

WATERSHED MANAGEMENT
IN
NEW ZEALAND

Status and Research Needs

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Special Publication No. 4 of the
TUSSOCK GRASSLANDS
AND MOUNTAIN LANDS
INSTITUTE

1965

FOREWORD

From August 1964 until June 1965 Dr R. E. Dils, Professor of Watershed Management at Colorado State University, Fort Collins, Colorado, U.S.A., was attached to this Institute as a Fulbright Research Scholar.

Dr Dils travelled widely in New Zealand, particularly in the tussock grasslands and mountain lands, and on 27 May 1965, presented a report to the Committee of Management of the Institute. The Committee considered that the report was vitally important at a time when consideration is being given to changes in the administration of soil conservation and rivers control. Accordingly it arranged for immediate publication for wide circulation to interested organisations and individuals.

At the same time it should be understood that the Committee of Management does not necessarily concur with all the views expressed.

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WATERSHED MANAGEMENT IN NEW ZEALAND — STATUS AND RESEARCH NEEDS

ROBERT E. DILS

INTRODUCTION

Nature has endowed New Zealand with unique geologic, climatic, and biotic conditions. Her volcanic cones and majestic Southern Alps and her verdant plains and rolling hills provide a landscape as rugged and beautiful as will be found anywhere. Her indigenous fauna and flora are often quite different from that of the rest of the world and consequently have been of widespread interest to biologists everywhere. Her geologic youth and structure and her island climate, in combination with the biological resources, have made a land which is ecologically on edge. These natural endowments along with the manner in which she has utilized her land, have given New Zealand some of the most spectacular and rapid erosion to be found.

It is quite evident that geologic and climatic conditions combine to give unusually high rates of natural erosion. Present topographic features indicate the past occurrence of large-scale flooding as well. Prior to the arrival of the Maori, it is very likely that most of the land mass of New Zealand below present bushlines was covered with indigenous bush or forest. Forest fires of a catastrophic nature undoubtedly occurred as a result of lightning, and volcanic eruptions. The exposed soils left by these catastrophies contributed to natural deterioration. While vast areas of forest cover were destroyed, they probably were healed by nature with forest or with grass or herbaceous cover. Further, it is probable that large areas in the mountains were, as they are now, subject to landslides and slipping due to earthquakes and excessive local rainfall. Again, the healing process was probably rapid in most of such exposed areas.

With the coming of the Maori, accelerated erosion undoubtedly occurred. The Maori used fire for land clearing and to facilitate the capture of the moa. Again, large areas of bush were destroyed and, lacking suitable conditions and seed sources, and perhaps due to climatic change, former areas of bush became tussock grassland. The high rainfall and attendant floods occurring during this era contributed materially to the formation of many scree slopes, to the enlargement of alluvial fans, and to the aggradation of river channels.

The advent of the Europeans marked a new era in land use and in the erosion cycle. The tussock country proved to be outstanding pasture land. To make way for ever-increasing numbers of sheep, and, later, cattle as well, vast areas of bush and tussock country were burned and converted to grassland even in steep mountainous country. The farm

and pasture lands of the more fertile plains and hill country, along with the high-country sheep runs contributed immeasurably to the building of the nation.

In coming to New Zealand, the European found little in the way of familiar flora and fauna. For various reasons, many different forms of wildlife, domestic animals, and plants were introduced. Unwittingly this opened a Pandora's Box. Some of the introduced species such as the rabbit and deer, and later the thar, chamois, and opossum, found New Zealand much to their liking. Finding abundant food and lacking natural environmental controls such as predators, disease, competitors and climatic extremes which held them in balance in their native habitats, these animals increased in numbers almost astronomically. Rabbits soon became serious competitors with sheep. They literally "ate themselves out of house and home," causing untold damage due to removal of vegetation and the disturbance and compaction of the soil. Only within the last two decades has the rabbit been brought under control and has damage by deer been materially reduced in some areas. Similarly, some of the introduced plants have proved to be pests whose control and eradication is of extreme concern to the agricultural community. Such species as gorse, broom and sweetbrier have invaded and spread to the point where they now render thousands of acres of potential agricultural land unproductive.

There is no question that induced or accelerated erosion has increased materially in both area and rate since European occupancy. The East Coast mudstone country, the volcanic pumice lands of North Island, and the eastern slopes of the Southern Alps in South Island offer mute testimony to progressive denudation.

New Zealand has justifiably received worldwide plaudits on her treatment of and resultant agricultural production from her fertile plains and rolling hills. Similarly, the growth rates achieved and the production and management of her exotic forests have merited the attention of the professional foresters of the world. Paradoxically, though, the use and condition of her steep lands and sensitive hill country have been termed "shocking" by land-use experts in many fields and from many countries. Her own specialists have substantiated these opinions. Many New Zealanders are well aware of their serious erosion and attendant catchment problems, and of the consequences of continued abuse. Unfortunately, government organization, cooperation and/or policy have been poorly defined or absent, public awareness and acceptance of the problem have been inadequate, and action programmes to alleviate and improve catchment conditions and to prevent further deterioration are progressing with painful slowness or are still in a state of "lip service."

While New Zealand has generally been well-endowed with water resources she will, as have other nations, be faced with an ever-growing scarcity of water. Increasing agricultural production in some areas will be dependent upon the development of irrigation water. Her increasing population and growing industry will demand more and more high-

quality water for all purposes. Water shortages have already necessitated periodic reductions in power consumption. The various demands for water are not always compatible and competition for the available supply is inevitable. Planning for water-resource allocation should be initiated immediately—before competition becomes acute and present allocations irrevocable.

History has recorded the downfall of civilizations and the decline of nations as a result of land abuse or poor land husbandry. Man's use of land has been shown to have a marked effect upon soil and water resources. The removal of forests and the subsequent compaction of soil by grazing animals usually effects a marked alteration in streamflow. Under such conditions more runoff will appear as surface or overland flow, thus increasing erosion and flooding and necessitating larger reservoirs to contain water for man's use. Invariably, the water will be of poorer quality.

Conversely, the maintenance of a good vegetative cover promotes soil conditions which reduce overland flow, erosion and lower flood peaks. Streamflow from a good bush-clad catchment usually exhibits lower peaks and higher minimum flows than that from barren or abused watersheds. While the timing and quality of streamflow is thus improved, the total yield will normally be less due to increased interception and transpiration. It is unlikely that a forested catchment will materially reduce the peak of any *one* major flood; however, the protective cover it provides does aid significantly in reducing erosion and in cutting down the amount of debris available for transport and deposition by flood waters. Thus, over a period of time, the removal of bush and the deterioration of vegetation, followed by erosion, may in fact, bring about a marked increase in both flood peaks and flood frequencies. There is visual evidence that this is now occurring in New Zealand.

Catchment problems are usually of four inter-related types: maintaining or increasing water yields, maintaining or improving water quality, maintaining or improving the timing of streamflow, and providing protection from erosion and flooding. The principal catchment problems in New Zealand at present are centred on erosion and flood control. Problems in the other three areas are occurring locally and with increasing population and development, will become intensified.

Aggressive action has been taken and is now under way in downstream flood control in New Zealand. Unfortunately, very little control has been accomplished in upstream areas—the real source area of New Zealand's flood and erosion problems. Among several explanations, the absence of research information has been indicated as a reason for the lack of an equally aggressive upstream control programme. It has often been said that "to rule the mountain is to rule the river." The following analysis suggests a research programme in watershed management and watershed hydrology which may help New Zealand to control her mountains, to rule her rivers, and to protect her physical, economic and human resources.

CATCHMENT CONDITIONS

New Zealand consists primarily of two elongated islands extending some 1000 miles from 34° 4' to 47° 2' South latitude. Except for the Canterbury Plains, much of its 100,000 square miles of land mass is in rolling hills and mountains. In South Island 36 per cent of the land is situated above 3000 feet. The highest point in North Island is Mt. Ruapehu at 9,175 feet while Mt. Cook in South Island rises to 12,349 feet.

The principal geologic features of South Island are the Southern Alps, a chain of Permo-Jurassic greywacke mountains, the Canterbury Plains, Pleistocene gravels, localised areas of Paleozoic schists and gneisses, and limited pockets of limestone. Dominating the geology of North Island are the volcanic cones, the central volcanic plateau, and areas of late Cretaceous-Tertiary marine sediments, as well as the same, but lower greywacke mountains. The greywacke rocks are commonly weakly structured and deeply weathered. The surface veneers of recent volcanic showers are poorly consolidated and often the marine deposits contain high amounts of bentonite clay which has contributed to extensive slipping.

New Zealand possesses a diverse climate with, in most areas, abundant rainfall which is usually well distributed throughout the year. Annual precipitation ranges from a low of 330 mm (13 inches) in Alexandra up to at least 10,000 mm (400 inches) in the Upper Hokitika Catchment (Toebe, 1965). Much of the western slopes of the Southern Alps receives from 200 to 400 inches of precipitation per year, and falls of over 100 inches per year are common in the higher portion of the East Coast country of North Island. Above elevations of 5000 feet in South Island, a substantial portion of the precipitation occurs in the form of snow. Timberline or bushline occurs at roughly 4000 feet elevation. While temperature ranges are not extreme, much of the higher land is subject to frequent freezing and thawing cycles and all of New Zealand is subject to periodic earthquake activity. For the most part the soils are skeletal and immature and in many areas they have been materially altered through land use.

All these factors have contributed to an unusually high rate of geologic erosion. The extensive development of alluvial fans, the aggradation of shingle in stream channels, and the deposits of Pleistocene gravels attest to such geologic erosion and to the fact that floods of a catastrophic nature must have occurred to move this material.

