatible with watershed management in all but a few special cases, such as water supply reservoir catchments and already badly eroded regions.

As Harlan (1956) has put it "Fortunately, good management practices are in no way inconsistent with development of water resources", or Blackmore (1962) "To a very considerable extent watershed objectives are consistent with other objectives for grassland management."

Catchment conditions may have little effect on peak flows during flooding but well-covered land and a minimum of soil erosion are still worthy goals to preserve water quality alone.

A demand for high standards of water yield and quality can affect grazing stock in only one way-they can call for their numbers to be reduced or their complete removal. The many ways in which stock can affect water have already been listed. It has been shown that stock can have a beneficial as well as a harmful effect, either directly or indirectly, on the hydrologic characteristics of a catchment.

If grazing stock are to be tolerated in a catchment which is important for its watershed management values they must:

1. Be so managed and their grazing stock numbers and distribution so controlled as to reduce plant cover deterioriation and soil erosion to a minimum. On some sites it could well be that safe grazing intensity of an area might be so low as to be economically unattractive to the farmer.

2. Be grazed either at low intensity in balance with the resident vegetation so that its ground cover is not depleted, or at the optimum stocking rate needed to fully exploit the productive potential of improved pastures.

3. Be grazed on pastures so managed and serviced by facilities so designed that there is minimum mineral and organic pollution of the catchment runoff.

Only then can grazing be considered compatible with watershed management and the production from it used to maximise net returns from the catchment.

May I close with a quotation which appeals to me greatly:

"Rational individuals are always concerned with their personal survival and the returns and satisfactions they can secure for themselves and their families but they are also interested to a greater or lesser degree in the future welfare of the race, the welfare of their homes and the well-being of their fellowmen." (Barlowe, 1958).

I like to think that the present-day pastoralist, to whom we have given the custody of our hill and mountain catchments, is one of these rational men.

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HYDROLOGICAL EFFECTS IN THE FIRST TWO YEARS FOLLOWING MODIFICATION OF SNOW TUSSOCK GRASSLAND

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SUMMARY

At c. 920m (3,000 ft) on the Rock and Pillar Range, Central Otago, lysimeters containing single plants of untreated, burnt or clipped narrow-leaved snow tussock, or a sward of blue tussock, in triplicate, were installed. In the first two years, untreated snow tussocks produced the greatest water surplus. This was 66 and 81% of the measured annual precipitations of 100 and 163cm (i.e. 39 and 64 in.). The short blue tussock sward produced the smallest surplus (45 and 57%), while the burnt and cut snow tussocks were intermediate (57 and 70%; 47 and 64%).

The results suggest reduced water consumption by the larger untreated tussocks but measured transpiration rates of untreated, burnt and clipped snow tussocks indicate that the reverse is true. The increased water surplus under large snow tussocks, despite their greater transpiration, is attributed to gains by interception.

Water surplus values for an average rainfall of 143cm (56in) are estimated at: untreated snow tussock 77%; burnt snow tussock 68%; clipped snow tussock 61%; blue tussock sward 56%.

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A natural undistrubed cover is recommended to provide the maximum yield and control of water from the low-alpine snow tussock grasslands.

INTRODUCTION

Variations in the water balance within the first year of modifying narrow-leaved snow tussock grassland in the low-alpine zone on the Rock and Pillar Range, Central Otago, have recently been described by Rowley (1969). Using non-weighing lysimeters she found, rather surprisingly, that the largest plants, untreated snow tussocks, produced the greatest water surplus while the shortest cover, a blue tussock sward, gave the least. Intermediate amounts were produced by snow tussocks whose canopies had been considerably reduced by burning or severe clipping.

Maximum surplus from the largest plants was attributed to redistribution of precipitation by individual snow tussocks and to interception gains which were demonstrated to increase substantially with the height (or leaf area) of a tussock, especially during foggy weather.

We now present results for an additional 21 months, together with values for transpiration of untreated, burnt and clipped snow tussocks. Transpiration rates were measured to check the unlikely possibility, which the water balance values could nevertheless imply, that recently defoliated snow tussocks consume more water than those untreated.

PROCEDURE

1. Water Balance - The site on the Rock and Pillar Range and details of the installation and operation of the 12 non-weighing lysimeters there, have already been described (Rowley, 1969). A Sumner long-term rainfall-temperature recorder (Sumner, 1959) was installed in February, 1968. This measures air temperatures in a white, louvred screen 1.2m (4 ft) from the ground to provide records for estimating potential evapotranspiration (PE) as described by Thornthwaite (1948). Gravimetric determinations of soil moisture were discontinued after the first year since moisture had always proved freely available at the site, but in December 1968, six

gypsum soil moisture blocks were installed at a depth of 10 cm (4 in). Four were placed in the lysimeters, one for each treatment, while the remaining two were placed as controls, in the adjacent areas of burnt and untreated grassland. Moisture content is being recorded at 10-14 day intervals with a Bouyoucos moisture meter (model BN-2B). A pair of unmodified porous pot evaporimeters (Mark & Smith, 1962), using an antifreeze mixture of 20% ethanol in distilled water as recommended by Wilcox (1967), were installed in May, 1969 in an attempt to obtain evaporation values throughout winter. A Foxboro 0-5 ft water level recorder was installed in one of the untreated snow tussock out-flow tanks in May, 1969 to compare duration and rates of discharge with those of precipitation.

2. Transpiration - Nine snow tussocks were lifted from the field site in September 1968. Each had an overall height of about 90 cm; a basal diameter of 25 cm; a maximum canopy spread of 100 cm; green leaf oven dry weight (100°C) of 70-85g; and dead leaf weight of 50-70g. The soil around each tussock was trimmed so as to fit into a two gallon plastic bucket with holes in the bottom. This bucket was enclosed in a slightly larger one in which 10 cm (4 in) of water was maintained by a pair of plastic tubes inserted between the two buckets and connected to a reservoir above. Half-gallon bottles lagged with glass wool and shaded to minimise temperature fluctuations, were used as reservoirs. The gap between the rims of the two buckets was sealed with sheet polythene and this in turn covered by a circular metal shield with a 23 cm (9 in) diameter hole at its centre through which the crown of the tussock emerged (Fig. 1).

On a lawn in Dunedin the nine buckets were then sunk in the ground almost to their rims with 75 cm (30 in) between adjacent tussocks so that overlap of canopies was negligible. Clear polythene (0.005 in grade) on a wooden frame 3.7 m (12 ft) long x 1.3 m (4.3 ft) high x 1.8 m (6 ft) wide, but open at either end, covered the tussocks to prevent any effect from interception (Fig 2). Two tussocks were planted at either end to reduce edge effects. A pair of evaporimeters was set up among the tussocks and another pair on the open lawn.

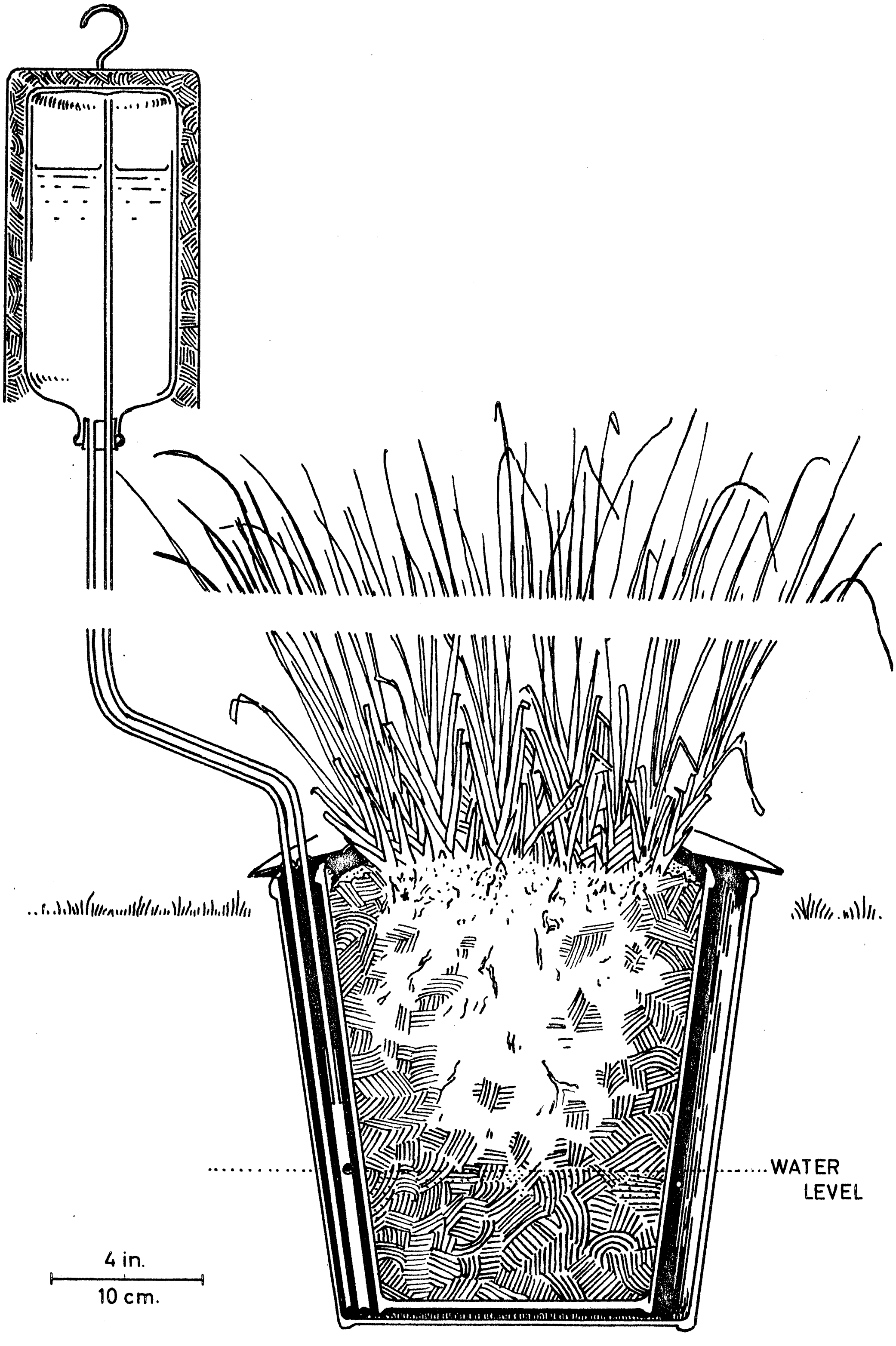

Figure 1

Autoirrigation system to measure transpiration of individual snow tussocks. The small vent in the brass tube at the water level lets more air into the otherwise air-tight reservoir. This in turn lets water run down into the buckets until the air vent is covered again.

