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HYDROLOGY

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A REVIEW OF RESEARCH IN THE TUSSOCK GRASSLANDS AND MOUNTAIN LANDS OF NEW ZEALAND

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IN THE

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Contents

SUMMARY

Deficiencies in regional and national goals and objectives for water management make it difficult to assess the relevance of New Zealand's hydrologic research effort to present and probable future needs. The situation is further confounded because the results from much hydrologic research are unpublished and publicly unavailable.

This review of published and "unpublished" research reports indicates that the attention paid to any topic does not necessarily reflect its hydrologic significance. The reader may well conclude that more difficult topics have been ignored in favour of those that are easier and less expensive to research.

In commenting on future directions for research, the authors have declined to list topics. To do so would merely reflect their biases. Instead, they believe that this should properly be the responsibility of a task force convened by the National Research Advisory Council.

The authors do, however, set out their attitudes to future research and research administration.

1. INTRODUCTION

The Purpose of this Paper

This statement is prepared in response to a request from the Committee of Management of the Tussock Grasslands and Mountain Lands Institute. It has been prepared for people who are not hydrologists but who need to use the results from hydrologic research.

It attempts to summarise and comment on the present status of hydrologic research activity with particular emphasis on the tussock grasslands and related lands and indicate where information can be found. Although it may also indicate the status of our knowledge its principal purpose is to outline the status of hydrologic research activity.

It has been prepared from published research papers and theses, reports and conference papers, otherwise available.

2. HYDROLOGIC RESEARCH IN NEW ZEALAND

Hydrologic research in the tussock grasslands region cannot be considered in isolation from that carried out in the rest of the country. This section therefore reviews some aspects of hydrologic research in New Zealand.

2.1 Research Objectives

Although some government agencies and local bodies have administrative policies for the use and control of water, there are no clearly defined regional or national goals or objectives for the comprehensive and efficient use of the country's water resources. Because of this major deficiency, we cannot be sure that the country's present research effort is completely relevant to its present and probable future needs.

We believe that the goal of hydrologic research should be to provide information so that the country's water resources can be efficiently managed and future uses planned.

What are, or should be, the objectives of water management and planning for which information is needed?

In our view, a first objective must be to provide individuals and communities with relative freedom from the extremes of floods and droughts. But as our collective survival and standard of living depends on our ability to produce, a second objective should be related to the maintenance and improvement of primary and secondary production. A third objective should be the maintenance and improvement of the quality of our environment. With increased affluence, New Zealanders have become more concerned for their physical and cultural environments and now expect research to be directed into what are popularly known as "environmental issues".

It is against these objectives that we now proceed to review former studies and comment on the present status and future direction of research.

2.2 Sources of Information

Campbell (37) and Ibbitt (101, 102) have outlined and discussed some of the more important sources of hydrologic and related information.

Rainfall and other climate data from meteorological stations are presented by the N.Z. Meteorological Service as monthly abstracts or annual yearbooks:

- "Climatological Tables", New Zealand Meteorological Service, Miscellaneous Publication 107:
  This monthly abstract from the New Zealand Gazette summarises temperature, rainfall and sunshine for meteorological stations throughout the country.

- "Meteorological Observations", New Zealand Meteorological Service, Miscellaneous Publication 109:
  This is an annual summary of climatic observations from meteorological stations throughout New Zealand.

- "Rainfall Observations", New Zealand Meteorological Service, Miscellaneous Publication 110.
  This yearbook gives rainfall summaries and statistics for all stations and intensity/duration statistics for selected stations.

Until 1968, "Hydrology Annual" presented information on precipitation and related flood flows, mean flows, low flows, water quality and stream sediments. Ibbitt (102) has discussed the problems of presenting hydrologic information in a yearbook form and has outlined the reasons in favour of the present computer-based filing system. The "Filed Data List" of the Ministry of Works and Development gives a list of the sites for which data are being processed and are available at any of their District Offices. Because the list is being continually updated, it is not available for general distribution but is circulated to known users of the data. Information formerly presented in "Hydrology Annual" is now stored in the Time-Dependent Data Processing Programme (T.I.D.E.D.A.) (101). Access to this information can be gained through the Ministry of Works and Development.

Information about hydrologic research and results of such research can be found from four principal sources:

1. "Annual Hydrological Research Reports" published by the Ministry of Works and Development:
   These reports contain yearly information from experimental basins and are available on restricted distribution from the Director of Water and Soil Conservation. There is a backlog in publication and the most recent reports cover the period 1970-1973.

2. "Annual Research Report, Water and Soil Division", Ministry of Works and Development:
   Research activities funded under the science vote of Water and Soil Division, Ministry of Works and Development, are reported annually, together with brief outlines of significant results.

3. "A Catalogue of Hydrologic Research in Progress in New Zealand", Hydrological Research Miscellaneous Publication series of Ministry of Works and Development:
   Since 1969, annual catalogues have been compiled of hydrologic research in progress in New Zealand. The most recent report is for the year 1972.

4. Journals and Conference Papers;
   The Journal of Hydrology (N.Z.) is an important refereed publication for hydrologic research but it is by no means the

only outlet for research results. These can also be found in the New Zealand Journal of Science, New Zealand Journal of Marine and Freshwater Research, New Zealand Journal of Geology and Geophysics and the New Zealand Journal of Forestry Science. Much information is presented as papers to professional society symposia and other meetings, the proceedings of which are sometimes published.