The history of European occupancy dates back to about 1840. Various estimates note that at this time from 50 to 60 per cent of the land was mantled with indigenous forest and approximately 40 per cent was covered with a relatively dense sward of tussock grass. Settlement gave rise to rapid agricultural development in which large areas of bush were removed, largely by burning, and the tussock country was frequently

fired to induce grass growth. Present estimates indicate that approximately 20 per cent of New Zealand remains in native forest and 20 per cent is yet in tussock grassland. The plains and downland have been developed into cultivated farm and sod-covered paddocks. Much of the intermontane valley and rolling hill country has also been successfully developed into highly productive grasslands. Some areas of flatlands such as the Mackenzie Plains, remain essentially undeveloped. Attempts to develop some areas of rolling country and more gently sloping mountainous lands have been abortive due to the invasion and spread of native and exotic plants such as fern, manuka, gorse, broom, and sweetbrier. While much of this land has been stabilized by these covers, it remains unproductive.

Serious difficulties were encountered in areas of unstable geologic formations and in much of the high country. The denudation of and the cover reduction on the native bush and tussock country, and the introduction of grazing animals, both domestic and wild, exposed the soil to intense frost action, consolidation and compaction, causing "erosion and flood problems of gigantic proportions" (Toebes, 1965).

The introduction of exotic animals (including the sheep when its habitat is in the unstable high country) has exacted a heavy toll in New Zealand's monetary and natural resources. The country is well aware of the damage occasioned by rabbits and of the cost of their control. Large-scale efforts to control the deer, chamois, thar, opossum, feral pigs and goats are presently under way. The introduction and spread of these animals has unquestionably aggravated erosion and flooding.

In surveying some 15,600 square miles of South Island, Gibbs et al (1945) estimated that 80 per cent of the surveyed area was significantly eroded and that 25 per cent of this area had less than 50 per cent of its topsoil left. In a survey of 24,000 square miles in North Island, Grange and Gibbs (1948) noted that 65 per cent of the land had been eroded to the point that soil conservation measures were required. Describing the magnitude of soil losses, Toebes (1965) gave the average annual suspended sediment measured on the Waipaoa River as 15 million tons—derived from a catchment area of 603 square miles. The recorded discharge for 1960 was actually double this amount.

Visits throughout the country, consultations with runholders, land-use specialists, and scientists, and an examination of photographic and written evidence, underline the fact that accelerated erosion is occurring throughout much of New Zealand. On the basis of the size of areas involved and the severity of the problems, the research recommendations herein are based primarily upon the conditions which obtain in the unstable greywacke country of the east slopes of the Southern Alps (exemplified by the upper Waimakariri) and the mudstone-argillite East Coast and central volcanic plateau areas of North Island. Many of these recommendations, however, will apply equally to other problem areas.

RESEARCH NEEDS

While some research has been conducted in catchment management and in peripheral fields, very little effort has been directed to studies of watershed behaviour and hydrology, particularly to management in the critical problem areas. The unique geologic, climatic and biotic conditions in New Zealand often preclude the direct application of results of research in other countries. Research is urgently needed to quantitatively assess New Zealand's striking conditions, to aid in delineating land-use policy, and to prescribe remedial action for severely-eroding and flood-source areas.

Research is a continuing task and, as solutions are found to some problems, increasing challenging questions and problems arise. With respect to South Island conditions the statement by Ellison (1957) is particularly apt:

"If one must wait until all the research results are in, and only then bring public opinion to bear, I think the eastern slopes of the New Zealand Alps will be without any soil at all."

While watershed research is urgently needed, it should not be considered as an excuse for lack of action or as a prerequisite to it—research, action and education should here proceed concurrently.

Watershed management problems are usually extremely complex, involving physical, biological and social problems simultaneously. Their solutions often involve specialized research in ecology, soil science, geology, forestry, hydrology, meteorology and engineering among the physical and biological sciences, and economics, sociology, law and political science among the social sciences. While some aspects of watershed research will continue to be investigated by such specialists working individually, solutions to many of the problems will require the coordinated effort of a team. Team research has obvious drawbacks. Experience, however, has shown that cooperative research can be effective even when it requires the cross-fertilization of specialties and the joining together of administrative departments in a common effort.

The suggestions herein have for the most part been stated previously. They are not intended to be all-inclusive: in fact, they are directed largely to the watershed problems as they presently appear. No effort is made to assess all the specific research needs which impinge upon New Zealand catchment management such as animal or plant genetics, ecology of exotic wildlife, geophysics, channel hydraulics, flow through porous media, and engineering structures designed for downstream flood protection. Similarly, no attempt has been made to include what might be considered largely basic research such as investigating the mode of uptake of water by vegetation. While such research is certainly valuable and applies directly and indirectly to watershed management, attention here has been directed to New Zealand's more immediate and serious watershed problems.

As a basis for these recommendations, it is assumed that erosion

problems are serious, often extreme, flood potential is unduly high, that certain changes in land use and the treatment of problem areas can effect an improvement, and that such improvement is in the national interest.

Personal observation and the observations of experienced specialists from many fields and from many lands have attested to the seriousness of New Zealand's catchment problems. The consensus of land-use specialists from both within and outside New Zealand, is that much of the South Island high country problem area lands should be retired from any intensive use. This involves virtually all the high country which would ordinarily be classified as Class VIII land, as well as that Class VII land which is already severely eroded or on the move. The optimum use of this type of land would be for watershed protection (erosion and flood control and orderly, high-quality water production) and recreation. Within this area are pockets of land that might safely be grazed; however, the intensive management and fencing or shepherding that would be necessary may render such use uneconomic.

On the more stable of the steep lands (the better Class VII lands) judicious grazing use could be continued. From the grazier's standpoint the most important of these areas are the north-facing or sunny slopes which he badly needs for winter use. Unfortunately, it is usually these same areas which are, or have been, most prone to erode—by virtue of climate, soil and vegetation development, and due to the fact that they have been commonly abused by burning and overuse. Consequently, the continued use of such land will necessarily be conditioned by expensive treatment and management, often involving oversowing and topdressing and careful control of grazing intensity and timing. Unfortunately, too, this type of land is frequently invaded by weed species which are difficult to control. The commonly advocated burning and "heavy hammering" to keep down weeds could not long be tolerated on this type of landscape.

In many cases, erosion has proceeded to the point where the sunny faces should now be taken completely out of production—or at least spelled until recovery. To do this will require the cultivation of lower land to produce winter feed—an added cost in run economics, or a reduction in flock size—which may reduce the runholder's net income. Since the control of erosion and floods, as well as the preservation of public resources, are decidedly in the national interest, some form of cost sharing or subsidy is warranted to aid in land-use and run readjustments. In extreme cases, and recommended only as a last resort, it may be in the public interest to purchase the leases, or even stations, in order to make necessary land-use adjustment.

In many cases it is felt that the production loss to the runholder and certainly to the public, can more than be made up by more intensive development and management of the more gentle slopes, fans, and intermontane valleys. More intensive management will include additional paddock subdivision, fencing, paddock improvement (oversowing) and fertilizing (topdressing), increasing use of cattle in preference to sheep,

and the cultivation of winter feed—practices now very effectively employed on many plains and foothill runs. More serious consideration is warranted, too, in the development of irrigation water to increase agricultural production.

The problems of the central volcanic plateau of North Island are somewhat different from those of the high country. Here, thousands of acres are being converted from bush, scrub and fern-covered land to developed grasslands, often apparently without regard for soil conditions, topography and erosion hazard. The formerly loosely-consolidated volcanic soils are soon compacted following cultivation and grazing. Early heavy grazing has been used to expedite the control of second growth fern and shrub. Commonly too, swamp and bog areas are drained to make way for a few more acres of grassland. All these conditions have contributed to what Thomson (1965) has termed "catchment explosion." A pilot investigation of infiltration rates by Nordbye and Campbell (1951) indicated declines as great as from 7 to .1 inches per hour of infiltration after conversion from fern to hard-grazed pasture. Surface runoff has obviously increased materially, a new cycle of erosion has been set in motion, access to some farm areas has been cut off by deep gullies, increasingly large areas of this recently developed land are going out of production each year, and hydro-power and recreation interests are expressing alarm at the additional load of sediment being poured into such rivers as the Waikato.

The high productivity of these lands indicates the desirability of their development. However, in future planning, the steep hillsides and more sensitive sloping lands should remain in bush. Where clearing has already created problems critical areas should be planted to exotic forests. Natural drainages and waterways should likewise be afforded a good protective vegetative cover and should be fenced. Swamp areas should be retained to store some of the excess of precipitation. Further, it may prove desirable to leave belts of bush or to introduce bands of exotic forest to reduce overland flow and to absorb excess water. Future development of these lands should be tempered with caution and should proceed only after the preparation of conservation farm plans.

The third area of major concern consists of the East Coast mudstone-argillite lands north and west of Gisborne. Most of these lands have been developed since 1900 and again, the erosion here is severe. This problem area has been described by Campbell (1946) in his very appropriately titled "Down to the Sea in Slips." The high content of bentonite clays in the soils and the high amounts of precipitation to the area, coupled with the decay of the former soil-binding root systems of the native bush make these soils extremely susceptible to slipping and sliding.

Large portions of this country are on the move and it appears that the best land use for much of the area would be production forestry. Where agricultural pursuits are continued they must be practised conservatively. Even if the entire area were returned to bush or planted to

exotic forest, slipping would undoubtedly continue; however, it should be much reduced. The new Mangatu State Forest within this area should serve well to demonstrate both the effects of tree planting on erosion, and the potential of this land for production forestry.

Finally, a realistic assessment should be made of probable long-term export possibilities for New Zealand. Such an assessment could have a decided impact on future land-use decisions. It very conceivably could be that from an economic and public interest standpoint, the best land use on most of these problem areas is in fact production forestry. The growth potential for exotic forests appears very high by world standards. Further, there appears to be a continuing increase in the world demand for timber products, and for pulp and fibre. The use of these lands for forestry purposes would undoubtedly provide the most efficient mode of erosion and flood control and, in the long run, would entail the least expenditure of public funds in catchment management and control.

The writer is aware of the physical, social, economic, and political consequences of the land use changes discussed and the difficulty in effecting them. Similar problems have been faced and solved in other lands as they must be in New Zealand. There are no easy solutions and each year of delay in realistically facing up to the situation makes the task infinitely more difficult. Moreover, unless remedial action is initiated soon, the ultimate cost to New Zealand may far exceed the cost of treatment now.