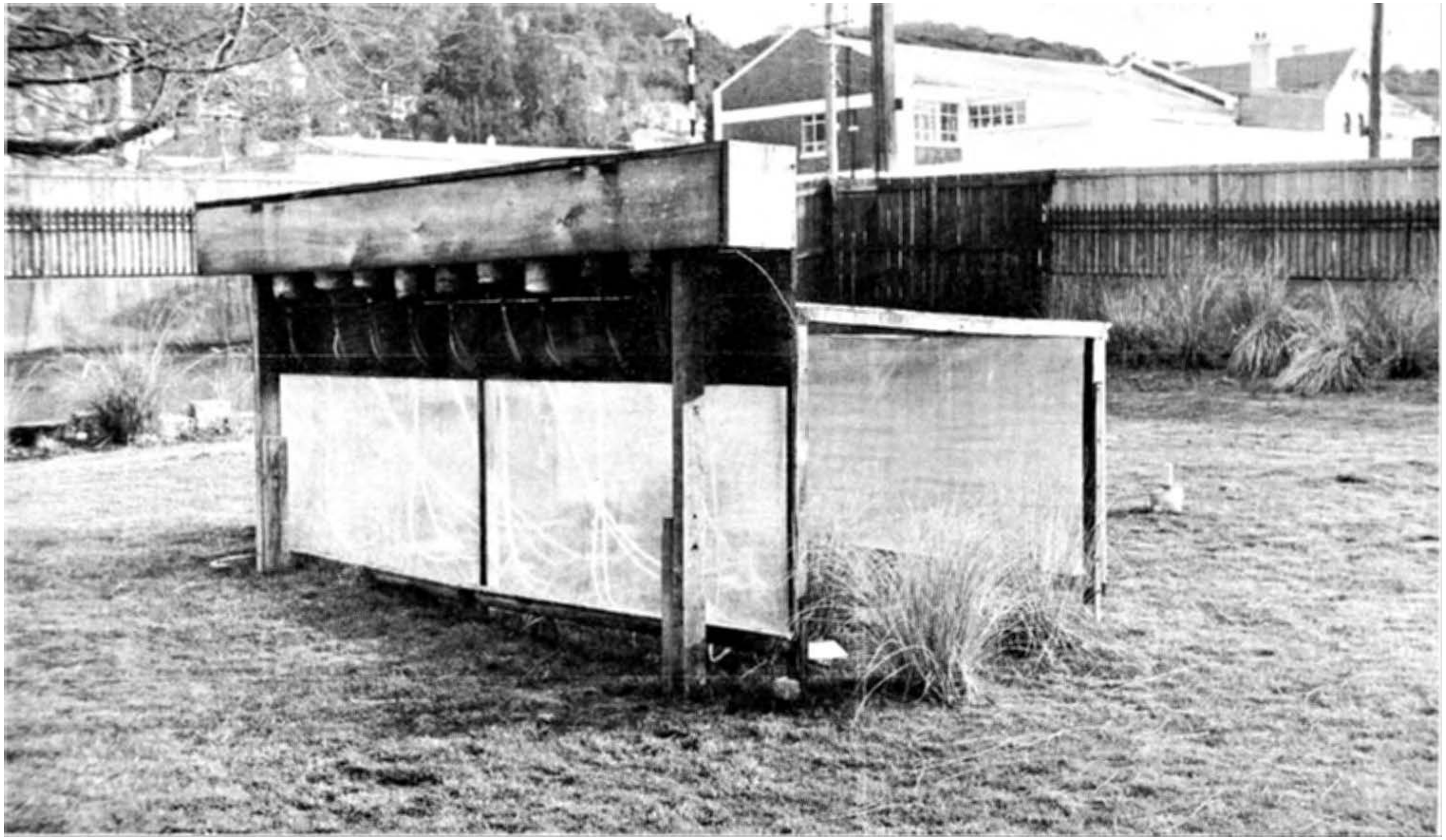

Figure 2

The set-up used to measure transpiration rates of nine snow tussocks at Dunedin. The panel of reservoirs is at the top on the south side, with a pair of polythene tubes from each, leading to individual tussocks. To eliminate interception effects, clear polythene covers the tussocks except for the ends. Additional tussocks are planted here to reduce edge effects. A porous-pot evaporimeter is located among the tussocks with another on the lawn nearby.

Reservoirs were refilled weekly. After six weeks for standardisation of the individual tussocks (correction factors ranged from 0.71 to 1.55), three tussocks were clipped back to the level of their leaf sheaths and another three burned on October 28th. The initial burning was not very successful and some kerosene added to complete it may have been responsible for the unusually poor recovery of these tussocks.

RESULTS

1. Water Balance - Precipitation and water surplus of the four treatments are shown for the first 33 months in Fig 3. The estimated monthly PE (being the difference between measured precipitation and water surplus) for the two contrasting types, untreated snow tussock and the blue tussock sward, together with estimations based on evaporation measurements (Rowley, 1968) and Thornthwaite's method for the same period, are shown in Fig 4. Annual values for the first two complete yearly periods are given in Table 1.

The conductivity measurements of soil moisture from early December, 1968 gave no values below 89% available moisture up to mid June, 1969 when freezing began to affect the readings. Freely available soil moisture throughout the 1968-69 season in the tanks of all four treatments, as well as in the surrounding grassland, is indicated by these results. It is therefore assumed that evaporative water loss from the lysimeters has continued at potential rates.

Analysis of variance on monthly water surplus values associated with the four treatments for the second yearly period showed that, as for the first (Rowley, 1969), the treatment effect is significant (P = 0.001). Mean monthly values for water surplus were: untreated snow tussock 11.1 cm (4.4 in); burnt snow tussock 9.6 cm (3.8 in); clipped snow tussock 8.8 cm (3.4 in); blue tussock sward 7.8cm (3.1 in), the least significant difference (P = 0.05) being 1.0 cm. Differences within each of the four treatments were not significant during the second year whereas one of the three untreated snow tussocks produced significantly low values in the first year (Rowley, 1969).

