WATERSHED MANAGEMENT

PART 2

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water resources

8

WATERSHED MANAGEMENT

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PART 2 OF THE PROCEEDINGS OF A SYMPOSIUM ON WATERSHED MANAGEMENT IN WATER RESOURCES DEVELOPMENT

EDITED BY

J. A. HAYWARD

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FOREWORD

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

The Lincoln Papers in Water Resources are published by the New Zealand Agricultural Engineering Institute and printed by the Lincoln College Press. All enquiries should be addressed to the Information Officer, New Zealand Agricultural Engineering Institute, Lincoln College Post Office, Canterbury, New Zealand.

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

The Programme was as follows:

Wednesday, 20th August

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

WHAT IS WATERSHED MANAGEMENT?

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

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

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

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

OBJECTIVES OF WATERSHED MANAGEMENT

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

"Land Management for Water Yield and Water Quality."

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

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

INFLUENCES OF THE "NON-MANAGEMENT" VARIABLES

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

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

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

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

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

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

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

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

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

THE INFLUENCE OF "MANAGEMENT" VARIABLES

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

"Forest Influences."

Mr J. G. Hughes, (Management Officer, Tussock Grasslands and Mountain Lands Institute).

"Is Pastoral Farming Compatible with Watershed Management?"

Dr A. F. Mark, (Botany Department, Otago University); **Miss J. A. Rowley,** (Plant Physiology Division, D.S.I.R., Palmerston North).

"Hydrological Effects in the First Two Years Following Burning and Severe Grazing of Snow Tussock Grassland."

M. E. Yates, (Field Research Officer, Water and Soil Division, Ministry of Works, Wellington).

"The Effect of Modifying Cover Type by Man and Animals on Some Flow Characteristics in Some New Zealand Experimental Basins."

I. R. Falconer, (Drainage Officer, Department of Agriculture, Dunedin).

"The Role of Small Structures for the Control and Use of Water."

Thursday, 21st August

Morning Theme: DOWNSTREAM CONSIDERATIONS

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

D. C. Best, W. R. Howie, (Water and Soil Division, Ministry of Works, Wellington).

"The Role of the Channel System in Determining Streamflow Characteristics."

P. Farlay, (formerly Engineer, Manawatu Catchment Board, Palmerston North).

"Flood Routing Methods and Techniques in the Lower Manawatu Scheme."

Dr A. J. Sutherland, (Senior Lecturer Civil Engineering, Canterbury University).

"Sediment Movement in Streams."

B. E. Milne, (District Electrical Engineer, N.Z. Electricity Department, Palmerston North).

"Siltation in Mangahao Power Project."

G. G. Natusch, (Investigation Engineer, Power, Ministry of Works, Wellington).

"Opportunities for Multiple Use of Hydraulic Structures."

Afternoon Theme: SOCIO-LEGAL CONSIDERATIONS

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

D. Reynolds, (Farm Advisory Officer, Department of Agriculture, Fairlie).

"Upstream Abstractions of Water as a Factor Limiting Downstream Development."

A. J. Gillies, (Chief Engineer, Otago Catchment Board).

"Formulating a Water Policy."

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

"Criteria for Water Allocation, Use and Conservation."

Afternoon Tea.

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

"River Drainage and Erosion Control for Kaikoura."

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

"Economic Principles of Multipurpose Resource Use."

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

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

Friday, 22nd August

Panel Discussion.

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

Chairman—Professor J. R. Burton.

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

Review of Symposium—Professor J. R. Burton.

"What does Watershed Management mean in New Zealand?"

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THE ROLE OF THE CHANNEL SYSTEM

D. C. Best, W. R. Howie,
Water & Soil Division, Ministry of Works, Wellington

INTRODUCTION

The basic role of the channel system is to transport the runoff and erosion products from the catchment it serves. Each system develops in a way characteristic of the catchment size, catchment cover, topography, soil and rock type, and rainfall. The shape of the channel evolved is usually defined by the water sediment complex and the alluvium in which the channel is formed. This paper sets out to describe the influences these factors have on the channel system and the considerations necessary in the management of the system to achieve stability in fulfilling its role. The examples of some New Zealand rivers are given to show the effect of unstable conditions and following from this the benefits that can be obtained from the maintenance of stable conditions.