The writer is also mindful of the fact that monetary and manpower resources that might be diverted to the needed research are limited and that it is impossible and impractical to initiate research in all the suggested areas at once. No order of priority is attached to the list of research needs; however, high priorities are obvious in some cases. It is felt that all the listed research is significant and that portions of it will be initiated as resources, manpower, scientific interests, and research organization permit. Because of the seriousness and extent of catchment problems and the paucity of quantitative research data available to guide solutions, a major effort is needed as soon as possible.

Based upon this analysis of New Zealand's catchment problems and the assumptions above, the following research recommendations are made.

1. QUANTITATIVE ASSESSMENT OF RATES AND EXTENT OF EROSION

New Zealand literature is replete with qualitative statements and analyses of her erosion. The visual evidence alone in the problem areas is sufficient to cause deep concern and to merit immediate remedial action. Research however, is urged to give guidelines to corrective programmes and to provide answers to the often conflicting and acrimonious testimony regarding the severity, rate and cause of erosion.

Periodic measurements (at selected intervals and/or following significant storm events) to measure soil loss, movement, and deposition

should be made under a variety of landscape, land-use and cover conditions. Land use should include non-use (or relatively undisturbed conditions) through light, moderate, and heavy grazing by both livestock (preferably sheep and cattle separately) and exotic wildlife. Cover conditions should include tussock grassland and subalpine scrub above bushline, and below that point, tussock grassland, native bush, exotic forest, and developed grasslands. Further, consideration should be given to varying landscape features such as elevation, slope and aspect. In addition to actively eroding sites, stable slopes and apparently stabilizing slopes and scree should be studied to ascertain conditions under which stability obtains and to aid in separating geologic from induced erosion.

All types of erosion measurements and analyses currently used (as well as new techniques which may be developed here) could be employed in such studies. These will include permanent datum stakes, gully surveying, measurements of alluvial and colluvial fans, aerial photographs, debris basins and troughs, and erosion indicators (such as erosion pavement measures, pedestals, spike and washer techniques, and paint bands about permanent features). Precipitation measurements should be made concurrently to permit an assessment of conditions under which erosion occurs. Where practical such measurements should be tied in with the experimental basin programme and as far as possible, standardized techniques should be employed.

2. RE-ESTABLISHMENT AND REINFORCEMENT OF VEGETATIVE COVERS

The most efficient and economic means of erosion and flood control in these problem areas appears to be the use of deep-rooted vegetation, preferably vegetation which provides a dense canopy cover and which produces large quantities of litter. Usually it is desirable to use native vegetation for such purposes. Because of the ecological weakness of New Zealand flora, more vigorous exotics along with suitable native species will be required on many areas.

Over large areas of the high country, protection from fire and grazing will permit natural recovery of a protective mantle of vegetation. Over other portions, particularly where present vegetation is thin or inadequate to hold the soil in place, and adjacent to more severely eroding areas, reinforcement or interplanting is desirable to speed up the recovery and to provide a seed source for natural recovery. Such treatment appears especially appropriate on exposed sunny faces where recovery could be rapid. While it is impractical to consider replanting all the already eroded country, certain critical areas should be rehabilitated as early as practicable to protect roads and developments and to arrest further wholesale soil movement. Revegetation in such areas will require the selection of species which can survive the rigorous soil and micro-climatic conditions of slip faces, gully slopes and scree fans. In some instances the assistance of mechanical treatments such as mulching and contour ditching may be required.

High priority research is recommended to determine treatment needs, to prescribe methods, and to measure recovery as noted:

(1) **Assessment of treatment needs**

An extensive survey of selected high-country areas is suggested in which site and erosion conditions will be analyzed from the standpoint of:

- (a) Areas which would likely recover without treatment other than protection.
- (b) Areas where limited reinforcement planting or seeding appear justified, and
- (c) Areas where revegetation and possibly mechanical rehabilitation appear warranted. Based upon this assessment, and the best information currently available, criteria for determining the need and type of remedial treatment should be prepared. As results from treatment experience and from research become available, these criteria should be altered accordingly.

(2) **Species introduction and methods of establishment**

Current research on species introduction and methods of establishment under high-country conditions should be continued and expanded. Several ecologists have expressed the opinion that it might be possible to increase the elevation of bushline by planting ecologically-strong exotic trees. If, on the basis of ecologic and climatic evidence, this appears possible, tests with selected species should be made. In this connection, as well as in planting on eroded sites, lodgepole pine (*Pinus contorta*) from North America has been suggested as a possibility. While fear has been expressed that the lodgepole pine might well become another "weed" it should nevertheless be tested. In its native habitat it grows under quite rigorous soil and climatic conditions. Its regeneration appears to require bare mineral soil suggesting that it may not invade good paddocks or grassland. Further tests on the practicability of seeding and/or planting native shrubs and grasses such as the snow tussock and cushion grass, should proceed along with that of promising exotics. Some of these tests should include the use of mechanical aids to establishment such as mulching.

In addition to investigations recommended on species introduction, growth rates of present plantations and wind-breaks of different species, on varying sites should be assessed to give indications of site requirements and production potential for early plantings.

(3) **Ecology of natural recovery**

As indicated above it will be necessary to rely upon natural recovery of much of the high country. Given protection from fire and grazing, native bush or forest appears to re-establish itself, albeit slowly, around present bush remnants. At the toe of some fans and at the side of some of the scree slopes native matagouri and tutu, and the exotic sweetbrier appear to colonize with some success. On other areas, where fire has been excluded, manuka often invades quite successfully—even

where sheet erosion has removed substantial amounts of surface soil. Observations at an enclosure in Starvation Gully (Waimakariri Basin) indicate that natural recovery of depleted grassland may be effected by the exclusion of fire and grazing.

Ecological studies, necessarily of a long-term nature, should be initiated or expanded to measure rates of recovery under varying conditions of cover, erosion, exposure, proximity to seed source and perhaps treatment. In the case of colonization by matagouri, sweetbrier and manuka, the question is posed, will native bush species, e.g. beech, invade following a period of site preparation by these early species? If so, how long a period of time intervenes? Could this process be accelerated by site treatment or planting? Observations, measurements, and treatments on permanent sample plots should provide valuable information in this regard.

3. ECONOMICS OF HIGH-COUNTRY LAND-USE

If, as recommended, the more sensitive high country lands are to be progressively retired from intensive use, and land-use readjustments made on much of the remaining steep land, high priority should be directed to studies of the impact of such changes both on station or run economics, and on national economics. A series of independent and/or related research efforts should give consideration to the following areas:

- (1) Assessment of present production from Class VIII and Class VII lands with production costs and returns, probably corresponding costs and returns to runs with Class VIII and eroding Class VII land out of production, and the cost and benefits of application of conservation measures necessary and/or desirable on remainder of the run.
- (2) Study of the increasing use of cattle in high-country agriculture with and without land use adjustments noted in (1) above.
- (3) Analysis of costs to runholders and costs to public of applying recommended conservation practices to readjusted runs under present subsidies (exclusive of treatments that might be recommended on retired lands). Particular attention should be directed to the determination of location, amount, and cost of fencing required for land retirement.
- (4) Cost studies of recommended treatment of critical areas on lands released by runholders under land-use readjustment (assumed to be borne by public).
- (5) Investigation of optimum flock size in relation to net income. It may be possible that present net income may be maintained even with smaller flocks where the resulting lower production figures are balanced against reductions in management costs (mustering etc.).
- (6.. Evaluation of possible cost-sharing arrangements with runholders willing to apply practices which actually reduce net run incomes but which are in the public interest.

- (7) Cost and benefit analysis of weed control (gorse, sweetbrier, broom, manuka, and matagouri) followed by good paddock development on presently infested lands.
- (8) Assessment of anticipated costs and returns from production forestry use on high-country lands. Due consideration should be given to the costs of establishment, treatment, and harvesting, and to the reduction of public expenditure for erosion and flood control. Consideration should be given to both long- and short-rotation species.

4. LAND-USE HYDROLOGY

Dense vegetative covers, especially forests, which provide a large mass of creeping, evaporating and transpiring surfaces, litter layers, and deep root penetration, have in other parts of the world been shown to have a decided influence on runoff, erosion, flooding and water yields. In general, forests tend to reduce erosion and sedimentation, reduce flood peaks and frequencies, delay the timing of peak flows, lower total water yields, and increase low flows. All these factors are quite significant in New Zealand. It is within the forest environment zone that watershed management offers the greatest promise.

Research of high priority should be initiated to evaluate the hydrologic impact of land use. A series of sites and experimental basins at different elevations and exposures and of varying conditions of cover and use should be selected for such evaluations. Research approaches will necessarily include gauged experimental catchments, replicated runoff plots, water-balance studies (soil-moisture, storage and depletion) and energy-balance, etc., investigations. Hydrologic comparisons should be made between native bush (grazed and ungrazed by exotic wildlife), exotic forest, tussock grassland (with varying grazing use/and or condition) improved grasslands, and severely depleted and eroded sites. Information from such studies is badly needed if realistic land use prescriptions are to be realized.

Initial effort will probably be restricted to the areas selected for the experimental basin programme. As additional resources and manpower become available and as early results from the experimental basin programme are analyzed, more experimental catchments will be needed. Runoff plot studies, water-balance studies and others should be correlated with the experimental basin programme.

(Note that runoff plot studies have recently been initiated at the Craigieburn Forest by the Forest and Range Experiment Station and at Cass by the Geography Department of the University of Canterbury. Further, the proposed experimental catchment in Broken River will provide valuable information in high-country hydrology.)