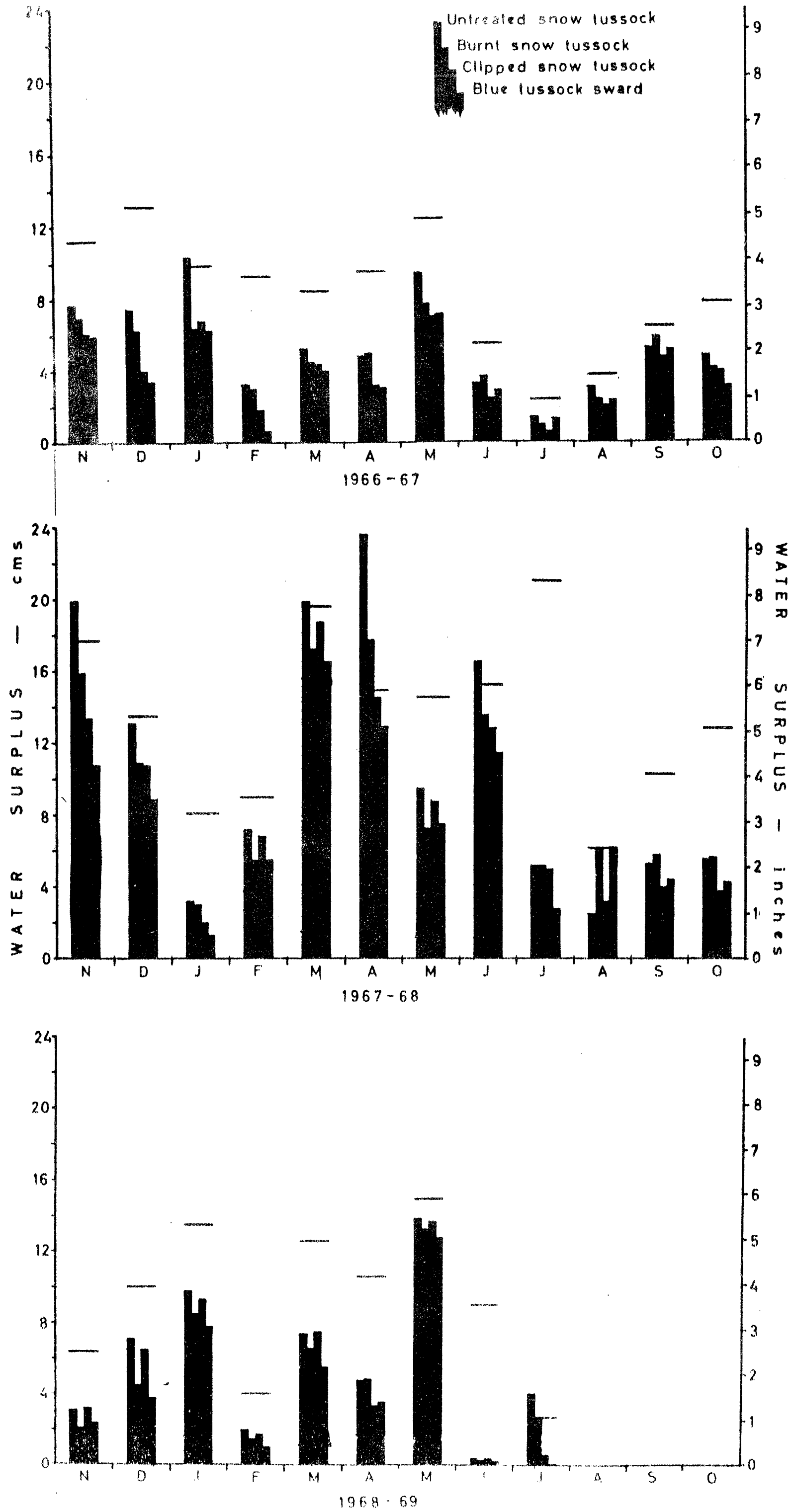

Figure 3

Water surplus values for each of four treatments (as indicated) and for precipitation (horizontal lines) for approximately monthly periods on the Rock and Pillar Range. Estimations of potential evapotranspiration are represented by the space separating precipitation and water surplus values. November, 1966 - July, 1969.

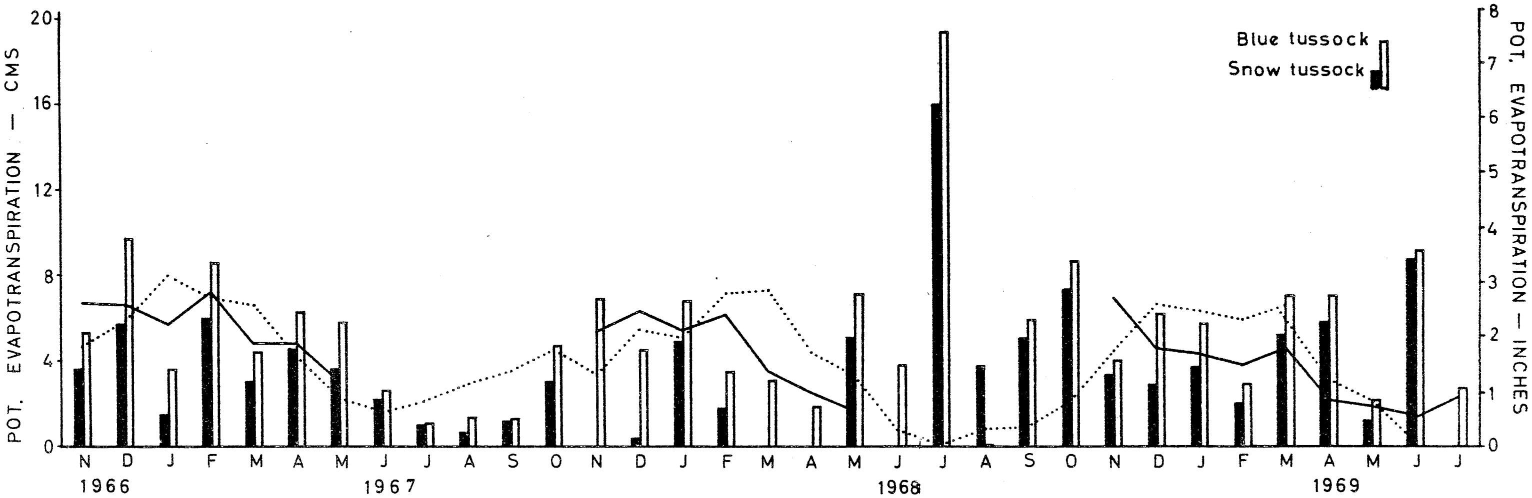

Figure 4

Estimated potential evapotranspiration for two contrasting cover types, untreated snow tussock and a sward of blue tussock, for approximately monthly intervals compared with estimations based on Thornthwaite's method (dotted line) and on evaporation measurements (solid line). Rock and Pillar Range, November, 1966 - July, 1969.

Table 1 - Water balance values for two 12-month periods and estimates for an average rainfall year in snow tussock grassland at 920m on the Rock and Pillar Range, Central Otago.

FACTOR	TREATMENT	PERIOD Nov.1966-Oct.1967 cm	(in)	%	Nov.1967-Oct.1968 cm	(in)	%	Est. Value for Avge Pcptn Year cm	(in)	%
Precipitation		99.5	(39.2)	69*	163.3	(64.3)	115*	143	(56)	-
Water Surplus	Untreated snow tuss.	65.5	(25.8)	66	131.7	(51.9)	81	110	(43)	77
" "	Burnt " "	56.3	(22.2)	57	114.2	(45.0)	70	97	(38)	68
" "	Clipped " "	46.6	(18.4)	47	104.1	(41.0)	64	87	(34)	61
" "	Blue tuss. sward	44.7	(17.6)	45	92.8	(36.6)	57	80	(31)	56
Est. PE	Untreated snow tuss.	34.0	(13.4)	34	31.6	(12.4)	19	33	(13)	23
" "	Burnt " "	43.2	(17.0)	43	49.1	(19.3)	30	46	(18)	32
" "	Clipped " "	52.9	(20.8)	53	59.2	(23.3)	36	56	(22)	39
" "	Blue tuss. sward	54.8	(21.6)	55	70.5	(27.8)	43	63	(25)	44
" "	Thornthwaite	53.0	(20.9)	53	40.4	(15.9)	25	47	(18)	33

* These values are for percentage departure from the long-term precipitation recorded at the closest official station, Garthmyl (200m; 650 ft) 8 miles away near Middlemarch.

Results for the second year essentially confirm those of the first. Untreated snow tussocks again produced the greatest water surplus and the blue tussock sward yielded the least. Values for surplus expressed as a percentage of the 12 months' precipitation were substantially higher in the second year, as was the total precipitation (Table 1). Estimated PE values showed the same trend for both years among each of the four treatments, and the actual values for each were generally similar for the two years except for the blue tussock sward which was substantially higher in the second year. Thornthwaite values, on the other hand, were less during the second year (Table 1). Yearly values based on evaporation rates are not available since only during the 1969 winter have evaporimeters continued to operate.

Some anomalous values are apparent from the monthly estimates of PE (Fig 4). Values from all the lysimeters are abnormally high for July, 1968 and June, 1969. Heavy snowfalls during these months, which were measured by the pair of rain gauges, largely blew away before melting. Other than these two months, the seasonal trends in estimated PE from the tussocks, in general follow those based on evaporation rates and on Thornthwaite's method, but the agreement is not close. Differential interception by the different types of tussock cover, probably accounts for most of these smaller anomalies.

2. <u>Transpiration Rates of Snow Tussocks</u> - Mean daily transpiration rates for untreated, burnt and clipped snow tussocks at Dunedin are compared in Fig 5 with evapotranspiration (estimated from evaporation from porous pots alongside) for a five-month period. Evaporation inside the polythene shelter (Fig 2) at Dunedin was 10% less than outside, and about 26% less than at the field site on the Rock and Pillar Range. The untreated snow tussocks consistently had the highest transpiration rates. Variations of transpiration generally follow those of PE except in the cut tussocks for the five weeks after clipping, the period of initial recovery. Transpiration of the clipped tussocks rose as the plants recovered but the burnt tussocks hardly grew at all and their transpiration remained low throughout.