2.3 New Zealand's Water Resources

Before the status and relevance of hydrologic research can be discussed, it is necessary to know something of the national and regional water resource.

Toebes (187) has estimated a New Zealand water balance for a period of about 10 years on the equation: $P = E + Q \pm \Delta S$.

Where P = Precipitation, E = Evaporation, Q = Streamflow, ΔS = Change in Storage

	Precipitation mm		Evaporation mm	+	Streamflow mm	±	Changes in Storage mm
North Island	1645	=	633	+	1052	-	40
South Island	2375	=	573	+	1808	-	6
New Zealand	2059	=	599	+	1481	-	21

These estimates may include large errors but they give a realistic indication of the amounts involved. Although the storage term is small, Toebes believes that it shows the imbalance of the system caused by ground water depletion.

Toebes further estimates the storage components as:

Ephemeral snow	7.7 km^3	(max. value)
Permanent snow and ice	50.0	
Interception storage	1.8	(max.)
Lakes	405.0	
Channel storage	13.3	
Soil moisture	13.2	
Ground water (base flow)	1392.0	
Deep ground water	265.0	
Biological storage	0.3	

Despite the inaccuracies inherent in these estimates, they provide one reference point against which to assess the value of hydrologic research; in partiuclar, that research which seeks to understand the impact that changes in land use may have on the water resource.

2.4 Representative and Experimental Basins

Representative Basins

New Zealand contains a remarkable array of physical environments. In order that information might be obtained in an orderly and economically defensible manner, Toebes and Palmer (189) provisionally divided New Zealand into 90 hydrological regions within which hydrologic similarity was presumed. These regions were defined on a general range of characteristics rather than specific features such as peak discharge or sediment production. (They noted that classifications based on specific features might have been different.)

Within most regions, basins have been established which are thought to be representative of each region for three objectives:

(1) To predict low flows and mean flows within the region.
(2) To study hydrologic processes.
(3) To develop mathematical prediction models.

Since 1960, 68 basins, ranging in size from about 10 to 250 square kilometres, have been established.

These basins were intended to provide information relevant to the region. For example, Waugh (196, 197), Grant (79) and Scarf (165) have each established that, with some reservations, low flows from representative basins in Northland, Hawkes Bay and Nelson can be translated for other catchments in the same region. Similarly, Chandler (43) has described how he used four years of data from Rocky Gully (Waitaki) to derive a flow duration curve for a Timaru City Council proposal for a water supply from the Paereora catchment. Waugh & McKertcher (198) have described the use of data from representative basins to develop regional flow frequency curves.

While it may appear that little use has been made of data from representative basins, it must be remembered that most records are very short. The problem with short hydrologic records is that they might not be representative of, for example, the total population of values of rainfall and runoff. As the record lengthens, the chances improve that it becomes more representative. Thus the value of rainfall-runoff information increases with the longevity of the record.

Representative basins were not intended as sites for field experimentation into the hydrological effects of changes in land use. Such studies were to be carried out on experimental basins.

Experimental Basins

The experimental basins programme (10,12) was intended as a major contribution in land use hydrology with three general objectives:

(1) To determine the influence of man on the water resources.
(2) To provide information on the hydrologic effects of land use.
(3) To define hydrologic processes for predictive mathematical models.

The basins were selected to cover the seven most important soil and vegetation associations in New Zealand.

Puketurua: Northern yellow-brown earths. A study on the conversion of scrub to pasture.

Manukau City: A study of the conversion of pasture to urban use.

Ototira: Yellow-brown pumice soils. A study on the conversion of scrub to pasture.

Purukohukohu: Yellow-brown pumice soils. A hydrologic comparison of grasslands, exotic forest and native forest.

Taita: Central yellow-brown earths. A hydrologic comparison of scrublands, native forest, exotic forest and grasslands.

Makara: Central yellow-brown earths. A hydrologic comparison of pasture and exotic forest, and of pasture management and improvement techniques.

Manorburn: Yellow-grey earths. The hydrologic implications of alternative short tussock management practices.

Moutere: Yellow-brown earths. Studies on the conversion of scrub to pasture and on pasture management, cropping and exotic forestry.

Camp Stream: High-country yellow-brown earths. Studies aim at improving knowledge of the influences of forest, tussock grasslands and animal control on the hydrology of a mountain catchment.

Adair: Yellow-grey earths. Investigations into the hydrologic implications of arable farming practices.

Mangatu: Unstable yellow-brown earths. A hydrologic comparison, exotic forestry and pasture.

In terms of the Experimental Basin Programme's objectives (1) and (2), results from Makara (208), Moutere (163) and Puketurua (168) have been reported. In view of the widespread interest in land use hydrology, this is a disappointingly small output. However, as the validity of the Experimental Basin method has been seriously questioned (91), it is doubtful that this method is capable of producing the type of information sought.

In terms of Objective (3), this programme has been more successful. A large number of the studies listed in the bibliography have been carried out on Experimental Basins.

The Representative and Experimental Basins are an important part of New Zealand's hydrologic research effort and have been central to perhaps one quarter to one half of the work which has been done. These studies can be broadly grouped into five categories:

(1) Estimation of surface water resources.
(2) Snow and ice hydrology.
(3) Hydrologic impacts of change in land use.
(4) Hydrologic process studies (such as interception, infiltration).
(5) Mathematical simulation of catchment responses.