DEVELOPMENT OF THE CHANNEL SYSTEM

The development of a channel system is a continuing process in which topography, catchment size, catchment cover, soil and rock type, and rainfall characteristics all play their part. Steep, mountainous terrain will generally be dissected much more readily than, say, a coastal plain where the angle of slope and intensity of rainfall are less. The relative resistance of the soil and rock to erosional forces influence the system development which shows a much different form for, say, a greywacke than a limestone land-form. Amounts of vegetal cover of the catchment has been related to the amount of precipitation with forest cover in highest rainfall regions and desert scrub in arid areas. The lessening of erosion by stabilising slopes and the armouring of channels by vegetation is well known.

All these processes are mentioned in a qualitative sense but it has been demonstrated that the drainage pattern so developed has a simple organisation; a feature that so often occurs in Nature. The work of Horton and Strahler (see Leopold, Wolman and Miller, 1964) on stream order showed quantitative relationships between the number of streams, the average stream lengths, the average stream slopes and the stream order. Catchment size then has its influence on the drainage pattern. It has also been suggested (Stall and Yu-Si Fok, 1967) that there is a relationship between sinuosity and stream order.

THE STABLE CHANNEL

A stable channel form is one in which the various hydraulic influences, such as tractive force or shear stress are in harmony with the physical properties of the material in which the channel is formed. For example, channels formed in the cohesive soils of a mildly sloping plain have characteristically steep banks and are often relatively narrow. On the other hand channels in non-cohesive alluvium, usually associated with steeper topography, tend to have more gently sloping banks and are usually rather wide. At the extreme end of the scale channels in erosion resistant rock are dominated almost entirely by the hardness of the rock and landform.

An ideal stable channel shape in non-cohesive alluvium, developed by Lane (1955), has the equation:

$$\frac{y}{yo} = \cos \frac{x \tan \phi}{yo} \qquad \ldots\ldots\ldots\ldots (1)$$

where the symbols used are shown in Fig. 1.

The factors which led to this result were the tractive force of the flow on the banks, the gravity forces on the alluvial particles, and the angle of repose, Ø, of the alluvium. If a section of constant depth is added to the centre of this section no difference to the theory of stability is made and so a stable channel with the required capacity is developed (Henderson, 1966). Such an approach combined with a flow resistance equation such as Manning's can be used to determine stable channel conditions, and as would be expected a particular relationship, for a given

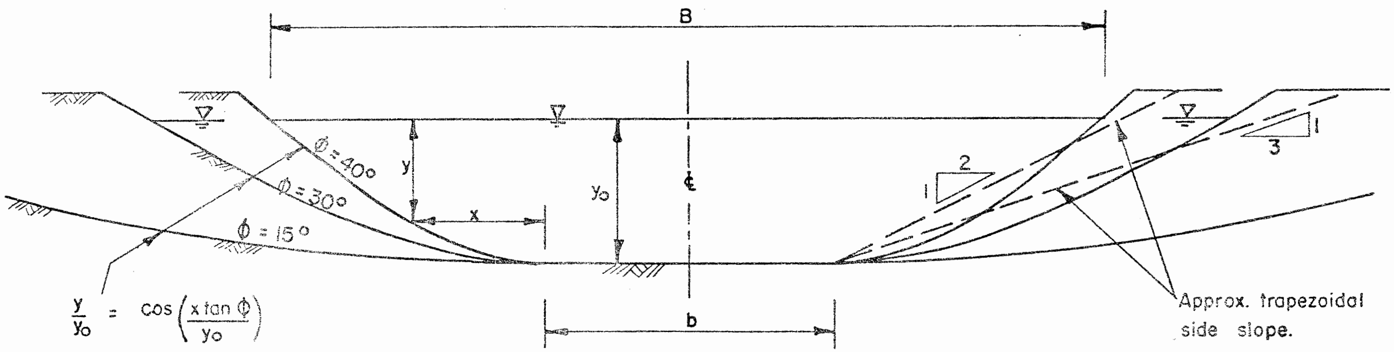

Figure 1

The natural stable channel.

discharge, between the channel slope, width, and stone size emerges. This approach has been used to develop a design procedure for gully control by check dams by one of the authors (Howie, 1968).