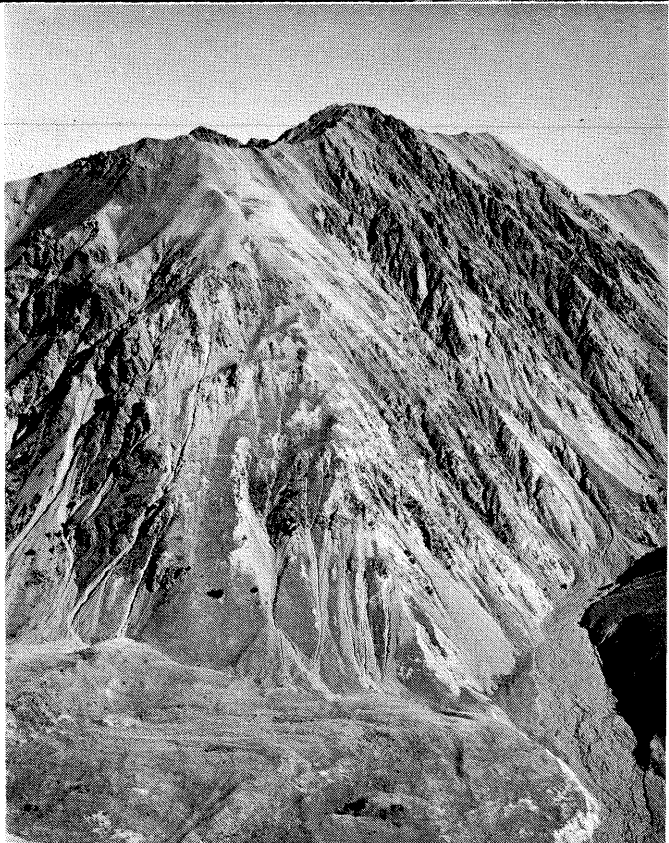
5. IMPACT OF EXOTIC WILDLIFE

Exotic wildlife including thar, chamois, deer, opossum and feral pigs and goats have unquestionably contributed to the deterioration of vegetation, to soil disturbance, and to accelerated erosion in the high country.



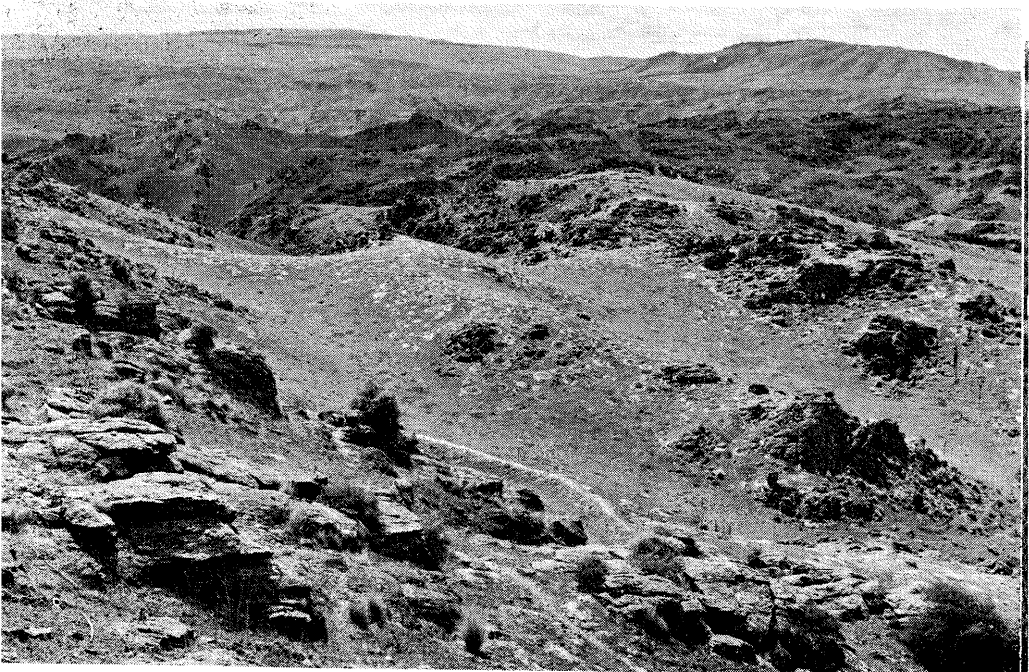
1. Protection forest of Mountain Beech on greywacke mountains at headwaters of Waimakariri River.

2. Steep shattered greywacke country, Canterbury. The original bush cover extended well up the slopes. The cumulative effects of bush removal, tussock fires, sheep grazing and deer browsing have resulted in soil erosion, and stream channels filled with debris.





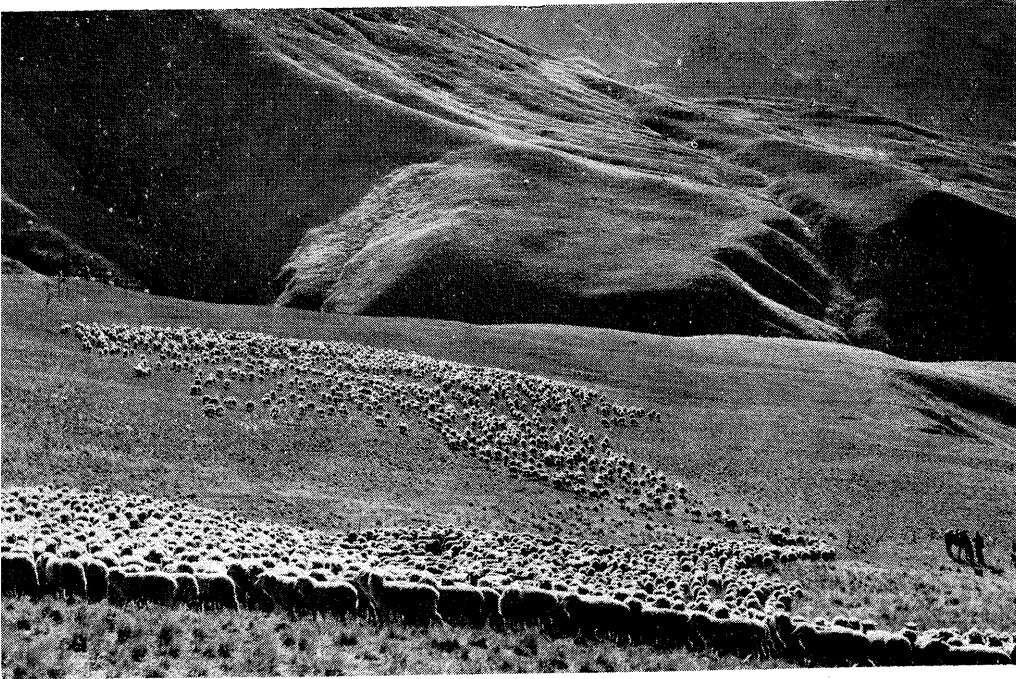
3. Bed of the Rakaia River showing the vast amounts of shingle brought down by South Island rivers from the greywacke mountains.



4. Schist upland country in Central Otago showing the near-desert conditions induced by burning, grazing and rabbits. With control of the rabbit, scabweed is slowly being replaced by volunteer native and introduced grasses.



5. Previously in scabweed as a result of rabbit infestation, this country on Molesworth is carrying a sole of cocksfoot and clover following on over-sowing and rotational grazing with cattle.



6. Mid-altitude tussock on schist in West Otago. With control of rabbits and good grazing management, soil erosion is at a minimum.



7. Stable fescue tussock in Southland at low and medium altitudes and suitable for improvement to carry increased stock. This will enable de-stocking of higher eroded country.



8. Fescue tussock in Canterbury at nearly 3,000 feet. Oversown with grass and clover and topdressed, it is leniently grazed to ensure retention of the tussock.



9. Noxious weeds, native and introduced, are a serious threat to tussock grassland in some areas. Here manuka is taking over in the Canterbury foothills. Burning, followed by heavy grazing, the only economic measure of control, would result in soil erosion and increased runoff.



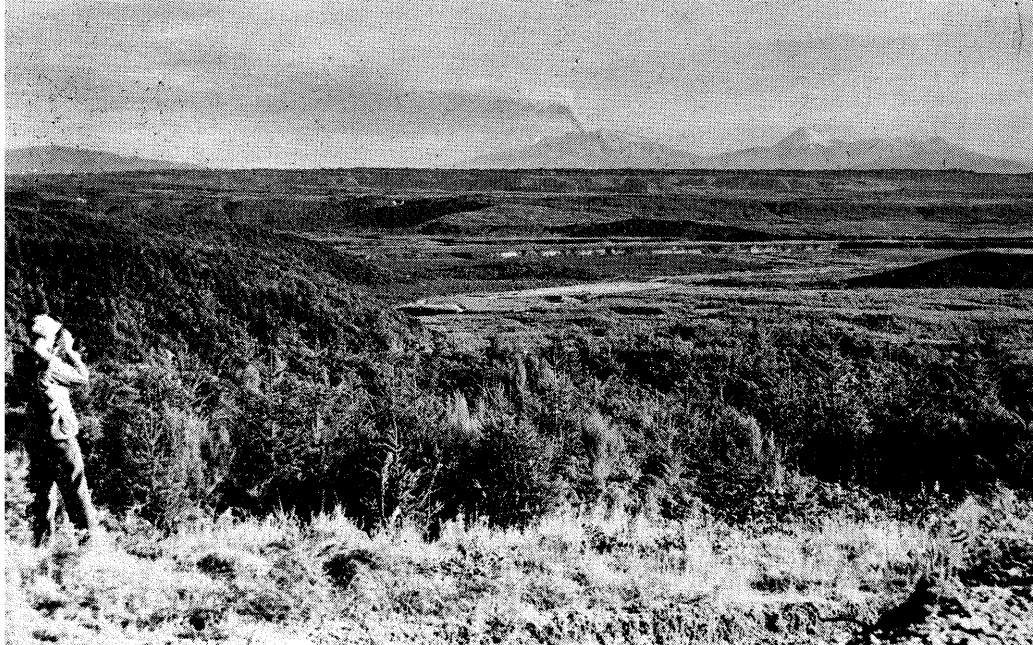
10. Heavy storms cause large-scale slipping in the Urewera forests on Tertiary mudstone. Concentrations of deer have depleted the undergrowth in these protection forests and aggravated soil erosion and flooding.