2.5 Other Research

Work done outside Experimental and Representative Basins includes:

(1) Determination of surface and groundwater resources.
(2) Relations between soil, water and plant production.
(3) Meteorological and climatological investigations.
(4) Land erosion and stream sediments.
(5) Limnological studies.
(6) Mathematical simulation of catchment responses.

2.6 Research Organisations

Hydrologic research transcends many disciplines and many agencies. The following list indicates involved agencies and their principal research interests:

2.6.1 Ministry of Works and Development:

Data collection, processing and storage, representative and experimental basins, water quality, erosion and sediment hydrologic process studies, systems hydrology, surface and ground water resources research, floods and low flows, snow and ice, urban hydrology.

2.6.2 Catchment Authorities:

Data collection.

2.6.3 New Zealand Forest Service:

Small catchment research (with particular emphasis on forest management influences), hydrologic and climatic process studies, erosion and sediments water quality.

2.6.4 Department of Scientific and Industrial Research:

Soil Bureau:	Hydrologic processes, soil water.
Geological Survey:	Ground water.
Institute of Nuclear Sciences:	Isotopic research and application of isotopic methods.
Ecology Division:	Water quality, hydrologic processes.
Applied Mathematics:	Theoretical and stochastic hydrology.
Plant Physiology:	Soil and plant water relations.
Cawthron Institute:	Water quality.

2.6.5 Ministry of Agriculture and Fisheries:

Irrigation and drainage, water quality..

2.6.6 Universities:

Auckland:	Hydraulic research, Karst hydrology. water quality, urban hydrology.
Waikato:	Hydrologic processes, erosion and sedimentation, water quality.
Massey:	Drainage, water quality, water management research.
Canterbury:	Hydraulic research, limnology, hydrologic processes, ground water, water quality, erosion and sediment, systems hydrology.
Lincoln:	Irrigation, drainage, hydrologic and sediment processes, water quality.
N.Z. Agricultural Engineering Institute:	Irrigation, drainage, systems hydrology, erosion and sediment processes.
Tussock Grasslands and Mountain Lands Institute:	Erosion, sediment and hydrologic processes.
Otago:	Hydrologic and climatic processes, water quality.

2.7 Commentary

Although it is beyond the scope of this paper to comment on the status of hydrologic research in New Zealand, three observations are pertinent to the next section:

(1) Hydrologic research is at present carried out by a wide range of government departments, universities and local bodies. While this ensures the multidisciplinary base that hydrologic research needs, it also presents a new range of problems. It is our opinion that while communication between individual scientists is good, co-operation among agencies leaves much to be desired. While, no doubt, there are many reasons for this, the situation is not helped by a lack of definition of, and agreement on, objectives and priorities for research.

(2) We have earlier noted the absence of goals and objectives for the regional and national use of New Zealand's water resources. We also noted that because of this lack it is difficult to ensure that research is always relevant to present and probable future needs. It is our opinion that hydrologic research in New Zealand shows an imbalance between that which needs to be known and that which it is merely interesting to know. For example, we suggest that the water resource manager or administrator who searches the sources of information listed in Section 2.2will conclude that too much attention has been devoted to studies of physical processes and too little attention has been given to, for example, predicting frequencies and magnitudes of floods or droughts.

(3) Regardless of the scientist's employing agency, there is a low volume of output of scientific results. We recognise that there are many ways to assess productivity and published papers are but one. But we emphasise that scientists have a responsibility to produce referential results. The 1971 Catalogue of Hydrologic Research in Progress listed about 200 projects which had been started since 1965. From these projects, there are only 40 published papers or reports. Between 1972 and 1975, the Journal of Hydrology (N.Z.) published 40 papers of which only 20 reported results from projects listed in 1971. It is also worth noting that about half of the 200 papers cited in the bibliography have been prepared by 25 authors. We think that these figures indicate that the results of much research remain unpublished and in a largely inaccessible form.

Before proceeding to the next section, we wish to re-emphasise the difficulties of presenting a critical commentary on the status of hydrologic research when there are no clearly defined goals for the management of New Zealand's water resources and the results of much past research remain unpublished.

3. HYDROLOGIC RESEARCH IN TUSSOCK GRASSLANDS AND MOUNTAIN LANDS

In this section we review research activity in the tussock grassland, mountain lands and related hill country.

3.1 Precipitation

3.1.1 Introduction

It has been well established that high-country regions produce much of New Zealand's water resource. For example, 95% of the water in the Waitaki system is derived from a limited area close to the main divide (142). But source areas such as these are steep and access is difficult. In consequence, records tend to be sparse. For example, in the Clutha catchment (136) only 15% of the rainfall stations are at altitudes greater than 500 m and none is over 1,000 m. Precipitation maps must, therefore, be approximate.

It does not necessarily follow, however, that additional information is always needed. The accuracy with which regional precipitation is estimated depends on the region and the degree to which the basin's water resources are allocated or likely to be allocated. It also depends on the purpose for which the information is needed.

3.1.2 Snow and Ice

Permanent snow and ice and snow have an important regulatory effect on stream flow (8). Winter flows tend to be decreased and summer flows tend to be increased relative to catchments without glacier snow.

Permanent snow and ice studies have been carried out on the Tasman and Ivory glaciers (5, 6, 7, 9, 45). Under the present climatic conditions, glaciers are releasing more water than they are receiving by way of snowfall. If this trend continues, most of the small glaciers will disappear in the next 100 years (8). The Ivory glacier is a Representative Basin in which water, ice and energy balance studies are carried out (6).