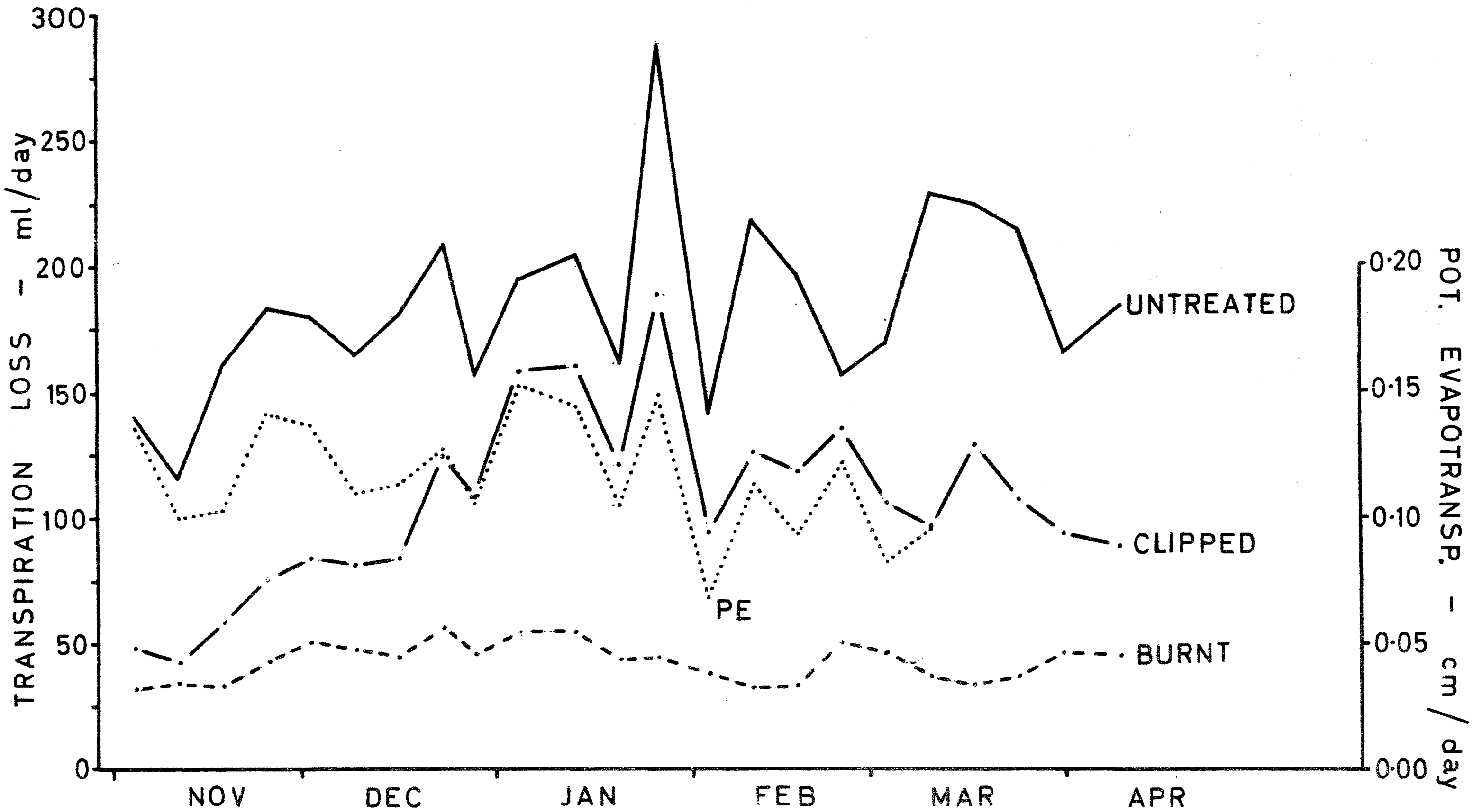

Figure 5

Mean daily transpiration rates for untreated, burnt and clipped snow tussocks at Dunedin compared with potential evapotranspiration estimated from porous-pot evaporation. October, 1968 - April, 1969.

The maximum rate of transpiration in the untreated snow tussocks was close to 300 ml per day. Analysis of variance of the weekly transpiration rates showed that the treatments were significant (P = 0.001), whereas differences within treatments were not. Mean weekly transpiration losses per tussock were: untreated 1,236 ml; clipped 612 ml; burnt 300 ml (L.S.D. at P = 0.001 = 165 ml).

DISCUSSION AND CONCLUSIONS

It is standard practice in lysimetry, when soil moisture is freely available, to calculate potential evapotranspiration (PE) as the difference between water intake measured with a rain gauge, and the surplus water discharged (Sutcliffe, 1968). However, in field studies in snow tussock grassland, such calculations are likely to be quite erroneous because of substantial and differentiating gains by interception. The magnitude of interception gains by clipped and untreated snow tussocks and the redistribution of precipitation by individual tussocks have been assessed by Rowley (1969).

Nevertheless, our estimates of PE give generally similar values, with the exception of blue tussock, for each of the two yearly periods, but because of the increased precipitation in the second year the percentage values are quite different (Table 1). Additional data are required, however, before definite conclusions can be reached on this aspect.

Water surplus from each treatment, on the other hand, was much greater in the second year than the first. This increased surplus is shown by both the actual and percentage values and reflects the substantially greater precipitation during the second year. A similar relationship between values for total and percentage water surplus and PE during wetter and drier years was reported by Likens, *et al*. (1967) for forest analysed on a catchment basis in a humid area of the northeastern United States.

The estimated PE values for each of the four treatments (Table 1, Figs 3 & 4) could reflect a substantially greater water use by the short blue tussock sward and the

burnt and clipped snow tussocks than by the larger untreated snow tussocks. However, transpiration rates of individual snow tussocks that were ventilated yet screened by clear polythene to prevent interception effects, were significantly higher in untreated tussocks than in those which were recovering from either burning or clipping. The recovery from burning was so poor that the transpiration rates recorded for these plants may be quite misleading. This experiment is being repeated.

A large untreated snow tussock, similar in size to those used in the lysimeters and containing 70-85 g (O.D.Wt) green leaf material, transpired about 200 ml of water per day in the Dunedin experiment. Greater evaporation rates at the field site suggest that such tussocks consume about 250 ml per day on the Rock and Pillar Range during mid summer. This would amount to about 7.5 litres per month or 3.0 cm (1.2 in) of precipitation in the lysimeter. Because the surface of the lysimeter (0.24 sq. m or 2.7 sq. ft) is only slightly smaller than the mean area occupied by a snow tussock at the site (0.34 sq. m or 3.7 sq. ft) these values should be reasonably representative of the grassland.

Inspection of Fig. 4 indicates that evapotranspiration from the lysimeters containing the large untreated snow tussocks can reach about 6 cm (2.4 in) during the summer months, assuming no gain from interception. The difference between the 3.0 cm value for monthly water consumption by a snow tussock and the 6.0 value from the lysimeter, presumably is due to evapotranspiration from bare soil and intertussock vegetation in the lysimeter. Peters and Russell (1959), studying the transpiration of corn over a range of densities (8,000-24,000 plants/acre), reported that as much as 50% of the total evapotranspiration was from the soil surface, so suggestions of a similar proportion for snow tussock grassland may not be unreasonable. But the monthly values for both water surplus and estimated PE in our study are liable to error in cases where rain fell close to the end of the measurement period. Observations to date suggest that about three days are required for all the gravitational water to be released from the lysimeter but the water level recorder recently installed in one of the out-flow tanks should eventually provide a reliable measure of this.

The values for water surplus for each of the two yearly periods show conclusively that large snow tussocks, which are associated with the least disturbed types of low-alpine grassland, produce a substantially greater water surplus than do any of the shorter, more open types of cover associated with modified forms of these grasslands.

On the basis of data for only two complete years, estimations of water consumption and water surplus in each of the four treatments for an average rainfall year must be speculative. With this reservation, we predict that for the field site during a year of average rainfall (143 cm or 56 in), untreated snow tussocks will produce a surplus amounting to about 77% of this amount, whereas for an induced blue tussock sward the surplus will represent only about 56% of the precipitation. For snow tussocks that have been either recently burned or severely grazed, the water surplus values will be intermediate; 68% and 61% respectively. These estimations of water surplus are based on the mean of the two yearly values for PE for each treatment, while precipitation is estimated by adjusting each of the two yearly totals according to deviations from long-term values at the nearest official station, Garthmyl, for these same periods.

As the burnt and clipped snow tussocks continue to recover, their water balance values should converge towards those of the undisturbed tussocks. There is no indication of this for the first 33 months even though the burnt and clipped tussocks have regained 70% and 73% respectively, of their original height.

Further results from this project may modify our estimates but are unlikely to alter our general conclusion: the maximum water yield (and control) from the low-alpine snow tussock grasslands is obtained from natural undisturbed cover.

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THE EFFECT OF MODIFYING COVER TYPE BY MAN AND ANIMALS ON SOME FLOW CHARACTERISTICS IN SOME NEW ZEALAND EXPERIMENTAL BASINS

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F. Scarf, Ministry of Works, Nelson

ABSTRACT

The effects of two levels of grazing on some hydrological characteristics of both unimproved and improved small grass-covered catchments at Makara are discussed. The results of some preliminary analyses of flow data from cultivated, gorse and grass-covered catchments at Moutere are also discussed.

Changes in hydrological characteristics such as total flow, flow distribution, peak discharges, flow before the first peak and surface detention have occurred and these are related to the differences in cover type and condition, and management.

INTRODUCTION

This paper is an extension of the analysis of the Makara data which was outlined by Toebes, Scarf and Yates (1968).

Both Makara and Moutere are experimental basins, where 13 and 12 small catchments respectively, are under investigation. The purpose of these basins is to assess the influence of land management practices on the hydrological regimen. The small catchment research programmes at Makara and Moutere have been discussed elsewhere by Yates (1962) and Dixie (1966).

CATCHMENT CHARACTERISTICS

The soils of both Moutere and Makara are central

yellow-brown earths. The soils are silt loams, but in the case of Makara they are derived from Triassic-Jurassic greywacke - and in the case of Moutere from Pleistocene greywacke gravels.

The Moutere catchments are larger and of steeper topography than the Makara catchments. Despite this steeper topography the major part of each of the Moutere catchments can be or has been cultivated.

Because of the favourable climate, the soils and pastures have a potential for high production provided they are adequately topdressed. Over eight ewe equivalents per acre have already been carried on some of the Makara catchments and up to seven ewe equivalents per acre have been carried on grassed catchments at Moutere. With good management both areas can sustain a perennial-ryegrass/ white clover dominant sward.

CLIMATIC CHARACTERISTICS

Rainfall distribution is reasonably uniform and enables a fairly dense permanent pasture to be maintained throughout the year. Most flow occurs during the winter months, although intense short-duration storms do occur at other periods of the year and these frequently result in high peak discharges.

Generally speaking, long-duration storms with intensities well below 25 mm per hour are responsible for most of the annual flow. For example, at Makara when the soil is very moist or saturated, runoff occurs from unimproved pastures when the rainfall intensity exceeds 5 mm/hr.