11. The Tarndale slip on the east coast of the North Island, the result of bush removal and land development on highly-sensitive mudstone-argillite soils. This country will be planted in exotic forests or allowed to revert to bush.

12. Slipping country in the southern half of the North Island may be stabilised and kept in occupation by spaced planting of willows and poplars.





13. Part of the pumice country in central North Island showing the type of land being developed for farming.



14. Clear felling in part of the Kaingaroa Forest of over 285,000 acres in the central pumice plateau.



15. South Island beech forest with undergrowth in good condition.



16. South Island beech forest showing the effects of a heavy population of deer.

The complete eradication of such animals appears to be impractical. Consequently, control programmes of poisoning and shooting will be necessary indefinitely. Investigations are recommended to measure the impact of these animals and to determine a reasonable level of control. Since the country occupied by these animals, especially the thar and chamois, is usually difficult of access, it appears that periodic surveys will be necessary to assess changes in cover, soils, and erosion. Vegetation surveys should include measurements of composition, density and condition as well as litter conditions. Studies should include soil exposure, soil compaction (utilizing a penetrometer) and possibly physical studies including bulk-density measures. Surface soil profiles, gully surveys and measurements of erosion indicators may all be employed. Periodic censusing and notation of concentration areas will be necessary to relate animal use to damage and to select study areas.

In connection with these investigations it is suggested that the understory vegetation and forest litter be removed from selected plots in relatively undisturbed indigenous forest. Erosion, soil characteristics and vegetative recovery should be assessed and comparisons made with similar plots where understory vegetation has been and is being depleted by exotic wildlife. Since the sample plots would be protected from further soil compaction and disturbance, such a comparison would provide more exact measurements of the damage done by these species.

6. BEDLOAD (SHINGLE) MOVEMENT IN STREAMS

One of the most striking landscape features in South Island, and in parts of the North Island as well, is the tremendous amount of shingle and debris carried by and deposited in streams. Conflicting views have been offered with respect to the source of this debris in the lower reaches of these rivers where major effort and expense in river control has been concentrated. Some claims indicate that the source of the material in the lower reaches of streams such as the Waimakariri is largely bank erosion. Others feel that most of the shingle is from the rapidly eroding high country. Both sources undoubtedly contribute to the problem. It is quite important however to attempt to determine what the relative proportions of each are. If, as suspected by the writer, a substantial portion of the material is being moved downstream from the high country, a marked increase in effort and funds should be directed to upstream river control and catchment improvement works.

The periodic surveys now conducted should be expanded and every effort made to pinpoint the major source of shingle, changing bank conditions, rate of bedload movement, areas of and rates of aggradation and degradation and the flood or flow conditions under which these movements occur. It is anticipated that such surveys and research will require the measurement of channel cross sections and stream profiles using surveying techniques as well as the analyses of aerial photographs taken before and following major storm events (see also recommendation 18).

7 NOXIOUS PLANT CONTROL AND ERADICATION

Frequently, on the better hill country, the invasion and spread of noxious plants has proved a serious deterrent to agricultural development. The retirement of much of the steep country dictates the need for maintaining and increasing agricultural production on the more favourably-sited lands, including large areas of land now idle or of low productivity because of the noxious plant problem. Native and exotic species commonly included in this category are manuka, kanuka, fern, mata-gouri, gorse, broom and sweetbrier. On down lands and on the plains, management, which includes oversowing and topdressing followed by heavy grazing, often appears to be sufficient to control such plants. Unfortunately, the more steeply-sloping lands cannot take the heavy grazing required without damage. In the past fire has been used as a means of weed and brush control. Fire not only led to accelerated erosion but actually favoured the weed species. Further, these sloping hill-country lands are endowed with a forest climate indicating that the noxious plant problem will be in fact a continuing one.

Increasing research effort is needed to develop methods and techniques for the eradication or control of such vegetation. Chemical, mechanical, burning and management measures, single and in various combinations, should be tested. When promising techniques are tried out on a pilot-plant basis, economic analyses of treatment costs should be made concurrently. If research proves weed control uneconomic on some infested areas, they should be planted to exotic forests to put them to productive use, for protection purposes, and to reduce source areas of weed infestation.

8. PHYSICAL AND CHEMICAL SOIL CHARACTERISTICS AND THEIR ALTERATION

It is largely through changes in the physical and chemical properties of soils that accelerated erosion can proceed and alterations in runoff occur. Bush removal and tussock grassland burning destroy the organic matter and the deep roots (the latter more slowly) that bind the soil as well as exposing the soil to intense frost action, thus setting the stage for increased erosion. The inevitable increase in soil consolidation and compaction due to trampling by domestic and wild animals and to exposure, results in increasing proportions of rainfall running off the catchment as damaging overland flow rather than as subsurface (interflow) and ground-water (base) flow.

The chemical characteristics (particularly nutritional) are especially significant in that they determine in large part the type, density and quality of vegetation that the soil will support. Nutritional deficiencies can be corrected by application of chemicals (fertilizers, soil amendments, and trace elements).

An important key to conservation and to increased agricultural production lies in a knowledge of soil characteristics. Such knowledge will, in turn, guide land use. Studies of physical characteristics of the soil will assist in predicting susceptibility to compaction and erosion. Chemi-

cal studies will point out the requirements for revegetation, afforestation, and increased production on the better lands.

A programme of measuring and reporting the physical and chemical properties of New Zealand high country soils is necessary. Where such a programme exists, it should be expanded; where it is absent, it should be initiated.

9. DISTRIBUTION OF PRECIPITATION IN HIGH-COUNTRY BASINS

Because of the difficulty of access and high cost of measurements and maintenance, very few precipitation gauges are located in the high country. Paradoxically, the high country often receives three to five times as much precipitation as does the down country. Because of this higher precipitation and the high incidence of erosion in the steep mountain lands, they contribute an inordinate proportion of flood water. A much more accurate picture of the areal distribution of precipitation is necessary than is presently available for the design of flood-control structures, for the planning of water developments, and for the allocation of funds for conservation and flood-control measures.

It is recommended that on selected mountain basins, preferably those chosen as regional or experimental catchments, intensive precipitation-gauge networks, including adequate sampling of high country, be established to permit an accurate assessment of the distribution of precipitation. Following appropriate correlations, key stations within the network should be retained on a permanent basis. Efforts in this direction have already been initiated by the Soil Conservation and Rivers Control Council (Hokitika Catchment) and by the New Zealand Forest Service (Craigieburn Forest).

10. EFFECTS OF SOIL FREEZING ON EROSION AND RUNOFF

The severe frost-climate experienced in New Zealand high country is a major factor contributing to the erosion problem. Much of this country is subject to more than 200 days of frost with very frequent freezing/thawing cycles. Bare soil is particularly prone to loosening, detachment and dispersal by frost action.

Where concrete frost exists, infiltration will be impeded and, hence, surface runoff and erosion increased. Comparable high country in North America and Europe is normally covered with a protective mantle of snow from six to nine months of the year; the limited occurrence of such snow-cover in New Zealand makes this problem more acute.

Research is recommended to assess the occurrence and type of soil frost and its effect on surface runoff and soil movement under varying degrees of land use. Runoff plots and temporary plots should be utilized and the value of such treatments as mulching should be investigated. (Note: A pilot study on soil frost action has been initiated by the Forest and Range Experiment Station. The Soils Bureau, D.S.I.R., is also conducting studies at high altitudes.)

11. SIGNIFICANCE OF SNOW IN HIGH-COUNTRY HYDROLOGY

The contribution of the high-country basins and their seasonal snowpacks to floods, to total water yields, and to low floods is unknown. At present, water supplies are adequate and often over-abundant; however, increasing emphasis will be placed upon water yields, particularly summer and low flows. With higher elevation, both precipitation and the proportion of that precipitation occurring as snow increase. This increase is particularly marked near the divide of the Southern Alps. During the winter and early spring, snow cover has an ameliorating influence upon flooding since it stores large volumes of precipitation as a "frozen asset." It can absorb large quantities of rainfall for subsequent slow release, if it is not "ripe" at the time of rain. Further, during late spring and early summer drought periods, the high-country basins are undoubtedly supplying much of the water for streamflow.

Because of difficult access there are extremely few weather stations in the high country above 3,000 feet. As a consequence total precipitation in many high mountain basins is largely a matter of an educated guess. Better information from these high-country basins will permit more accurate flood routing and better design of flood protection works.

Consequently, an expansion of research in other high-country areas and conditions such as is now under way and/or proposed (under the International Hydrological Decade programme) at the Craigieburn Forest is recommended.

Preliminary investigations by the Forest and Range Experiment Station in this area indicate that at elevations about 5,500 feet, 30 per cent of the annual precipitation occurs as snow.

Based on preliminary reports, snow cover appears to be continuous above 5,000 feet from May through November. The hydrologic behaviour of the high country is of greater significance than is often realized. Increasing erosion problems and greater demands for basin and water use will serve to underline this inescapable fact.

12. ROOT HABITS AND CHARACTERISTICS

The protective properties of vegetation in erosion and flood control lie both in the aerial and in the underground plant environment. In addition to their functions in anchorage, absorption of water and nutrients, and food storage, plant roots play a significant role in soil development, in maintaining or increasing soil stability, and in plant renewal and spread.

Often the most rapid and economic method of attaining a vegetative cover is through the seeding or planting of species which reproduce themselves rapidly by tillering, layering or by rhizomes (modified stems) and root suckers. Vegetation which puts down relatively deep roots of high tensile strength in the juvenile stage is much less susceptible to frost damage and to erosion. Plants with well-developed deep root system tend to provide for increased infiltration and percolation of water into

and through the soil reservoir thereby reducing damaging surface runoff. The litter produced by both the aerial and subaerial portions of the plant significantly influences soil development, and decayed root channels provide hydraulic passageways for the subsurface flow of water. Moreover, deep-rooted vegetation has often proved to be the only practical means of reducing or arresting slides or slumps.