3.1.3 Snow

Studies based on snow courses have been made in the Devils Elbow Catchment, Lake Pukaki (134), the Frazer catchment, Central Otago (68), Round Hill ski field (44), Lake Ohau (44), Twin Stream, Ben Ohau Range (15), Mt Ruapehu (94), Tasman Glacier (44), and the Craigieburn Range (132, 144, 145). Snow studies have been made continuously on the Ivory Glacier since the winter of 1969.

Snow makes a significant and perhaps undervalued contribution to runoff in many New Zealand rivers (8, 64). Fitzharris (64) considers that the traditional snow course method of estimating the snow resource is unsuited to New Zealand conditions and that simple empirical relationships between snow accumulation and elevation are not likely to be reliable. The snow pack varies with elevation as a snow wedge and from a knowledge of the processes which control the shape of this wedge, Fitzharris has proposed an alternative method of estimating snow accumulation.

3.1.4 Rainfall

Unlike river flow which can be measured directly, rainfall must be estimated from samples taken over a catchment. Reliable estimates are possible if individual samples are accurate and the sample points are representative of the region or catchment.

There are 1,500 rainfall stations in New Zealand (51), but it is still true that rain gauges are less than adequately distributed through mountainous and remote areas. However, a number of studies have established the character of rainfall in the Kaweka Ranges (77); Craigieburn (131, 157): Rock and Pillar (99); Old Man Range (128); Cupola Basin and Black Birch (49, 121); and Lammerlaw and Lammermoor Mountains (173). Several ecological studies (48) have recorded short-term rainfalls and other climatic data to provide useful bases on which to construct estimates of the distribution of rainfall. The most common method has been by isohyets or zones of supposed rainfall uniformity.

An alternative method of estimating rainfall in sparsely gauged areas was presented by Hutchinson (98) for Otago but has not yet been validated in other areas. The method, based on multiple regression analysis involving site and topographic features, has particular value to water resource studies. If it were adapted for daily rainfall, it could be of value for flood estimation.

Several studies have been carried out to determine the accuracy with which rainfall is measured at a point (77, 55, 97, 109, 110, 135). The object of these studies has been to explore variations in rainfall measurement at a site to improve methods and techniques of determining "true" rainfall.

While there is an obvious need for reliable estimates of rainfall, it is also true that the topic is attractive because it is a relatively easy and inexpensive area of research. The international literature on this subject is vast. For example, 20 years ago Kurtyka's "Precipitation Measurements Study" listed 1,079 references! (120).

It is sometimes suggested that it is possible to get better estimates of humidity in a space capsule orbiting the moon than for rainfall in a mountain catchment. While this might be true, it cannot by itself be accepted as a justification for more intensive rainfall investigations. For many purposes, approximate values of rainfall are sufficient. The effort put into rainfall measurement must be determined by the use to which the data will be put.

3.1.5 Fog

In some areas fog may be a significant form of precipitation. Franks (66) reported on fog measurement at Makara experimental basin and suggested that the results from standard fog gauges were not entirely satisfactory. She suggested that even if the confounding influence of rain could be eliminated, additional information would be needed on wind velocity and fog droplet size.

Vegetation, particularly tall tussocks, is commonly observed to have intercepted fog, but despite studies on the Rock and Pillar Range (129, 161, 162), the significance of fog to total precipitation is unknown.

3.2 Interception

Interception is a well-known element of the hydrologic cycle and a number of studies have attempted to determine its significance and role in modifying rainfall. These have been carried out in radiata pine forests in coastal Otago (61), gorse and manuka at Taita (1,3) mountain beech forest in the Craigieburn Ranges (159) and Kaweka Ranges (80) and Taita (4), mixed forest in North Westland (160), Kamahi at Taita (111) and snow tussock grasslands in the Rock and Pillar Ranges (161, 162) and Tararua Ranges (127). In addition, Blake has carried out studies on a range of forest, scrubby and herbaceous species at sites throughout New Zealand (19, 22, 24, 25, 26).

With data from a field experiment, Ibbitt (100) has developed a successful mathematical model of catchment interception.

From these studies, it would appear that interception capacity, regardless of vegetation, is in the order of 1-6mm. Higher values have been reported, usually associated with light rain or fog, when interception capacity becomes "super-saturated".

The hydrologic significance of interception is open to debate. Fahey (61) reported that 49% of a 9-month rainfall of 36" was intercepted by a pine forest canopy. He claimed that his results showed "how important a forest cover can be, both in acting as a protection against soil erosion during periods of heavy rainfall and in modifying stream flow". An alternative view could be that percentage values merely effect the frequency of small rainfall events which do not cause erosion or produce runoff and stream flow.

Because the absolute value of interception storage is small, it is difficult to conceive of any situation in which interception *per se* can be of significance to flood hydrology.

The significance of interception to water yield is also open to debate. Mark and Rowley (129) have shown that water surpluses under large snow tussocks exceed those from burnt or clipped snow tussocks. These increases are attributed to gains by interception. This study is a significant contribution to our knowledge of tussock grassland ecology. The authors' conclusion, however, that "maximum water yield (and control) from the low-alpine snow tussock grasslands, is obtained from natural undisturbed cover" has not been the subject of hydrologic research.

While the hydrologic significance of canopy interception is open to question, it is clear that it has been the subject of considerable research effort. It is, therefore, surprising that the interception of water on ground litter has been largely ignored. Dry plant residues will absorb 250-300% moisture (190). As tall tussock grassland soils may carry up to 1000-2000 kg dry matter per hectare (201), it would appear that litter interception could have greater hydrologic significance than canopy interception.