Temperature, although less significant than rainfall, is important because of its role in evapotranspiration and hence, indirectly, in changing the available soil moisture storage capacity over time. Of the two stations Moutere is more influenced by temperature, and drought conditions are more frequently experienced.

Wind, apart from its influence on evapotranspiration, also gives rise to rainfall-sampling problems. At Makara wind can cause such variations in the rainfall pattern

within a catchment that it is believed that both wind direction and velocity should be taken into account when selecting storms for very detailed hydrograph analyses. Wind velocities at Moutere are considerably less and do not present problems of the same magnitude.

ANALYSES OF HYDROLOGICAL CHARACTERISTICS

Total Flow - Double-mass curves for the three treatments have been plotted against the control treatment at Makara, and these indicate breaks in the curve which coincide with the time of change in land management (Fig. I). From 1962 onwards there have been decreased total annual flows from all the treated catchments. Linear regression lines were calculated for the annual runoffs, and covariance analysis showed that for the treated catchments the intercept of the regression lines had significantly changed but that the slope of the regression lines had not changed.

The order of decrease in the annual flows from the smallest to the greatest has been: lax-grazed unimproved, hard-grazed improved and lax-grazed improved.

Flow Distribution - Since the annual flows had changed with the change in treatment, a flow-distribution curve was plotted for each of the treatments using daily runoff values in millimetres. These have indicated graphically the nature of the changes (Fig. 2).

The flow-distribution curve for the control treatment during the evaluation period has been virtually identical to the mean curve derived from all the catchments at Makara during the calibration period.

A change in land management to hard grazing of improved pastures or to lax grazing of unimproved pastures has resulted in virtually no change in the number of days on which runoff occurred. The interesting feature has been the reduction in the number of days on which flows in the middle and higher ranges occur - this being especially the case with the hard-grazed improved treatment.

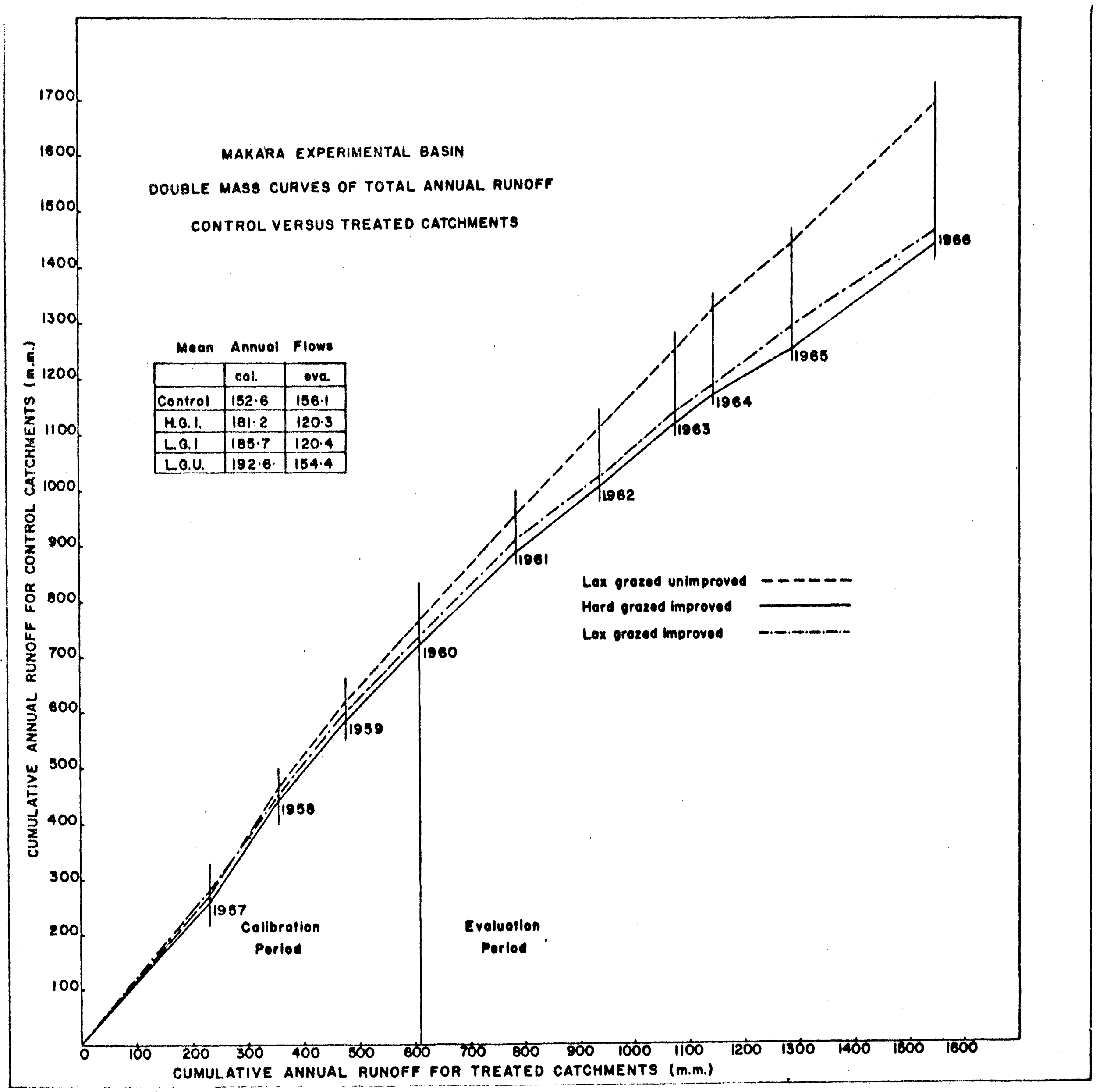

Figure 1

Double mass curves of the total annual runoff for the control versus treated catchments at Makara.

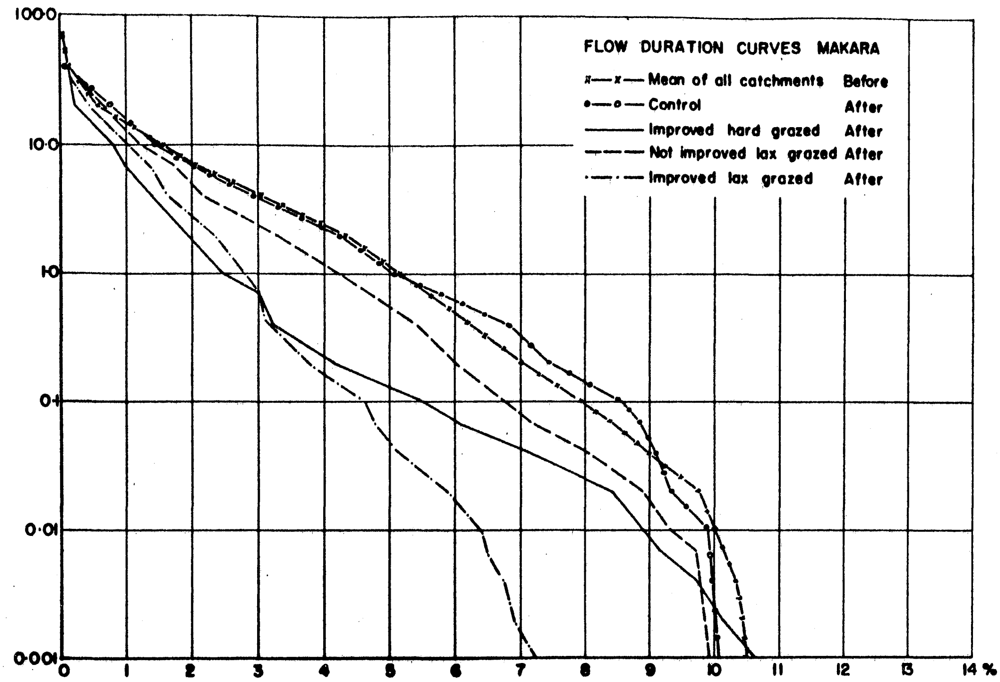

Figure 2

Flow distribution curves for the Makara treatments.

For the lax-grazed improved catchments it has been found that the number of days on which flow occurred was greatly reduced. There was a general reduction over all the flow ranges except at the very low range.

Peak Discharges - These have been reduced at Makara with change in land management, the order of reduction being the same as for the total flow. There is evidence, however, that with long-duration storms the later peak discharges of multipeak hydrographs from treated catchments are not reduced to the same extent as are the initial peak discharges. (Actual analyses are yet to be completed.)

At Moutere when the gorse cover was changed to cultivation the peak discharges more than doubled (Fig. 3).

Flow before the Peak - Plotting and analysis of the Makara data have shown the following changes:

(a) There has been an insignificant change in the amount of flow before the first peak for the not improved lax-grazed treatment (Fig. 4).

(b) The improvement of hard-grazed pastures has resulted in a general reduction (Fig. 5).

(c) Lax grazing of improved pastures has caused a reduction in flow before the peak, especially for the lower range of flow (Fig. 6).

Flow after the Peak - In the case of the Makara catchments little or no base flow occurs. Hydrographs in which there was evidence of base flow were not selected for surface-detention analyses; this avoided errors that may be associated with the separation of this flow from the hydrograph. It was, however, necessary in the case of Moutere data to separate base flow in surface-detention determination.