In considering species to be selected for erosion and flood control, major emphasis must, then, be given to root characteristics. Consequently, investigations designed to determine the rate, type and volume of root growth under varying climatic and soil conditions should be undertaken.

13. RANGE AND FOREST CONDITION AND TREND

The use of indicators of range condition and trend has been used to advantage in assessing grazing use in the United States and has been introduced into New Zealand by Riney and Dunbar (1956)*. It is felt that the employment of this tool would be very useful to land managers, conservationists and grazing-lease administrators. The present criteria* should be expanded and brought up to date to include the results of more recent research and experience. Examples of the application of these criteria to actual management recommendations should be included. On the basis of the best information and data available, it is suggested that a range-condition scoresheet be devised which could readily be used by runholders, pastoral land officers and conservationists. Rankings or scores on range condition should then be used as a guide to land management (type and intensity of stocking, spelling, etc.).

The concept and condition and trend should also be applied to the mountain forest lands. Data obtained from Forest Service Watershed Surveys will be most useful in developing criteria. The application will be useful in assessing the impact of introduced animals on vegetation and soil, and will serve as a guide in determining conservation measures.

Consideration should also be given to the possibility of including factors of hydrologic condition and trend in such criteria. Such factors as the degree and type of erosion, the hydrologic condition of soil (possibly utilizing simple infiltration tests), soil depth and storage characteristics and channel conditions might be included.

14. LONG-TERM PROJECTION OF DOMESTIC AND WORLD MARKETS

New Zealand is presently an agricultural nation, and will probably remain so within the foreseeable future. Wool and meat make up the large majority of her exports and provide the principal source of her overseas funds. The economy of the nation is so closely aligned with these two products that it is extremely sensitive to their world demand and price.

*Riney, T. and G. A. Dunbar. 1956. Criteria for determining status and trend of high-country grazing lands in the South Island of New Zealand. Soil Conservation and Rivers Control Council. Wellington. 32pp.

Much of New Zealand is endowed with a climate that yields outstanding growth of both forests and grasslands. Growth rates of exotic forest species rank among the highest in the world. Large areas of idle and eroded land and economically marginal agricultural land are capable of high productivity of forest products. There appears to be a steadily increasing world market for these products. Further, an increase in such exports would tend to act as a buffer against fluctuating prices and market demands for wool and meat.

Analyses of the world market and price situation should be made in comparing sheep and cattle grazing. Due to differing grazing characteristics and use, large areas of land now used by sheep could more safely be grazed by cattle from a conservation standpoint.

Thus, a continuing assessment of and long-range projections of both local requirements and overseas trade prospects are needed as a guide to land use decision and policy.

15. WATERSHED MORPHOLOGY

Studies in the United States have led to the establishment of quantitative measures which can be used to describe the hydrologic and drainage characteristics of catchments. These measures are not only very useful in describing and comparing basins, but also offer promise in the extrapolation of hydrologic data. The difficulties and expense involved in stream gauging in New Zealand point to the necessity of such extrapolations—and these should be made on as sound a basis as possible. Quantitative comparisons of basin characteristics can provide useful information in assessing erosion and bedload movement, drainage-network patterns, and changing channel and stream geometry. Watershed morphology measures include such factors as size (area), shape, orientation or aspect, slope, elevation, drainage pattern, drainage density, relief ratios, basin and stream profiles, channel size, shape and interruptions, and stream orders. Such analyses appear quite appropriate to New Zealand's topographic and erosion conditions. It is recommended that initial effort be directed to analyses of basins selected as regional, or experimental catchments. The bases for such analyses are usually good topographic maps and/or aerial photographs—with appropriate ground checks. Analysis techniques may be derived from published information (particularly from the United States Geological Survey).

16. CLIMATIC VARIATIONS AND LONG-TERM HYDROCLIMATIC CHANGES

Among others, the work of Holloway (1954), Raeside (1948), and Molloy *et al* (1963) relating to climatic change has provided valuable insight to past hydrologic, climatic, vegetative and erosional history and gives clues to present regimes. Additional evidence of this nature will aid materially in providing an understanding of present ecological structures and hydrologic behaviour as well as in suggesting solutions to present problems such as wildlife control.

In addition to a continuation of the work under way, further study is suggested in the interpretation of glacial history (involving the extraction and analysis of ice cores from present glaciers and examining evidence of past glacial advance and recession), in landform analysis (utilizing lakes, former lakes and lake levels, closed lakes, varves, and river benches and terraces as indicators of paleohydrology and paleoclimatology), and in analysis of charcoal, wood remains, and fossil pollen recovered from exposed soils, lake beds, bogs and swamps.

17. WATER QUALITY

With increasing population and increasing demand for water, additional attention will necessarily be directed to the quality of water derived from New Zealand catchments. Water quality may be damaged by high stream turbidities which may be caused by natural and accelerated erosion and constructional disturbances; by pollutants and organisms derived from plant and animal decomposition and from domestic livestock and wildlife; and by human use of catchments. A lowering in water quality usually necessitates more expensive water treatment. For example, the continued or increased use of catchments in the Tararua Mountains for both recreation and water supply for the citizens of Wellington will undoubtedly entail the installation of additional water treatment facilities. Similarly, hydro-electric plants on streams carrying large amounts of sediments and high turbidities find frequent and costly replacement of turbines necessary. Overseas experience, too, indicates that caution must be exercised in the use of chemicals on the landscape such as insecticides, weedicides, herbicides and fertilizers. These potential sources of pollution are probably more significant than the much more spectacular problem of atomic fallout.

In view of the increasing significance of water quality, a series of monitoring stations should be established to measure physical, chemical and biological characteristics of water under varying catchment conditions and under varying flow regimes. Supplemental research will be necessary in the future to relate and apply the results of overseas research on water quality to New Zealand conditions.

18. EROSIONAL CHARACTERISTICS OF GEOLOGIC MATERIALS

In the South Island, large areas of the Southern Alps are classified and mapped on a geologic basis as greywacke. Similarly, in the North Island, areas are designated as mudstone and argillite and as pumice lands. Experience and observation indicate that within these rather broad categories the parent materials behave quite differently in regard to rate and depth of weathering, susceptibility to erosion, and in potential productivity from the soils derived from them. In some areas of greywacke for example, the materials decompose and disintegrate much more slowly and appear to be much more strongly indurated than in others. It has been suggested that some forms of greywacke may disintegrate so rapidly that they may be altered from bedload size material in the upper

reaches of a catchment to suspended sediment in the lower reaches within the course of a single flood. Consequently, there is considerable variation in erodibility within areas of the same classification. Similar observations are applicable in the mudstone and argillite area near the north-east coast of North Island. Knowledge of these characteristics will be helpful in guiding land management activities and in the application of conservation measures.

Investigations are recommended to ascertain the properties, characteristics, and behaviour of geologic materials, particularly those of the principal problem areas. New or revised geologic maps based on the criteria developed from such investigations will then provide a valuable tool in land management.

19. LAND TREATMENT AND STRUCTURAL CONTROL MEASURES

Various types of land treatments and structures such as contour furrowing, range pitting and ripping, strip cropping, chiseling, grassed waterways, gully plugs, and the construction of debris dams and small detention reservoirs have been employed as conservation measures. These measures have been successfully used in North America to conserve water, to protect the soil, to reduce surface runoff and promote infiltration, to prevent and arrest erosion, and to aid in rehabilitation of poor catchment conditions. Some of these techniques have been used in a limited basis in New Zealand, others have yet to be tested here.

Research and tests to assess their applicability, effectiveness, and economics as far as New Zealand problem areas are concerned should be expanded or undertaken.

20. IRRIGATION POTENTIAL

Large areas of South Island, particularly in Central Otago where precipitation is limited, appear susceptible to the successful development of irrigation agriculture. Similarly, in drought-prone areas of the Canterbury Plains, its development and increased use appear warranted. Undoubtedly, irrigation of these areas could contribute much to the needed increases in productivity.

Engineering, soil, and economic analyses are suggested to assess the practicability of such development in New Zealand.

In addition to these areas, research to meet local problems, or to solve those of less-immediate concern is desirable in such areas as the hydrology of swamps and bogs, hydrologic effects of land drainage, fluctuations in ground-water levels and quality, comparisons of water consumption by different crops and vegetative covers, and effect of Molesworth type of land management on hydrology.

In the planning and execution of research every effort should be made to use and develop standardized techniques in measuring, recording, and reporting data (see report by Soil Conservation and Rivers Control Council on International Hydrologic Decade Experimental

Basins). Such standardization will permit the correlation and more widespread application of the results of research.

EDUCATION AND TRAINING NEEDS

If this much-needed research is to be undertaken, increased effort must be directed to the education and training of personnel for work in watershed management, hydrology and related disciplines. In addition to work in specific fields, such training should include more attention to the basic sciences and further instruction in research technique and methodology. A five-pronged approach of the order indicated should be initiated as soon as possible to train adequate manpower for the implementation of a research programme. Moreover, the complexity and the inter-disciplinary nature of soil and water-resource problems emphasize the need for active inter-relation of diverse fields. Present educational programmes in New Zealand do not appear to be sufficiently broad or flexible to permit such an interdisciplinary approach. Academic programmes specifically designed for work in watershed management and hydrology have not yet been organized. Qualified staff will be needed for full-time research careers and for university teaching. Post-graduate study by interested personnel should be urged and encouraged in order to provide this staff.

1. SCIENTIFIC PERSONNEL

Until such time as full professional curricula can be developed and justified within New Zealand, it will be necessary to select promising researchers and to provide them with bursaries for graduate study in overseas centres. To provide for interdisciplinary training and for future team research, personnel should be selected with prior training and experience in different lines of endeavour including agriculture, biology, ecology, geology, geography, soil science, mathematics, chemistry, physics, agricultural, civil and sanitary engineering, atmospheric science, range or grassland management, and forestry. Some of the personnel selected should be from present university faculties to facilitate the initiation of comparable programmes in New Zealand. Such programmes will ordinarily vary from one to three years' duration. To provide for the early initiation of some of the research recommended, it is suggested that a few professionals be sent to the 12-week specialized course in hydrology offered by the University of New South Wales (or comparable courses).