3.3 Soil Moisture

3.3.1 Infiltration

Infiltration studies have been reported from a range of hill country soil and vegetation types (141) and from Otutira (169). Puketurua (25), Makara (208), Porters Pass (69) and Torlesse (90).

All studies note a lack of consistent results but most show that there are significant differences between different soil and plant associations.

At Porters Pass, Gillingham (69) set up a study to investigate possible differences in infiltration rates on ungrazed, regenerating and depleted snow tussock grasslands. Although his results tended to show that infiltration rates decreased with intensity of use, he was unable to establish that significant differences existed.

A study in the Torlesse research area (90) found comparable values to those reported by Gillingham but also noted that regardless of vegetation type and condition, point infiltration values were in excess of all but the most extreme values of rainfall intensity.

While hydrologists concerned with land use have tended to emphasise point values for infiltration rates, engineers have generally been more concerned with the average rate at which water is retained within a catchment during a storm. This loss rate (123) includes the loss through infiltration. As an expression of the integrated losses for a whole catchment, it has been found to be a more useful concept for engineering design.

Published information on loss rates for New Zealand is limited to de Leon's (122) estimates for the Roding catchment in Nelson.

3.3.2 Soil Water

For many years our understanding of the processes by which rainfall is converted to runoff has been dominated by Horton's rainfall excess theory. This theory holds that when rainfall intensity exceeds infiltration rates the excess rainfall moves to the stream channel as overland flow. However, results from infiltration and runoff studies at Torlesse (90) are in line with a growing recognition that the classical Hortonian runoff theory represents only some special cases of the processes of runoff generation. The alternative partial contributing area theory (59) is a logical concept but one which poses formidable problems of data collection for simulation models. One important area is the understanding and measurement of soil water and its related soil physical properties.

Information about the rate of water movement through high country soils is sparse.

Gradwell (73) has presented information on the moisture retention characteristics and saturated hydraulic conductivities of some New Zealand soils, including a few high country soils. In addition, Harvey (88) has given saturated conductivity values for some soils in the Dog Range, Central Canterbury. Gradwell and Jackson (74) have discussed the broad differences in hydrologic behaviour that are to be expected among major soil groups as a result of the pore space characteristics of the soil. Jackson (106) has discussed some aspects of the contribution of soil characteristics to the hydrologic behaviour of forest and pasture.

The seasonal variation of soil moisture (moisture regime) by direct measurement has been studied for a number of soils in Otago and Southland (193, 194). The use of such information in testing improved water balance models has been discussed by Jackson (108).

The measurement of soil moisture itself presents a number of problems which have been outlined by Painter (148), Watt (192), Murray *et al* (137).

3.4 Water Quality

3.4.1 Chemical and Biological Quality

Hill and high country streams have generally been presumed to have few water quality problems and in consequence, few quality studies have been made.

Claridge (46) has presented a chemical balance at Taita and Duncan, Gilchrist and Gillingham have investigated the movement of nutrients on sprinkled plots at Moutere (57, 67). In Northland, McColl has studied chemical runoff during conversion from manuka to pasture (124). Stout has carried out extensive studies into the limnology of mid-Canterbury lakes (178), hydro storage lakes in the Waitaki (179) and lakes in Fiordland (180). In Otago studies have been made on Lake Hayes by Burns and Jolly (31, 32, 33).

3.4.2 Physcial Quality

Erosion in New Zealand hill and high country has been a much publicised topic. It has been frequently asserted that the physical quality of rivers from eroded catchments is downgraded by the sediments they carry. In view of the interest, concern and economic significance of stream sediments, it is surprising that the topic has been virtually ignored by those doing or administering research.

Suspended sediments have been measured in many rivers and streams but most of this information has not been interpreted or published. The Clutha River is a notable exception with Thompson's recent description of siltation in Lake Roxburgh (183).

In Nelson and North Westland, twelve heavily forested catchments are currently being monitored for bed load and suspended sediment by staff of the New Zealand Forest Service (149).

Stream bed investigations have been made in the Branch and Leatham Rivers (Marlborough) (158), Centre Creek (Rakaia) (146) and Camp Stream (113).

The multi-disciplinary Torlesse programme (89, 92) has shed new light on the character of erosion and sediment in a small mountain catchment. The findings from this study call into question some of the more traditional views on relations between land management, hydrology, erosion and stream sediments in this area of mountain land. The extent to which these results are applicable to other regions is unknown and inadequately tested.

3.5 Catchment Research

3.5.1 Representative Basins

Twenty of the 27 South Island representative basins are in part or in whole within the tussock grasslands and mountain lands. In the North Island, 11 of 41 basins are in mountainous or hilly regions.

As outlined earlier, the prime function of these basins is to monitor precipitation and streamflow to provide more reliable estimates of New Zealand's water resource. In addition, some have been used as sites for hydrologic process studies. The most notable are Ngahere (Kaweka Range) (80) and the Ivory Glacier (6, 7, 9).

3.5.2 Experimental Basins

The experimental basin programme has been successful in providing a better understanding of some of the processes in the land phase of the hydrologic cycle. It has been less successful in establishing the hydrologic effect of land use and the influence of man on the water resource.

Findings from 10 of the 11 experimental basins could have some degree of relevance to the tussock grasslands and mountain lands of New Zealand. (The exception is Manukau City). Comprehensive results of the hydrologic impact of land use have been published for Makara (208).