The analysis results show that surface detention has

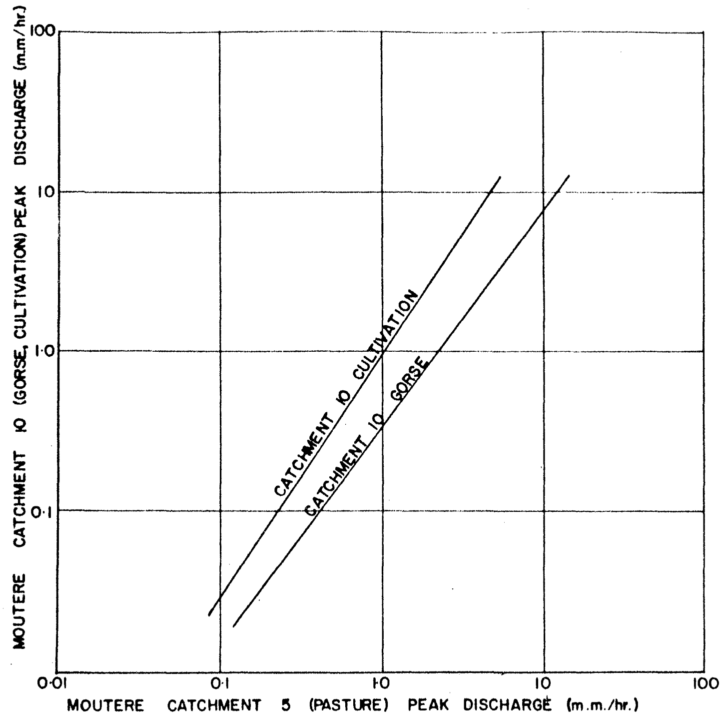

Figure 3

Change in peak discharges with cultivation of a gorse catchment at Moutere.

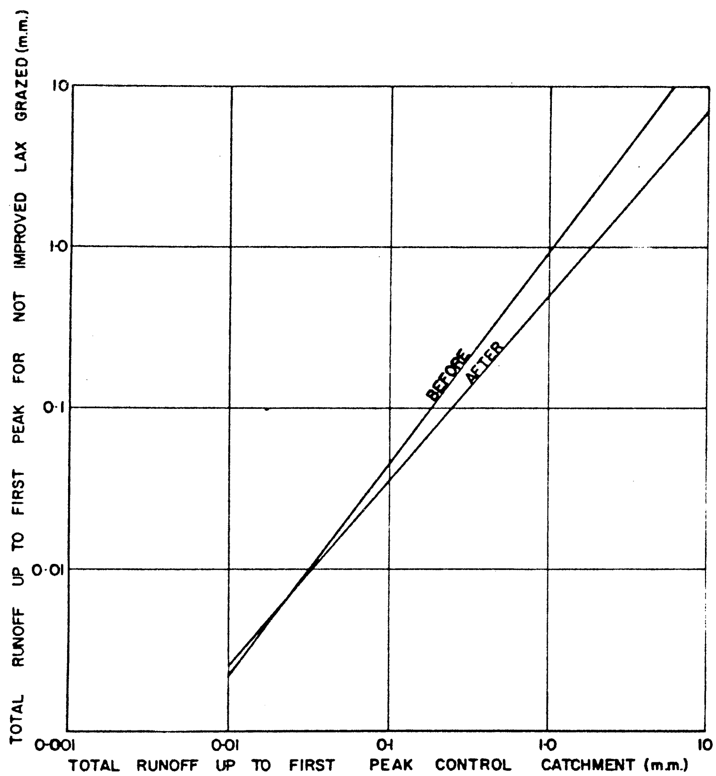

Figure 4

Flow before the first peak for not improved lax-grazed and control catchments at Makara.

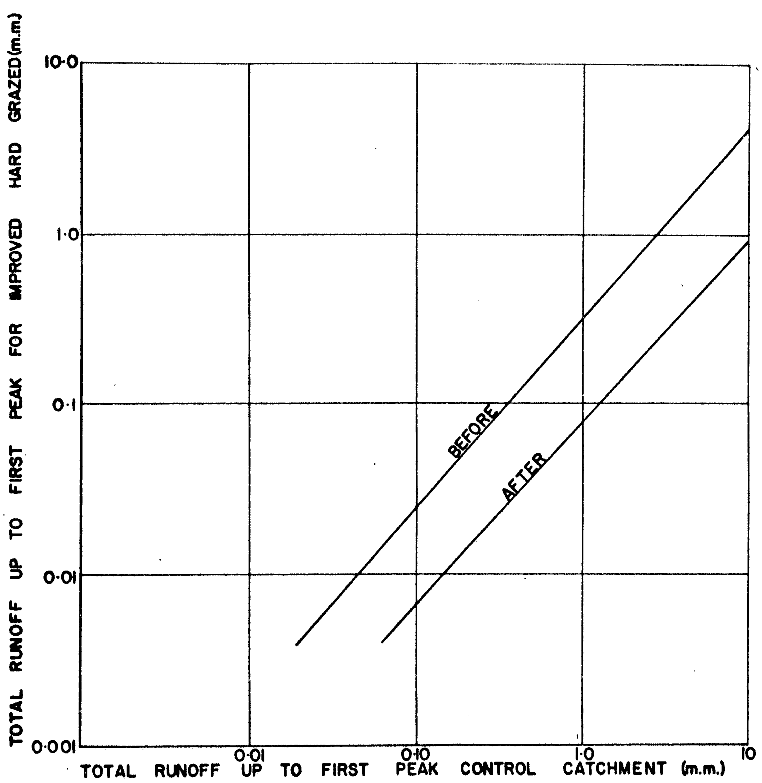

Figure 5

Flow before the first peak for improved hard-grazed and control catchments at Makara.

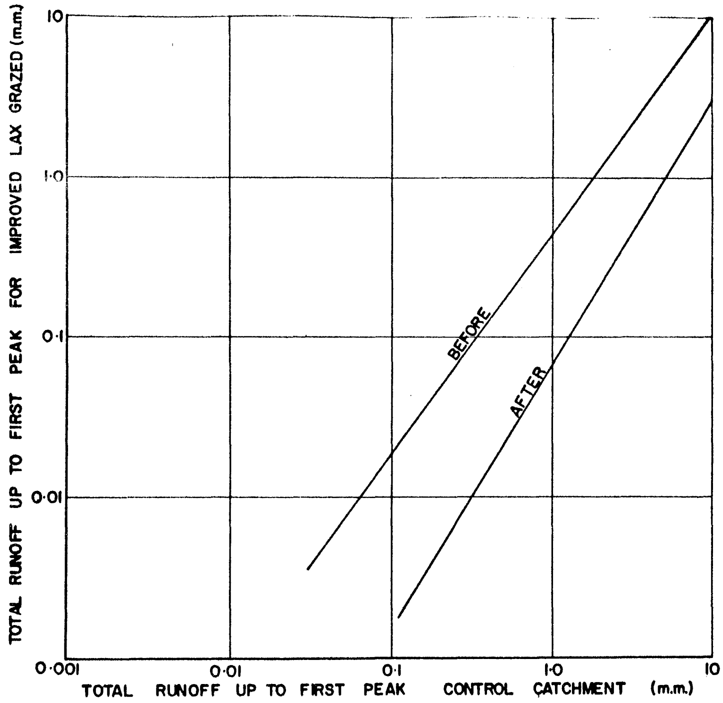

Figure 6

Flow before the first peak for improved lax-grazed and control catchments at Makara.

been modified by the changes in land management. Summarised they are:

(a) Makara: the control catchments and the lax-grazed unimproved pastures have not changed significantly (Figs 7 and 8). The most notable change has occurred with improvement of the cover by oversowing and topdressing. The surface detention has been significantly increased irrespective of whether or not the improved pasture is lax grazed (Figs 9 and 10). The change has, however, been greater when the improved pastures are hard-grazed, e.g. for a peak discharge of 1 mm the surface detention has increased under hard grazing from 0.33 mm to 0.70 mm (an increase of over 100%) and under lax grazing from 0.62 mm to 0.83 mm (an increase of 33%).

(b) Moutere: Significant differences have occurred with the different covers. The depth of surface detention for a given peak discharge was considerably and significantly less for cultivation than for gorse or pasture (Fig. 11). Rather unexpectedly, the gorse and pasture did not give significantly different results.

DISCUSSION

The double-mass and flow-distribution curves have shown that the improvement of pastures at Makara causes a reduction in flow from the catchments. There is evidence that the reduction is due to three major causes, namely, increase in infiltration capacity, an increase in infiltration opportunity, and an increase in initial abstractions.

Preliminary infiltration analyses have indicated that there is increased infiltration with the improvement and that it becomes slightly higher still when the improved swards are lax-grazed.