A similar analysis of the conditions required for stability in cohesive materials is not yet available, probably because the action of water in the erosion of cohesive materials is considerably more complex. There are, however, many equations which are said to describe the stable channel in these conditions. In the authors' experience a particularly useful concept has been Blench's side and bed factors (Blench, 1957). It has been found that these parameters are a good measure of the cohesive materials resistance to erosion.

THE LONGITUDINAL PROFILE

The reaches of a channel system, typical of many New Zealand rivers, can be placed in three zones, a control zone, including tidal or estuarine section, a sediment balancing zone, and a steep erosive high sediment transporting zone (Campbell, 1965).

The development of the profile is complex and involves many factors of which some are interdependent and others independent. However, irrespective of these complexities, the basic shape of the profile is concave upwards; this concavity is generally more pronounced where there is an increase in discharge or marked decrease in particle size downstream.

Mackin (1948) defined a profile in equilibrium as one in which, over a period of years, slope is delicately adjusted to provide with available discharge and with prevailing channel characteristics, just the velocity required for the transporting of the load supplied from the drainage basin.

(a) The control zone - The tidal reach is different from any other reach in a river in one important respect. In the section of a river remote from tidal effects discharge is independent, being produced by the catchment, and to this discharge the channel accommodates itself. However, in an estuarine channel the discharge is a dependent variable governed by the way in which flow and sediment formed the channel. It can be shown that one of the criteria of a stable estuarine channel is the convergence of the banks from the mouth upstream at a rate which will maintain amplitude of the tidal range by compensating for friction and loss into temporary storage in filling the tidal prism. The log of the channel width in this reach usually shows a linear variation with distance from the mouth.

Particularly where there is a littoral drift along the coast and where tidal influences predominate, it is generally found that a lagoon forms just inside the mouth of the river. It is contended that an optimum size of this lagoon is required to keep a bar from forming at the mouth.

As the width of the tidal reach reduces to the normal regime width for the river, the tidal rise and fall reduces rapidly and the upper part of the control zone is reached.

Depending on slope and bed size the channel form may be either braiding or single thread. Using American data Leopold and Wolman (1957) found a line could be drawn having the equation:

$$S = 0.06\,Q^{-0.44}$$

where S = slope ft/ft
Q = bankfull discharge cusecs

such that all points above the line represented braided channels and those below the line, with few exceptions, represented meandering channels. This is a useful criterion for the designer and gives weight to the fact that high slope and transporting values go with braiding channels; the transporting power being expended on the banks. It follows that braided channels can be confined to a meander pattern if the banks can be made strong enough to resist lateral attack.

(b) The sediment balancing zone - The control zone and works within it can only be maintained if supply of sediment to it is in balance with its ability to transport it. This leads to the next zone in the river profile; the sediment balancing zone. It is in this zone that the battle in control of some New Zealand rivers will need to be fought in the future (e.g. Waimakariri River). In such a river with long reaches of wide channel there are vast areas in which natural storage of sediment can occur and be helped to occur especially when the probable flow and sediment discharge characteristics are known.

(c) The upstream zone - This zone is the steep actively eroding area of a typical relatively short New Zealand river. It is the zone from which the river obtains its fresh supply of sediment and generally the condition of this zone is an indicator of overall stability of the channel system.

(d) Predicting changes in the channel profile - Changes in the trend of a channel profile will result from changes in practically any of the influences which form the channel system. Of these many influences, the two that are usually manipulated in the management of a river system are the amount of sediment supplied to the river and the sediment transporting power of the river

Because there are two causes, a prediction method must be designed so that it can be successfully used with data from both the catchment and the river channel. It is also desirable that the method be such that the professional skills of catchment scientists and river engineers can be brought to bear separately or together as required.

An approach now being developed by the Water and Soild ivision of the Ministry of Works, takes account of these requirements by studying the erosion-sediment transport-aggradation (or degradation) chain in two steps.

The first step establishes a technique using existing or other readily obtainable data to evaluate total sediment transport, over given periods, past two observing points on a river. The method allows for data inputs by hydrological workers as appropriate.