Moutere (163), and Puketurua (168).

At Moutere, two small (about 5 ha) gorse-covered catchments were used to study the hydrologic impact of development of cultivation and cropping.

With development, peak discharges increased particularly in the low and medium flow ranges. Development had little effect on high flows. Total annual runoff was approximately doubled but there was a reduction in the number of days in which runoff occurred.

Studies on 0.6 - 1.5 ha catchments at Makara compared the hydrologic impacts of hard and lax grazing on unimproved and improved pastures.

Pasture production was increased three-fold by oversowing and topdressing. This allowed two and three-fold increases in the stock carried when improved pastures were lax and hard grazed respectively. Pasture improvement was found to reduce the total annual runoff, the number of days during which runoff occurred and peak discharge. The magnitude of these changes was greater when improved pastures were lax grazed.

Schouten (168) has presented the most detailed account of results of an experimental basin in his report of the Puketurua project. Although floods lasted for only short periods they were responsible for about half of the total annual water yield, and most of the suspended material, nitrogen and phosphorous. The frequency and size of floods increased after the conversion of the ground cover from scrub to grass pasture. The most dramatic changes were found to be during the actual period of land development. In consequence of the increased frequency and magnitude of flooding there was an increase in gully activity. The yield of suspended matter increased during the period of cultivation, but the more interesting finding was that before and after conversion the yield of sediment was found to depend on its availability within the channel and gully system. This last point is similar to the findings from the very different environment of the Torlesse research area (92).

The major limitations of these studies is that they cannot be quantitatively applied to other catchments. The problems of extrapolating results from small experimental catchments to larger basins have been known for many years (91). The lack of research effort in this topic is a major research deficiency.

3.5.3 Research at Other Areas

Craigieburn Range: In addition to climatic and hydrologic research (131, 132, 156, 157), studies are being made of transpiration and plant physiology at high altitude (18). This work is of fundamental importance, not only to an understanding of plant growth and responses at high altitude, but as the only source of information on high altitude evapotranspiration.

Chilton Valley, Cass: Canterbury University's mountain field station at Cass has been established for more than 60 years. In the last 10 years, climatic and hydrologic studies have been carried out by staff and students in the Geography Department (82-84, 174-177).

Silverstream Catchment, Otago: In the course of a watershed analysis (195), Watt and Leslie concluded that annual water yields from certain afforested areas within the catchment had been reduced by up to about 20% through conversion of manuka scrub to exotic forest. Watt (191) later estimated a 10% reduction in total flow if afforestation was extended in certain other areas of the catchment. Forest practices within municipal water-supply catchments is further discussed by Barton (16).

3.6 Systems Hydrology

Modelling has always been a feature of research, but in recent years, developments in computers and systems analysis have allowed mathematical modelling of hydrologic systems to develop rapidly.

The most common water resource management problem is a lack of hydrologic data. In hill and high country, as elsewhere, there are longer rainfall records than there are streamflow records. Although rainfall information is often incomplete, it is often possible, by weighting and correlation, to derive reasonable estimates of mean catchment rainfall. A model is then used to relate short-term runoff to rainfall for the same period. Once a reliable runoff response to rainfall can be shown to be sufficiently accurate for the purpose of the investigation, the model can be used to extend the short runoff record by generating synthetic data. It is important to recognise, however, that this synthetic record cannot be more reliable than the data from which it is derived.

Boughton (28) developed a mathematical model which used daily rainfalls to generate daily runoff volumes. His approach has been modified by others to simulate flows in the Opihi River, Waiau River and Weka Stream (86), and for the upper Taieri River (173). Wood and Sutherland (202) have applied the Stanford model to four experimental basins and have suggested a procedure to its use in ungauged catchments. Ibbitt (103) has developed a conceptual model to predict flow in the Maungaparerua River and Sutherland and Taylor have applied the Laurenson model to catchments in attempts to investigate the hydrologic impacts of land use.

These studies have shown that catchment modelling is a powerful, convenient and inexpensive technique in hydrologic research.

4. COMMENTARY

4.1 Future directions of hydrologic research

Based on the information we have reviewed in sections two and three, we could produce a list of topics that we think important for future study. However, to be meaningful such a list would ignore the equally important questions of: whose responsibility is it to carry out such work?; what are the resources available for future hydrologic research?; and the priorities that should be assigned to each study.

We believe that the scope and emphasis of future research programmes should be determined by a special task force of the National Research Advisory Council.

This commentary is intended as guidance for such a task force.

4.2 The nature of hydrologic research

The main purpose of hydrologic research is to provide data and techniques for the design of hydraulic structures and the management of water and soil resources.

The science of hydrology had its origins in water engineering and developed from the need to predict future rates and amounts of runoff for the design of water control structures. Hydrology has long since emerged as a distinctive branch of earth science in which much research effort is devoted to the fundamental understanding of hydrologic processes and the function of biophysical systems. Yet it remains a pragmatic and "learning-by-doing" science. Because of this there will always be a close involvement between hydrology the science, and hydrology the art of water and soil management.

In New Zealand, as in most countries, basic hydrologic data are inadequate. The urgency of the many practical problems facing water and soil managers dictates that such research as can be undertaken must often be of an immediate and ad hoc nature. Under these circumstances, planning and design exercises tend to become applied research projects. It is difficult to distinguish between survey, data collection, investigation and research since these represent a continuous spectrum of endeavour, all directed towards the better management of water and soil resources.