2. TECHNICAL TRAINING

The technician is an integral and essential member of the research team. In the interests of saving money and manpower, technicians should be trained and employed for such tasks as the installation, calibration and maintenance of instruments and equipment, routine data-collection and processing, field and laboratory assistance, drafting, and for facility maintenance. At present it appears that the needs of New Zealand could be fulfilled through on-the-job training and through

periodic short training courses (possibly inter-agency in nature). When the demand for trained technicians increases, training schools similar to the Ranger Schools operated by the New Zealand Forest Service may be necessary.

In view of the rapid advances in technology, particularly in such areas as micro-instrumentation, electronic circuitry, radioactive tracing, radiotelemetry, and electronic computing, it is recommended that, periodically, competent technicians be sent to overseas development centres to insure that such techniques can be adapted to New Zealand research as early as practicable.

3. CONTINUING EDUCATION

To foster education, to provide for the exchange of information and ideas, and to encourage inter-disciplinary research activity, a planned programme of periodic conferences, symposia, and seminars is suggested. The technical symposium on hydrology and land use held under the auspices of the Soil Conservation and Rivers Control Council in 1962 and the National Water Resources Symposium in 1964 are excellent examples of such activity. Smaller working groups of scientists meeting on specific problems and joint conferences of professional organizations (such as the Association of Soil Conservators and the various engineering groups concerned with soil and water conservation) should prove mutually beneficial.

4. EXTENSION EDUCATION

Adequate provision needs to be made for the publication of research results—publication in an understandable language. An informed government and an enlightened public should be the strongest supporters of research and action programmes in conservation. As the results of research become available, they should be translated to management and design prescriptions. A sound extension education programme designed to explain the necessity for these prescriptions—to sell them to the public—would improve the public image of conservation and conservation agencies.

5. INTERNATIONAL HYDROLOGICAL DECADE

Scientific hydrology and watershed management in New Zealand can gain much from and can contribute to the current international effort through its active participation in the International Hydrological Decade. The proposed expansion of present activities in regional and experimental catchments is an excellent contribution to this effort. Attendance at and participation in international meetings and symposia by New Zealand representatives is urged to the greatest possible extent. New Zealand should be aware of and take advantage of educational opportunities proposed by the United Nations, and its participating countries under the Decade programme.

In the conduct and planning of both educational and research programmes, closer cooperation among the universities and the national and

local agencies is urged. When research centres are developed they should be located on or near university campuses. Elsewhere such arrangements have proved to be mutually beneficial. They provide for ready consultation and exchange of scientific information and often obviate the necessity for expensive duplication of facilities and equipment. When practical the research agency should support extramural projects by appropriate faculty and students. Where outstanding competence exists in government agencies, they should contribute to the training of new scientists through guest lectures, participation in seminars, and by providing research guidance, particularly to graduate students. In turn, as far as it is consistent with their educational programmes, the universities should make available to the agencies such specialized facilities as libraries, laboratories, computing centres, glass houses, and specialized equipment or instruments. Experienced faculty members can contribute materially to agency training sessions and short courses.

WATER RESOURCES PLANNING, POLICY AND ADMINISTRATION

The abundant supply of water and the absence of intense competition for its use has permitted the development of water resources in the absence of multipurpose planning and a national policy. The inevitable increase in such competition and the need for much more activity in catchment protection and flood control highlight the need for multipurpose water planning and for a guiding policy in water development, watershed use, and soil and water conservation. Statutory provisions should be established to permit the orderly allocation of water resources. In this regard the recommendations of the National Water Symposium (Wellington, December, 1964) are fully endorsed.

Similarly, through observation and through published reports, the need for more adequate administration of soil and water conservation is evident. The implementation of the recommendations of Dr D. A. Williams (1964) would achieve much in providing the climate and status required to meet the challenge of catchment control and management in New Zealand.

ACKNOWLEDGEMENT

The cooperation and assistance rendered by the Tussock Grasslands and Mountain Lands Institute, the New Zealand Forest Service, the Soil Conservation and Rivers Control Council, local catchment boards, and the United States Educational Foundation in New Zealand and their personnel have contributed immeasurably to this study and are deeply appreciated. The writer is particularly indebted to Mr L. W. McCaskill, Mr John Y. Morris and Mr John T. Holloway.

BIBLIOGRAPHY

- BATCHELOR, C. L. and LOGAN, P. C. 1963. Assessment of an animal-control campaign in the Harper-Avooca catchment. *N.Z. Forest Service FRI Publ. No. 27*. 27 pp.
- BILLINGS, W. D. and MARK, A.F. 1961. Interactions between alpine tundra vegetation and patterned ground in the mountains of Southern New Zealand. *Ecology* 42 (1): 18-31.
- BLACKMORE, J. 1962. Watershed management. Food and Agriculture Organization of the United Nations. *Occasional Paper No. 13*. Rome.
- BURROWS, C. J. 1960. Recent changes in the vegetation of the Cass area of Canterbury. *N.Z. Geog.* 16 (1): 57-70.
- CAMPBELL, A. P. 1963. Hydrology in New Zealand. *N.Z. Eng.* 15 (8): 281-287.
- 1963. Methods of obtaining hydrological evidence on climatic change. *N.Z. Ecol. Soc.* No. 10.
- CAMPBELL, D. A. Down to the sea in slips.
- 1964. Restoring severely eroded and depleted tussock country at Tara Hills. Soil Conservation and Rivers Control Council. *Bulletin No. 17*. 25 pp.
- COCKAYNE, A. H. 1910. The natural pastures of New Zealand; I. The effect of burning on tussock country. *N.Z. J. Agr.* 1: 7-15.
- COCKAYNE, L. 1926. Monograph on the New Zealand beech forests. *N.Z. For. Ser. Bull.* 4.
- COMMITTEE OF ENQUIRY. 1939. Maintenance of vegetative cover in New Zealand, with special reference to land erosion. *N.Z. Dep. Sci. and Ind. Res. Bull.* 77. 51 pp.
- CONNOR, H. E. 1960. Some aspects of the botany of tussock grasslands. *Proc. Lincoln College Farmers' Conf.* 1960.
- COSTIN, A. B. 1957. High mountain catchments in Victoria in relation to land use. Soil Conservation Authority, Victoria.
- 1959. Vegetation of high mountains in Australia in relation to land use. Biogeography and Ecology in Australia. (*Monographie Biologicae*, Vol. VIII). pp. 427-451.
- 1962. Some impressions of a visit to parts of the South Island. *Tussock Grasslands and Mountain Lands Institute Spec. Pub. No. 2*. 16 pp.
- COX, J. E. and MEAD, L. B. 1963. Soil evidence relating to post-glacial climate on the Canterbury Plains. *Proc. N.Z. Ecol. Soc.* No. 10.
- CUMBERLAND, K. B. 1944. Contrasting regional morphology of soil erosion in New Zealand. *Geographical Review.* 77-95.
- 1944. Soil erosion in New Zealand. Soil Conservation and Rivers Control Council. 227 pp.
- 1962. Climate change or cultural interference. New Zealand in Moa-hunter times. In: Murray McCaskill (ed.) Land and Livelihood. Geographical Essays in honour of George Jobberns, N.Z. Geographical Society. pp. 88-142.
- DANSEREAU, P. 1964. Six problems in New Zealand vegetation. *Bull. Torrey Bot. Club.* 91 (2): 114-140.
- DICK, R. D. 1952. The changing tussock grasslands. *Proc. 14th Conf. N.Z. Grasslands Assoc.* pp. 114-122.
- DRUCE, A. P. 1957. Botanical survey of an experimental catchment, Taita, New Zealand. *N.Z. Dep. Sci. and Ind. Res. Bull.* 124. 81 pp.
- DYKSTERHUIS, E. J. 1952. Determining the condition and trend of ranges. *Proc. 6th Int. Grasslands Cong.* pp. 1322-1327.
- ELLISON, L. 1957. Observations on erosion in relation to grazing in the high country of the South Island of New Zealand. Unpublished report.
- FAHEY, B. D. 1965. The hydrological relations of vegetation in the Silverstream catchment. M.A. Thesis, Otago University, 230 pp.
- FOOD AND AGRICULTURE ORGANIZATION. 1962. Forest Influences. FAO, United Nations, *Forestry and Forestry Products Studies No. 15*, Rome.
- FOREST SERVICE. 1964. New Zealand Forestry. R. E. Owen, Govt. Printer, Wellington.
- GAGE, M. 1958. Late Pleistocene glaciations of the Waimakariri Valley, Canterbury New Zealand. *N.Z. J. Geol. Geophys.* 1: 123-135.
- GIBBS, H. S., RAESIDE, J. D., DIXON, J. K. and METSON, A. J. 1945. Soil Erosion in the high country of the South Island. *N.Z. Dep. Sci. Ind. Res. Bull.* No. 92. 72 pp.
- GLASS, A. N. 1957. Soil conservation on North Island hill country. *N.Z. J. Agr.* (reprint).
- and DROSS H. 1962. Pumice ash soils, conservation problems and suggested hydrological investigations. Proc. Technical Symposium Soil Conservation and Rivers Control Council.
- 1965. Pumice land conservation problems. Paper presented at 11th N.Z. Science Congress, Auckland.
- GRANT, P. J. 1963. Forests and recent climatic history of the Huiarau Range, Urewera Region, North Island. *Trans. Roy. Soc. N.Z.* 2 (12): 143-172.