The denser, improved swards provide a greater retardance to overland flow, the velocity of which is decreased. This in turn means there is an increase in the time of overland flow with a consequent increase in the time of infiltration opportunity. This is most clearly shown by

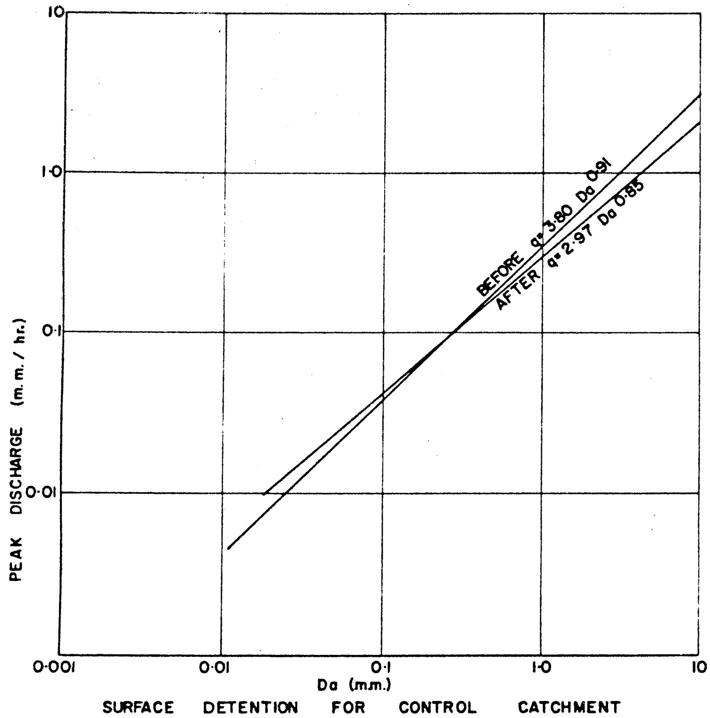

Figure 7

Surface detention for a control catchment at Makara.

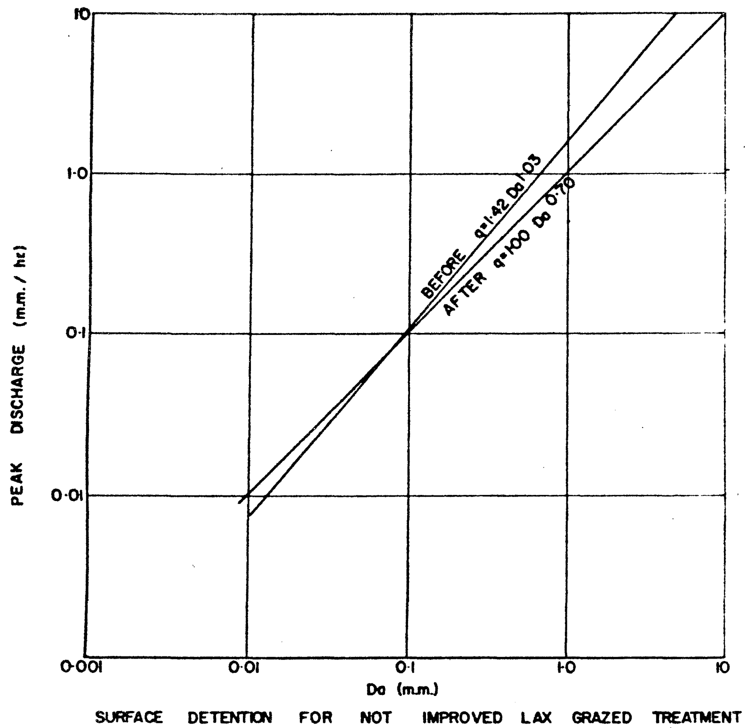

Figure 8

Surface detention for a not improved lax-grazed catchment at Makara.

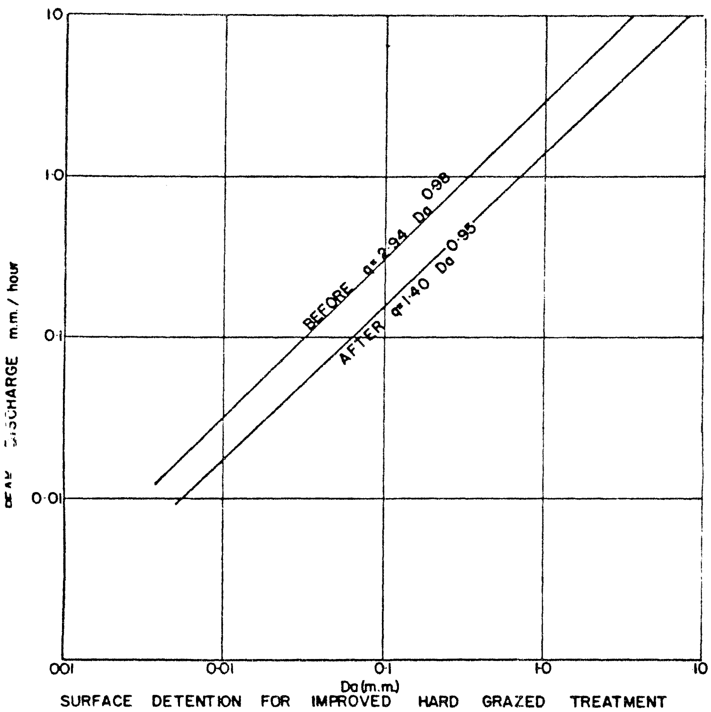

Figure 9

Surface detention for an improved hard-grazed catchment at Makara.

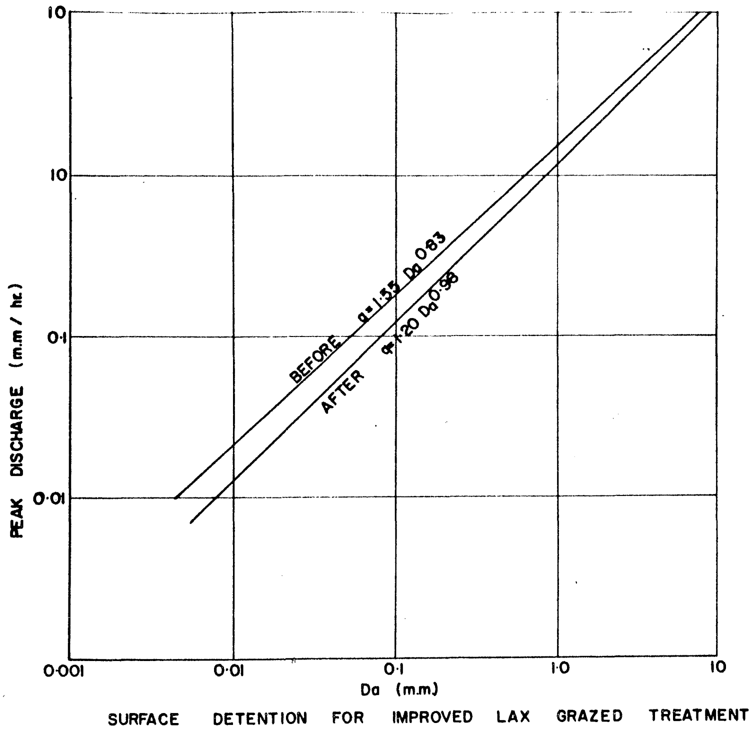

Figure 10

Surface detention for an improved lax-grazed catchment at Makara.

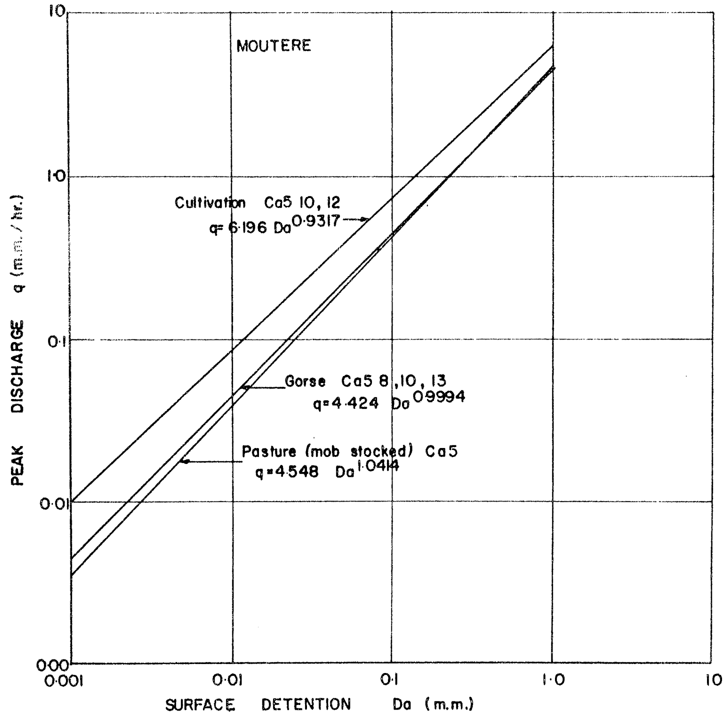

Figure 11

Surface detention for pasture, gorse and cultivation at Moutere.

comparing the Moutere treatments of gorse and cultivation. The gorse, which had a considerable litter layer, had an average duration time of overland flow after the peak of 25 minutes. Cultivation, with its consequent high proportion of bare ground, reduced this to 14 minutes.

The lax grazing of unimproved pastures has not changed the amount of flow a great deal. The change that has occurred is believed to be due to a higher initial abstraction by way of interception. These swards, although long, are open at the base and they do not have any more retardance value - as is evidenced by the insignificant change in surface detention - than do the hard-grazed unimproved swards.

The lax grazing of improved pastures has given the greatest reduction in total flow. The flow distribution has shown a reduction in the number of days on which runoff occurred. This reduction is due to the fact that small-type storms no longer produce runoff. The pastures are now abstracting at least the 12 mm of rainfall by interception (provided, of course, the vegetation is dry). This either reaches the soil surface more slowly or returns to the atmosphere by evaporation. As the surface-detention data indicate, changes in retardance have not been as great as with hard grazing of improved pastures. An explanation for this can be found in the observation that these lax-grazed pastures are somewhat more open at the base than are the hard-grazed swards. The sward is, however, more dense than the hard-grazed unimproved swards.

Experimental changes in the type of cover and its manipulation through changing the intensity of grazing have shown that it is possible to manipulate the nature of flow from small catchments. Because analysis of data from some facets of the hydrograph is not complete it is not yet possible to explain fully the flow responses to the changes in management.