This concept of a spectrum of endeavour is important to the question of allocating the limited resources of finance and manpower to research programmes. The allocation of resources should be determined by considering the accuracy and precision of the proposed research programme in relation to the practical needs for design and planning. For example, there is little point in developing techniques for which data are not available. Likewise there is little point in studying components of a hydrologic process with far greater accuracy than the basic data or design objectives warrant.

Our concern for the relevance of research programmes does not imply a lack of appreciation for the long term value of more fundamental research. The art of successful research management is to balance the importance of short term practical solutions to immediate problems with the longer term value of more fundamental research. In this respect, we are not convinced that past hydrologic research management has been successful.

In the final analysis, both hydrologic research and hydrologic design are dependent upon the availability and adequacy of basic hydrologic data. As a broad generalisation, we think that the need for better data is more urgent than the need for more research. Indeed it might be argued with some justification that New Zealand's water and soil managers would be more effectively served if all research were to cease for the next five years and the financial and manpower resources so made available, devoted entirely to the extension and improvement of the data collection network.

While the need for better data collection can hardly be over-emphasised, this generalisation, like all others, has its limitations. The collection of hydrologic data for its own sake may become a more fruitless exercise than the pursuit of hydrologic research for its own sake. There is little value in collecting data to a higher degree of accuracy than is needed. The most fundamental data for water resource management are streamflow data. It is important to realise that under New Zealand conditions such data can rarely be collected with an order of accuracy of better than ± 10%. The estimation of flood flows is usually much less accurate. There is more to be gained from an extension of the hydrologic data collection network to give as broad a coverage of typical conditions as possible without undue emphasis on accuracy than from an upgrading and intensification of the existing data system.

This clearly suggests some directions and priorities for hydrologic research. There are shortcomings in the existing data collection network and the availability of improved data is as much a function of time as it is of expenditure on equipment and stream gauging installation. It is thus apparent that a strong case can be made for an immediate emphasis on hydrologic research which aims to develop acceptable design and management techniques on the basis of the kinds of data which are now available. A potential spin-off from such research would be an improvement in the data collection system itself. Once it becomes clear just what constitutes minimum data for given kinds of design and management exercises, it should be possible to extend the data collection network so as to maximise its effectiveness given the limited resources available.

So far as the design of water management structures is concerned the most effective research project that could be undertaken in the short-term would be to take all the currently available rainfall and runoff data and apply them to a regional assessment of the streamflow characteristics of a representative range of rivers and streams. In many cases, the results would indicate that a reasonable prediction can be made with available data and techniques. In those regions where data or techniques prove inadequate, the project would clearly indicate where further research and data collection could most effectively be implemented.

An appreciation of the limitations of available basic data and the requirements of data and technique for practical design and management activity must also provide the starting point for the planning of more esoteric research. Currently in New Zealand there are several on-going research projects which seek to measure selected components of the runoff process such as interception or evapotranspiration with considerable accuracy. The significance of these projects must be called to question when the runoff component in the same experiment cannot be measured to better than ± 5% and the future design or management exercise for which the experiment in question might be relevant will be acceptable if it can predict peak rates of runoff or low-flow conditions to an accuracy of ± 20%. Under these circumstances it would be sufficient simply to "guesstimate" interception losses on the basis of known values rather than devoting limited resources to their precise and unnecessary measurement.

In recent years hydrologic research in New Zealand has become increasingly problem-oriented. Priorities for research of this kind were clearly emphasised in Dunford's report (58), and have since been emphasised in the reorganisation of the Water and Soil Division of the Ministry of Works and Development.

While we agree that the selection of priorities for publicly funded hydrologic research in New Zealand should be based on the significance of practical resource management problems, this approach needs to be adopted with caution. Much of the work so far undertaken in New Zealand on experimental basins and similar research has been ineffective because it has been tackled in the manner of an agricultural plot trial where the quantitative effect of a specific change in management practice has been measured <u>ad hoc</u> without any real attempt at insight into the hydrologic processes involved. The results obtained can rarely be extended to other areas or other kinds of problems and these experiments contribute little to improved knowledge of runoff processes or the workings of hydrologic systems. It is important that problem-oriented research be planned in such a way that it gives insight into basic hydrologic processes, capable of extension to similar kinds of problems elsewhere and improves the general ability to predict the likely consequences of hydrologic changes. The land treatment research conducted so far in New Zealand, while it has been directed towards the solution of specific problems, has done no more than record the effects of specific land management practices on specific catchment areas.

Emphasis on problem-oriented research may also divert activity from more fundamental research which contributes to a better understanding of hydrologic processes. Given the limited resources of finance and manpower available for hydrologic research in New Zealand, it is inevitable that priority will be given to the solution of problems of immediate and local interest. Little is to be gained, in any case, from the expenditure of resources on research projects which can be undertaken more effectively overseas. There are some areas, however, which include sediment transport and groundwater, where New Zealand conditions and New Zealand expertise offer an opportunity for the tackling of research projects having international significance. Quite apart from the importance that such research might have for the advancement of the science of hydrology, there are real national benefits to be gained from the involvement of New Zealand hydrologists in work of international standing.

The importance of more fundamental research as a training ground for hydrologists should also not be overlooked. Within the New Zealand universities, in particular, a strong case can be made for undertaking hydrologic research which has little application to immediate problems as an investment against problems which have not yet been defined. We believe that criteria for supporting such work should include its value for student training and its scientific excellence.