The second step comprises the action needed to make use of the method of prediction purposes. This will involve two different studies:

i. Determining how to use land inventory and other catchment data to predict sediment supply.

ii. For the various estimates of sediment transported determining the effect on aggradation or degradation of river training programmes.

SOME CONSIDERATIONS IN THE MANAGEMENT AND CONTROL OF RIVER CHANNELS

(a) Problem areas - Aggradation is being experienced in many New Zealand rivers and is particularly acute, for example, in the Waipaoa River where rates of up to 0.43 ft/yr have been measured. This has already caused some farms to be less productive through poorer drainage and is reducing the life of the investment in downstream flood control works.

So severe are the problems in the Poverty Bay-East Coast district that a full regional plan of land use and soil conservation practices has been prepared to combat the severe erosion and to bring further economic and social prosperity to the area. The analysis of this project has been particularly comprehensive involving sociologists and economists as well as the more usual disciplines associated with projects of this kind.

The effect on water quality of suspended sediment is an area which will require increasing attention in the future in dealing with stability of the channel system. One incident in which bank erosion on the Tarawera River brought pumice into the supply of process water for the pulp and paper mill at Kawerau points a warning that this aspect should not be overlooked.

(b) Techniques of Management and Control - It can be seen that the problems to be solved in the management of braided channels are ones of sediment supply, alignment and strengthening of banks; flood rise being of lesser importance. In single thread channels concern is most often to limit flood rise giving lower, safer stopbanks and easier, less costly drainage to the river. This is usually accomplished by bend or widening improvements and may also be accompanied by a separate floodway to take all the flow over a safe limit from the main channel (e.g. Manawatu River and proposed Rangitaiki River scheme). A separate floodway is an ideal concept not only in allowing lower flood levels to be maintained in the main channel but also as an insurance against the catastrophic flood; damages are likely to be much less in this event.

To assess the effectiveness of continuing maintenance on the river channel and to ensure that the capacity to pass the design flood discharge is maintained a procedure for observed flows has been developed (Campbell and Caddie, 1967). These channel efficiency surveys provide data that show whether the intention of the work is being achieved or not and highlight those reaches of the channel where perhaps more effort is required.

(c) Benefits to be obtained - Of prime importance to the control of the channel system, is control of the supply of sediment to it, and within it. Not only does an oversupply of sediment decrease the hydraulic efficiency of the channel, but it also gives rise to aggradation which can cause lateral attack in braided channels and higher flood levels in single thread channels. This can seriously affect the economics of flood control works and the effectiveness of reservoirs and dams. So far, however, this latter problem has not become serious in New Zealand. Added to this is the important aspect of water quality; the term being used in the sense as freedom from solids; which is a requisite for most industrial process water, particularly the pulp and paper industry which will be requiring increasing amounts of clean water in the future.

Other benefits which may be expected to accrue from stable channel conditions are, the protection of permanent works along the river banks, the minimum of maintenance of intakes for irrigation, the permanence of drainage of lands adjoining the river, increased productivity from the land with reduced flood risk, and in some areas the maintenance of levels for the recharge of aquifers.

CONCLUSION

The channel system in fulfilling its role of transporting runoff and debris is subject to both physical and hydraulic influences which are working to achieve stability and it is imperative that works in the catchment be planned and constructed to enhance or cause the minimum of upset to this process. The design of these works requires the combined and co-ordinated efforts of many and varied disciplines. Land classifiers and hydrological scientists, soil conservators and engineers, economists and administrators, must all contribute their specialised training, knowledge and experience to the solution of the complex problems of river channel management and control.

ACKNOWLEDGEMENTS

The authors wish to thank the Commissioner of Works for permission to publish this paper and Mr A. P. Campbell for his encouragement and assistance.

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FLOOD ROUTING METHODS AND TECHNIQUES IN THE LOWER MANAWATU SCHEME

P.J. Farley [1]

INTRODUCTION

In March 1965 a major flood occurred in the Manawatu River. The flow at Palmerston North was about 118,000 cusecs and the flow from the Oroua River and other tributaries joining below Palmerston North was about 26,000 cusecs, making a total of 144,000 cusecs at the sluicegates. This was the third highest flood this century and gave an opportunity to check the flood level and the behaviour of the sluicegates under high flow conditions.