These results have not proven conclusively the fate of precipitation on these catchments other than that less is going through the gauging site. It is hoped that more intensive soil-moisture measurement at Makara will make it possible to determine whether precipitation which no

longer goes from the catchment as surface flow is returning to the atmosphere by evapotranspiration or is contributing to either base flow or deep percolation.

ACKNOWLEDGEMENTS

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THE ROLE OF SMALL STRUCTURES FOR THE USE AND CONTROL OF WATER

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INTRODUCTION

So far in this Symposium the methods for controlling and conserving water have been limited to manipulations of plants and soils. Tomorrow we will hear of major down-stream engineering schemes which are more usually concerned with water control.

This paper attempts to show that there are very real opportunities for the upstream control and conservation of water by a variety of small engineering structures and tillage practices.

Although the primary benefit from these structures is higher agriculture production and profitability, they have important downstream benefits and as such they form a bridge between the activities of the soil conservator and those of the river engineer.

WHAT ARE SMALL STRUCTURES

Small structures can be described as being man-made constructions, used on farm lands. They are made by the farmer for the control and retention of water and the successful use of these results in a wider benefit to the catchment and community as a whole.

The prime purpose of a small structure is to hold, collect, or direct surplus water. There are two main groups of structures which are widely used and which function at:

(a) ground level

(b) below ground level

Table 1

Some small structures

FARM STRUCTURES AT GROUND LEVEL

Name of Structure	Soil Type	Type of Coverage	Cost Acre Per Chain	Use: Irrigation	Use: Drainage	Use: Conservation	Advantages	Disadvantages	Life Expectancy
Corrugation Contour	Low Permeability	Dense	Upwards to $5 per acre	Excellent - turn an undulating paddock into a flat one	Nil	Excellent	Cheap	Limited on steep slopes	On low grade slopes permanent
Graded Corrugations	Low permeability	Dense	Upwards to $5 per acre	Excellent - keeps water to ridge	Nil	Excellent	Cheap	Limited on steep slopes	Permanent if grades are lower than 1 in 15
Pasture Furrows Graded Banks	Low Permeability	Moderate at 20' to 100'	$1 1 to 15 chains	Excellent	Excellent	Excellent	Cheap	Maintenance high. Hinders surface workings	5 to 10 years
Grass Waterways or Elevated Drains	All soils high and low permeability	1% to 5% of ground coverage	$1 1 to 4 chains	Excellent Border Dykes	Excellent	Excellent	Can be summer grazed when tile line included	Cannot be ploughed	Permanent
Dams or Ponds	Low Permeability Soils	Limited depending on land gradient	Depending on Site Formation	Storage of water	Nil	Flood retention	If water 4' deep or greater retains fresh water	Requires fending	Built to normal engineering standard, permanent
FARM STRUCTURES UNDER GROUND LEVEL									
Mole Drainage Closed Blade Slit	Clay loam or compacted silt	Dense	$6 per acre	Nil	Excellent	Not generally used	Low cost permits full utilisation of crops	Nil	Permanent if conditions suitable
Mole Drainage Open Blade Slit	Clay loam or compacted silt	Dense	$6 per acre	Nil	Excellent	Not generally used	Low cost permits full utilisation	Increases runoff discharge	Permanent if conditions suitable
Tile Drains	Any soils use fibreglass filter in sands	Spacing depends on permeability	$10 for 4" tile laid 100' $14 for 5" tile laid 100' $19 for 6" tile laid at 2.5' deep/100'	Requires treatment to prevent blockage by plant roots	Excellent	Not in general use	Low maintenance costs	Nil	Permanent
Open Drains or V Drains	Any soil	Spacing depends on permeability	$1 to $8 per chain depending on capacity	Water may require pumping unless for subsurface irrigation	Excellent	Excellent	Cheap	Requires fencing and maintenance	Permanent
Wells				Water storage and supply	Can be excellent	Could be used for recharging ground water seepage retention dams	Can be combined with surface dam structure	Nil. Water may require treatment for hard water saline	Permanent

Each of these two broad groups are made up of four structures given in order of their decreasing ground coverage and in order of their ability to deal with increasing amounts of water. The four structures at ground level are:

Corrugations, pasture furrows, grass waterways and dams.

The four structures below ground level, given in the same order are:

Mole channels, tile drains, open drains and wells.

The tile drains are used for seepage drainage in silt soils, or as terminal outfalls for mole channels in clay soils. Open drains take up limited ground, and are designed to carry and direct surplus water. Wells are very useful for underground storage and when a permeable stratum has been reached they are useful points to return drainage water in order to recharge underground supplies.

THE TYPE OF SMALL STRUCTURE

The type of small structure to be used for any given situation will be determined by a number of factors such as soil type and its permeability, the climate and rainfall, site aspects and locality and the type of farming that is to be carried out (i.e. animal grazing, cropping, horticulture etc.). Once the decision has been made to install any or several of the structures, it is essential that they are installed efficiently so that they will function adequately.

MOLE AND TILE DRAINAGE

Mole and tile drainage could have a more important place if it were recognised as a valuable land treatment technique. For all too long there has been too much woolly thinking about the nature of mole drainage. There is a body of opinion which has considered that the installation of tiles and moles, coupled with fertility increases, will adversely affect the normal drainage pattern. The view is that peak discharges will increase, due to more rapid movement of water by the drainage system. This may have

been true when the old mole plough was used many years ago but with the modern mole plough, which does not leave an open blade slit, the rate of discharge is slower.

In order to reduce and slow runoff still further there is the opportunity of discharging drainage water into seepage wells. Another method of reducing rates of discharge is to locate tile drains on the dry ridges and then mole drain at reduced gradients, from the wet hollows round to dry ridges, and tile outfall.

As soon as all those who are concerned with the use and control of water understand what modern techniques of mole and tile drainage can do to smooth out drainage patterns and flows, the sooner the proper integration of the whole of the watershed's management will be achieved. Only when this integration is achieved will there be a complete and effective national and individual water control within many of our catchments.

RETENTION DAMS

These have not been exploited on our farmland, and there is considerable scope to develop a low cost, temporary storage barrage dam constructed on paddock and pasture sites. These dams would be constructed by making a low soil retaining wall across a valley floor. Or the walls could be constructed on the lower sides of a paddock to give temporary storage for two or three days. This type of dam would be of limited depth and extensive area and its capacity related to the catchment area.

If such pondage areas did have either natural or installed under-drainage, there is no reason why the ponding area could not be used for crops and pastures.

THE INTEGRATED EFFECT OF SMALL STRUCTURES

Mr Ian Roy's farm of 530 acres is on a clay soil within a 35" to 40" rainfall and is an example of the use and integration of small structures. Over an eight year period he has installed a total of 140,000 feet of tiles and completely mole drained the whole farm. Other small

structures included in the development programme are dams, and the tapping of springs for water supply. These have been most worthwhile and a profitable farm development, but more important, have demonstrated a valuable off-site effect.

From the farmer's point of view this has allowed the ability to grow wheat over all the farm with an assured yield of 80 bushels, compared to a probable 40 bushels eight years previously. The present carrying capacity has risen from 1,000 ewes to 3,000 ewes.

An interesting farm management aspect of this drainage is Mr Roy's practice to "lock" the main ewe flock continuously on swedes and kale over the winter. This practice would have been impossible a few years ago.

In the opinion of Mr Roy and his neighbours, the changes of the drainage flow pattern have pointed the way to the opportunities for assisting the drainage problems of much of South Otago. Not only has the stream flow pattern been smoothed out but the flow continued right through the summer of 1968-69, which was a particularly dry summer in South Otago. The local experience is that this would not have occurred prior to 1960. Another factor is the lack of sediment in the drainage water, even after continuous and prolonged rain.

STRUCTURES FOR PUTTING WATER TO WORK

In New Zealand over the past two or three decades a considerable amount of money has been spent in river control work but a comparatively small amount has been spent upstream. As the most critical downstream problems are attended to, it becomes important to devote more money to the upstream area. It may well be that the present ratio of expenditure of 85% to 15% could be altered to something like a 50% - 50% which may result in a significant drop in the total annual cost of water control. In a great many cases it is probable that the expenditure of a comparatively small amount of money in the headwaters will result in the saving of large sums of money in downstream works.

As an example of this I would quote the situation in the headwaters of the Owaka and Puerua streams. Here two farmers are combining in a drainage scheme on a peat swamp.

The drainage of this peat swamp goes down the Puerua stream, which in the lower reaches becomes part of the Clutha flood protection scheme. Included in the latter is the re-location of part of the Puerua stream and associated protection banks and this promises to be a major construction. It is estimated that the peak flow from the swamp could come to 160 cusecs and it would seem to be to the advantage of the farmers to divert this flow, not only to meet the requirements of the two farmers, but to divert the flow to the safe out-fall of the Owaka Stream.

A further development for the two farmers would be to make use of the estimated three cusec summer flow from the above diversion and lead this water by special water race to a convenient site, where there is a 240' drop, and here establish a 50 h.p. generating station. This type of development would be putting water to work, and the power yielded could be used for a hay drying plant.

CONCLUSION

Whilst the main interest of the farmer will be in the maintenance of an economic farming enterprise, he may be able to include in any water resource development which his farm requires, measures which will aid in a downstream benefit. It is, therefore, of the greatest importance that the community realise the real opportunities for the on-site control and use of water which do exist on our farms so that in the future the farmer may be given adequate recognition and assistance to achieve these objectives.

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