- HAWLEY, C. B. AND COY. 1923. Report on Waimakariri power project. Charles B. Hawley and Co. Inc., Engineers, Washington, D.C. 32 pp.
- HERCUS, J. M. 1961. Tussock grassland improvement by grazing management. *N.Z. J. Agr.* 103: 257-261.
- 1964. Sheep in the tussock grasslands. *Proc. N.Z. Ecol. Soc.* 11: 36-39.
- HOLLOWAY, J. T. 1949. Ecological investigation of the *Nothofagus* forests in New Zealand. *N.Z. J. For.* 5: 401-410.
- 1954. Forests and climate in the South Island of New Zealand. *Trans. Roy. Soc. N.Z.* 82 (2): 239-410.
- 1959. Noxious-animal problems of the South Island alpine watersheds. *N.Z. Sci. Rev.* 17 (2).
- 1960. Research in mountain land management: New Zealand problems in light of overseas experience. *N.Z. J. For.* 8 (2).
- 1962. Forests and water, the New Zealand problem. *N.Z. Forest Service Information Series* No. 36, 12 pp.
- *et al.* 1963. Forests, subalpine-scrub lands and alpine grasslands of the Tararua Range. *N.Z. For. Ser., Forest Research Institute Tech. Paper* No. 41, 48 pp.
- 1964. Asia-Pacific Forestry Congress Working Party on Watershed Management—The New Zealand situation. *N.Z. Forest Service, Mimeo.* 14 pp.
- 1964. General trends in forest modification by introduced animals. *Proc. N.Z. Ecol. Soc.* 11: 24-26.
- 1964. The forests of the South Island: The status of the climatic change hypothesis. *N.Z. Geog.* 20 (1): 1-9.
- 1964. Banks lecture, 1964—Man and the mountain lands. *J. N.Z. Inst. Hort.* 5 (6): 240-248.
- HOWARD, W. E. 1965. Control of Introduced Mammals in New Zealand. *N.Z. Dep. Sci. Ind. Res. Information Series* No. 45. 86 pp.
- HUGHES, J. G. 1962. High-country fencing. *Tussock Grasslands and Mountain Lands Institute Special Pub.* No. 1. 27 pp.
- JOHNSTON, J. A. 1958. Recent climatic change in South Island, New Zealand. A geographic analysis. M.A. Thesis, University of Canterbury.
- JOHNSTON, W. B. 1961. Locating the vegetation of early Canterbury: A map and the sources. *Trans. Roy. Soc. N.Z.* 89: 5-15.
- KIDDIE, D. G. 1962. The Sika deer (*Cervus nippon*) in New Zealand. *N.Z. Forest Service Information Series* No. 44. 35 pp.
- LANDS AND SURVEY, DEPARTMENT OF. 1964. The land utilisation survey of Gisborne-East Coast region. New Zealand Department of Lands and Survey. 89 pp.
- LEVY, E. B. 1951. Grasslands of New Zealand. *N.Z. Education Department.* 344 pp.
- MCCASKILL, L. W. 1965. What happens in the high country affects all of New Zealand. *Service, Ivon Watkins-Dow Ltd.* Fall issue, pp. 8-11.
- 1955. The indigenous grasslands of New Zealand and their plants of horticultural importance. (Banks Memorial Lecture, 1955). *N.Z. Science Review* 14 (1-2): 3-7.
- McKELVEY, P. J. 1960. Condition assessment of protection forests. *N.Z. J. For.* 8 (2): 324-334.
- McGREGOR, W. R. 1964. Noxious animals or national parks. *Forest and Bird* No. 154 (November 1964). pp. 3-26.
- MARK, A. F. 1962. Zonation of vegetation and climate on the Old Man Range, Central Otago. *Otago University Science Record*, 1962.
- SCOTT, G. A. M., SANDERSON, F. R. and JAMES, P. W. 1964. Forest succession on landslides above Lake Thomson, Fiordland. *N.Z. J. Bot.* 2 (1): 60-89.
- MOLLOY, B. P. J., BURROWS, C. J., COX, J. E., JOHNSTON, J. A. and WARDLE, P. 1963. Distribution of sub-fossil forest remains, eastern South Island, New Zealand. *N. Z. J. Bot.* 1: 68-77.
- MORRIS, J. Y. *in litt.* Climate investigations in the Craigieburn Range. *N.Z. Forest Service.*
- and O'LOUGHLIN, C. L. *in litt.* Snow investigations in the Craigieburn Range. *N.Z. Forest Service.*
- 1962. L'érosion des sols en Nouvelle-Zélande. (Soil erosion in New Zealand.) *Revue Forestière Française* No. 2: 93-104.
- N.Z. INSTITUTION OF ENGINEERS. 1965. Recommendations from the Water Symposium. *N.Z. Engineering* 20 (3): 105-108.
- NICHOLLS, J. L. 1956. The historical ecology of the indigenous forests of the Taranaki Upland. *N.Z. J. For.* 7: 17-34.
- NORDBYE, D. J. and CAMPBELL, D. A. 1951. Preliminary infiltration investigations in New Zealand. International Association of Scientific Hydrology.
- O'LOUGHLIN, C. L. 1964. Notes on the occurrence of concrete frost and other forms of soil-ice in Canterbury beech forests. *Protection Forestry Report* No. 5. *N.Z. Forest Service.* 5 pp. Unpublished.

- PACKARD, W. P. 1947. Lake Coleridge catchment: a geographic survey of its problems. *N.Z. Geog.* 3 (1): 19-40.
- POOLE, A. L., HOLLOWAY, J. T., McKELVEY, P. J., KEAN, R. T. and POHLEN, I. J. 1959. Browning animals in protective vegetation. *N.Z. Science Review*. Vol. 17, No. 2.
- PULLAR, W. A. 1962. Soils and agriculture of the Gisborne Plains. *N.Z. Dep. Sci. Ind. Res. Soil Bureau Bulletin* 20. 91 pp.
- RAESIDE, J. D. 1948. Some post-glacial climatic changes in Canterbury and their effect on soil formation. *Trans. Roy. Soc. N.Z.* 77: 153-171.
- 1960. An unsolved problem in soil and water conservation. *N.Z. Soc. Soil Sci. Proc.* Vol. 4.
- RINEY, T. 1956. A zoecological approach to the study of ecosystems that include tussock grassland and browsing and grazing animals. *N.Z. J. Sci. Tech.* 37 (4): 455-472.
- and DUNBAR, G. A. 1956. Criteria for determining status and trend of high country grazing lands in the South Island of New Zealand. Soil conservation and Rivers Control Council. 32 pp.
- ROBERTSON, N.G. 1963. The frequency of high intensity rainfalls in New Zealand Air Department. *N.Z. Meteorological Service. Misc. Pub. 118.* 53 pp.
- SCHUMM, S. A. 1965. *In press.* Geomorphic research applications to erosion control in New Zealand. *N.Z. Soil and Water.*
- SOIL CONSERVATION AND RIVERS CONTROL COUNCIL. 1959. New Zealand hydrology. Proc. Meeting of design engineers employed on hydrological works. December 1959.
- 1962. Hydrology and Land Management. Proc. Technical Symposium held under the auspices of the Council at Canterbury Agricultural College, Lincoln, Christchurch, 14-16 May, 1962. 172 pp.
- SOONS, J. M. Ice-marginal drainage channels in the Rakaia Valley. *N.Z. Geog.* 20 (2): 153-164.
- SPEIGHT, R., COCKAYNE, L., and LAING, R. M. 1911. The Mt. Arrowsmith District: A study in physiography and plant ecology. *Trans. N.Z. Inst.* 43: 315-378.
- WALL, A., and LAING, R.M. 1927. Natural history of Canterbury. Philosophical Institute of Canterbury. 299 pp.
- THOMSON, J. L. 1965. The volcanic plateau and the erosion problem. Paper presented at N.Z. Assoc. Soil Conservators' Biennial Conf. Taihape, April, 1965.
- TOEBES, C. 1965. *In litt.* The planning of representative and experimental basin networks in New Zealand. Paper to be presented at the International Association of Scientific Hydrology Symposium on Representative and Experimental Areas, Budapest, 28 Sept.-5 Oct., 1965.
- TUSSOCK GRASSLANDS RESEARCH COMMITTEE. 1954. The high-altitude snow tussock grassland in South Island, New Zealand. *N.Z. J. Sci. Tech.* A36 (4): 335-364.
- U.S. DEPARTMENT OF AGRICULTURE. 1962. Range research methods. *U.S. Department of Agriculture, Forest Service Misc. Pub. No. 940.* 172 pp.
- U.S. NATIONAL ACADEMY OF SCIENCES—National Research Council. 1963. An outline of international programmes in hydrology. *NAS-NRC Pub.* 1131. 46 pp.
- WARDLE, P., and MARK, A. F. Vegetation and Climate in the Dunedin district. *Trans. Roy. Soc. N.Z.* 84 (1): 33-43.
- 1963. Evolution and distribution of the New Zealand flora as affected by Quaternary climates. *N.Z. J. Bot.* 1: 3-17.
- 1963. Growth habits of New Zealand subalpine shrubs and trees. *N.Z. J. Bot.* 1: 18-47.
- WATERER, R. R. 1958. Some observations upon the condition of mountainous water catchment areas of New Zealand. Unpublished report. 21 pp.
- WILLIAMS, D. A. 1964. Soil conservation and rivers control organization and administration in New Zealand. R. E. Owen, Govt. Printer, Wellington. 23 pp.
- WRAIGHT, M. J. 1960. The alpine grasslands of the Hokitika River catchment, Westland. *N.Z. J. Science* 3 (2): 306-332.
- 1963. The alpine and upper montane grasslands of the Wairau River catchment, Marlborough. *N.Z. J. Bot.* 1 (4): 351-376.
- 1964. Modification of grasslands by grazing animals. *Proc. N.Z. Ecol. Soc.* 11: 27-32.
- 1964. Ecology and state of alpine grasslands of Westland. *Proc. 26th Conf. N.Z. Grasslands Assoc.* 90-94.
- ZOTOV, V. D. 1938. Survey of the tussock grasslands of the South Island of New Zealand. *N.Z. J. Sci. Tech.* A20: 212-244.

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