The Lower Manawatu Scheme was designed to carry 150,000 cusecs to the sea and save from flooding an area of about 70,000 acres. To achieve this 105,000 is diverted through sluicegates across a floodway to rejoin the river near the sea. The floodway is about six miles long compared to twenty miles via the river.

Two river models were built during the planning of the scheme and also a model of two of the sluicegates. The first river model of the sluicegate area gave flood levels over about four miles of river and was calibrated to give flows in the river and the floodway with the full range of gate opening and river levels. The second river model at the Opiki Bends area was used to fix the flow round major bends and across the loops between the bends. In this case it was found necessary to use two weirs and a number of guide banks to control the relative flow in the river and berm, and this resulted in higher flood levels at the

[1] Formerly: Engineer, Manawatu Catchment Board
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upstream end of this part of the river. In the remaining parts of the river the flood levels were based on calculations.

During the flood, gaugings were made at the sluicegate both in the river downstream of the gates and in the floodway. These gaugings were carried out by jet boat and mainly in the dark under difficult conditions. The line of the gauging below the gates was hard to maintain in the jet boat and variation of line could cause considerable variation of velocity. The results obtained were up to 40% different from the flow calculated on the basis of the model calibration of the sluicegates.

In order to determine what was the actual flow at all reaches of the river and in particular to check the model calibration it was necessary to route the flood flow from Fitzherbert gauge at Palmerston North River 49 miles to the sluicegates at 24 miles.

The routing of this flood also enabled a check to be made of the levels given by the model at the Opiki Bends area and on the calculated flood levels along the balance of the river.

ROUTING METHODS CONSIDERED

Muskingham method[1] - by calculation or analogue computer

Method of Characteristics - Ven Te Chow [2]

Finite Increment Solution of Complete Differential Equations - B. R. Gilcrest [3]

Storage Routing - F. M. Henderson [4]

The storage method was the only one that could be used with the limited data available for the Manawatu and Professor Henderson's semigraphical solution was adopted.

AVAILABLE DATA

As well as the flood hydrograph at Palmerston North there were records of flood levels at regular intervals along the river. These went back for a number of years and were available as a series of longtitudinal profiles. Survey data comprised aerial photographs and cross sections at each mile up the river.

DATA PROCESSING

Because of the limited amount of data available it was decided to use only a single valued (or variable) storage function and use short routing reaches in order to minimise the errors this would introduce. This meant that wedge storage was ignored but by using short lengths the volume of the storage was kept relatively small.

The length of river involved was divided into three reaches which coincided fairly closely with physical changes in the river; these were:

$49^m - 41^m$; shingle, grade 7 ft - 3 ft per mile

$41^m - 32^m$; silt and shingle, very meandering, 3 ft - 1 ft per mile

$32^m - 24^m$; silt, normal about 1 ft per mile

At each end of the reaches rating curves were compiled and by interpolation on the rating curves a complete range of flood profiles derived. From these the flood levels were plotted on the cross sections and the volumes of storage calculated for each reach at each flow. Using these figures a storage discharge (S-O) curve was drawn from each reach. This gave the volume of storage for any value of discharge. Then from each storage curve a further curve (O-N) was derived to simplify the calculations (Fig. 2).

The method for deriving the O-N curve and carrying out the routing is described by means of an example in appendix A.

RESULTS

Originally the calculations were carried out using a three hour routing period but this appeared to mask some of