4.3 The co-ordination of hydrologic research

Any research programme of consequence in hydrology or in soil and water conservation necessarily transcends many interests and disciplines. A feature of New Zealand interdisciplinary research in these areas has been an apparent lack of, or at best poor, co-ordination and co-operation. Although we have derived these observations from New Zealand scientists and practitioners they have also been cited by several foreign observers (53, 58, 200).

A major cause of this situation is the lack of a definite Government policy with regard to soil and water resources, and an effective vehicle to promote and ensure co-ordination and co-operation in research planning and conduct.

There is a legislatively mandated National Water and Soil Conservation Authority which is required, among other things, to carry out and co-ordinate hydrologic research. Theoretically, this Authority, and its Councils, are national and independent bodies. In fact, however, administrative services and technical support staff are provided by the Ministry of Works and Development. Personnel involved also have responsibilities to the Ministry and thus cannot help but have split loyalties. Williams (200), pointed out this administrative anomaly and documented some of the shortcomings of such an arrangement.

There is also a legislatively mandated and independent National Research Advisory Council. The purpose of this Council is to promote and develop scientific research in New Zealand. One of its functions is to determine priorities for research activities in Government departments having regard for research done by other organisations.

It is clear that the National Water and Soil Conservation Authority considers that it should have the responsibility for guiding, encouraging, and carrying out all hydrologic research in New Zealand (13). It is equally clear that the National Research Advisory Council does not agree with this view (140).

These divergent views on the question of who is to control hydrologic research in New Zealand have contributed, and are still contributing, to its poor co-ordination, and to a lack of harmony and co-operation between agencies and, to a lesser extent, between scientists.

In New Zealand, as in almost all countries, there are a number of agencies which have responsibilities for research and management for the natural resources of water and soil. Some duplication of effort is inherent in any administrative structures set up by governments. However, competition among agencies, as well as independent institutions, serves the useful purpose of keeping people honest and in improving the quality of research.

Agencies with land management or major construction responsibilities have needs for research to carry out of their specific charges. Rarely though are they assigned responsibility for all types of research in a given discipline. We think that there is little enthusiasm, outside of the National Water and Soil Conservation Authority and the Ministry of Works and Development, for the suggestion that N.W.A.S.C.A. be accepted as the source of advice on the overall development of hydrologic research in New Zealand. We recognise, however, that this controversy will continue until the Government provides more specific delineation of responsibilities.

There is an urgent need for a realistic solution to this problem. We favour a reassertion of the role of the National Research Advisory Council. We believe that N.R.A.C. should be totally independent of any Government department or agency. Further, we believe that N.R.A.C. should set up task groups (or subcommittees) with the responsibility of recommending research policies (including responsibilities), research needs and research priorities. The National Research Advisory Council should then balance those needs against other national needs for recommendation to the Government.

While such action would undoubtedly meet with resistance by the National Water and Soil Conservation Authority, we think that it would be accepted by other agencies and the research community at large. We believe it would also be in the best interests of the people of New Zealand.

4.4 Research Management

Although much can be said on this topic, we wish to comment on only three aspects. First, hydrologic research in New Zealand, including high-country hydrologic research, could be much more effective and efficient. The identification of researchable problems, research planning and the construction of problem analyses is at best highly informal and often weak. Second, once a project is undertaken, there is little or no formalised follow-up to report progress. Third, as indicated earlier, there are a large number of hydrologic research projects in New Zealand, but few publications which report their results.

With respect to the identification of research needs and research planning, we think that a more formal procedure should be established to identify and give priority to hydrologic research needs in New Zealand. We suggest that an *ad hoc* task force be set up under the Committee on Energy and Environment of the N.R.A.C. to consider research needs and priorities. This task force should solicit research problems and needs from the scientific community and the users of their information. These problems and research needs should be collated, summarised and given priority on the basis of national needs by the task force. The listing of problems and research needs would presumably include the specific needs of agencies (usually in terms of applied research), as well as applied and basic research, as viewed by scientists. The analysis and recommendations of the task force could go to the N.R.A.C.

Few organisations can afford the luxury of permitting scientists to do "their own thing" *ad infinitum*. This is especially true in a money-tight environment which faces most research organisations today. Thus, we think that research review procedures should be set up to ensure that researchers are in fact utilising public resources efficiently and effectively. As onerous as it might be to the individual scientist, annual progress reports and periodic peer reviews of research projects would be highly useful in ensuring the quality of the research effort and the continuity of research programmes. We think that there is an urgent need to develop research review procedures appropriate to New Zealand's administrative structure and research programmes.

Because of the number of hydrologic research projects reported in 1972, and the record of subsequent publication of results we believe that productivity is unusually low. Administrators responsible for the allocation of public research funds should take positive steps to hasten the publication of research results. As indicated by Dunford (58), "research information is useless unless it is communicated to someone who can use it".

Again, soil and water research in New Zealand has suffered for many years from the lack of co-operation and co-ordination. Speaking to the research programme of the Water and Soil Division of the Ministry of Works and Development, Dunford (58) says "the Division's research programme must shun duplication of effort and competition for a 'place in the sun'. Aside from being economically unsound, these fallacious principles would defeat rather than encourage harmony in the scientific community of New Zealand". An effective and co-ordinated research programme in this field is not likely to be realised until definite policy decisions are made and procedures established. The New Zealand Government owes it to its people and to its scientific community to resolve existing conflicts and to aggressively move ahead on a much needed co-ordinated research effort towards solutions for our unique problems and opportunities in the use, management and protection of the soil and water resources.

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