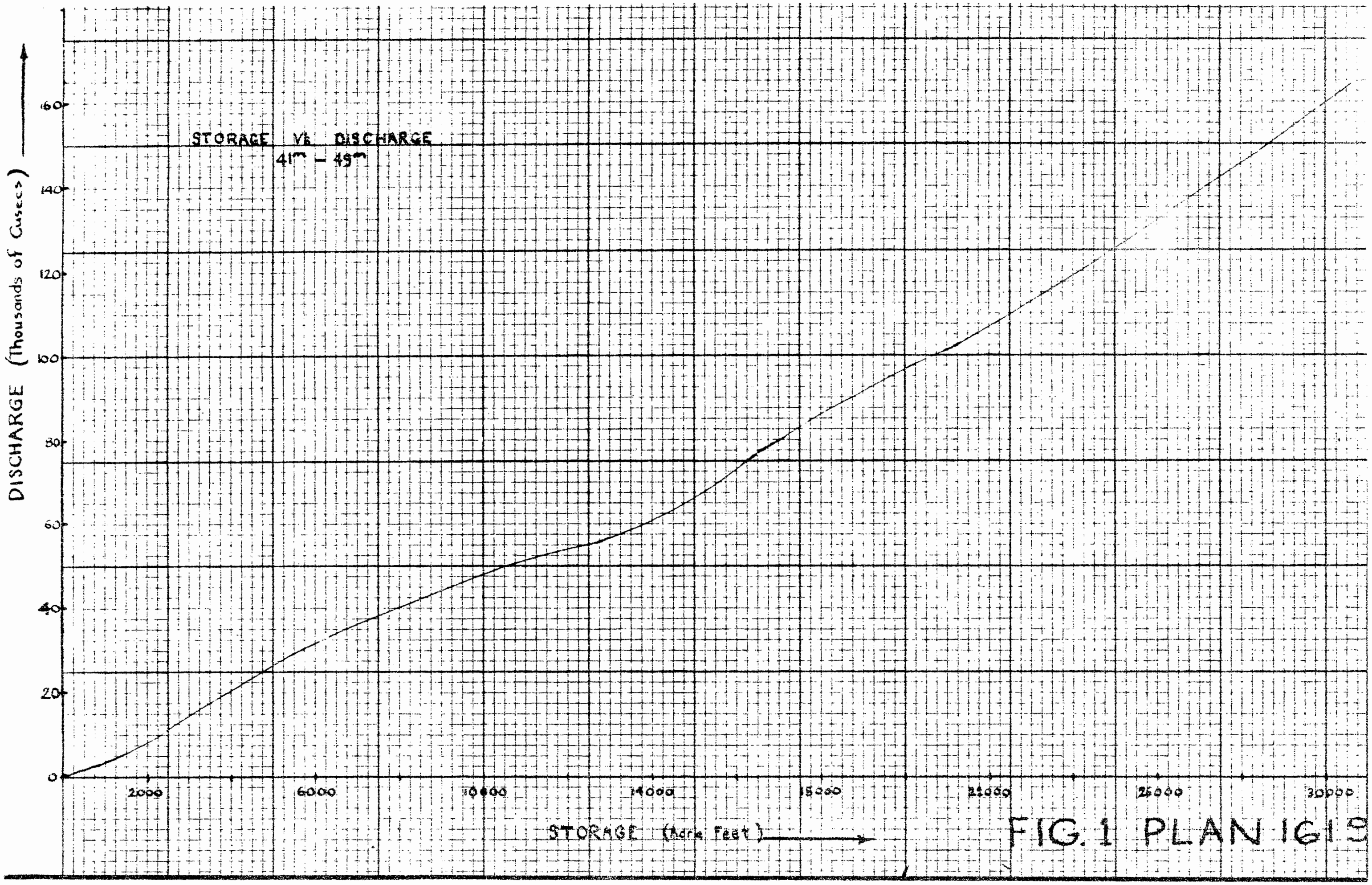

Figure 1

Discharge-storage curve for river section 41^m-49^m

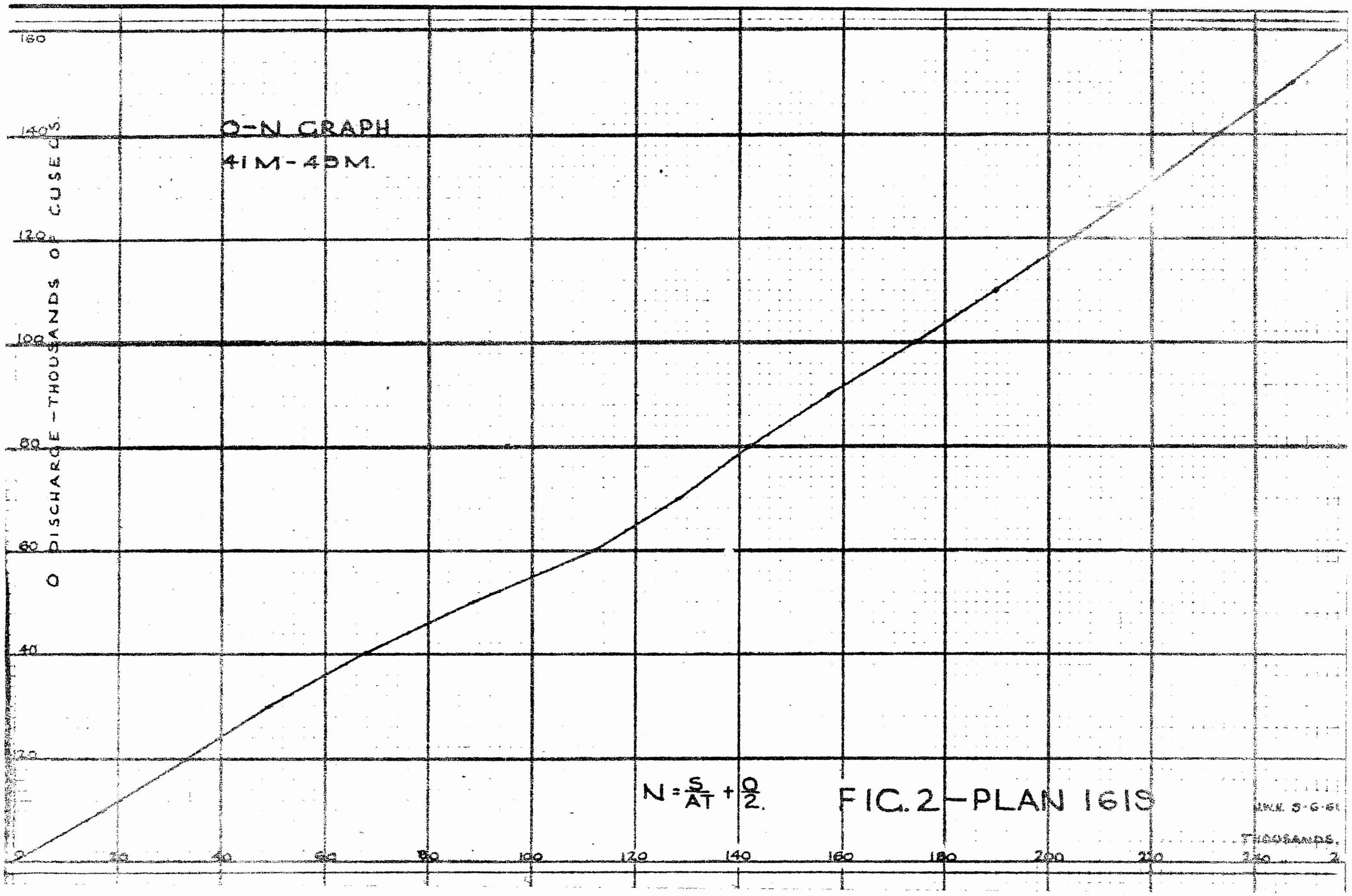

Figure 2

O-N curve for river section 41^m-49^m

the expected berm overflow characteristics. Another set of hydrographs was therefore calculated using a two hour routing period.

In both cases the speed of the flood wave and the general shape of the hydrographs were the same. The shorter routing period showed more accurately the effect of overflow into ponding areas in the Opiki Bends.

Although the detailed accuracy of the calculations may be questioned in several respects (e.g. ignoring wedge storage, incomplete survey data, unconfirmed rating curves), the derived hydrographs show clearly that the duration of the flood peak was reduced but that no significant attenuation occurred (Fig. 3).

Table 1 - Approximate Peak Flood Flows

Manawatu at Fitzherbert	120,000	
Manawatu at sluicegates (routed)	120,000	
Mangaone	1,000	
Tiritea	5,000	
Oroua at Manawatu junction	20,000	
	146,000	cusecs
Manawatu Catchment Board (calculations)		
River at sluicegates	56,000	
Floodway from model tests	86,000	
	142,000	cusecs
Hydrological Survey Party (gauging)		
River at sluicegates	42,000	
Floodway	61,000	
	101,000	cusecs

It is interesting to compare the routed hydrograph at the sluicegates with the hydrograph based on the model . In view of the simplifying assumptions made in the routing analysis they agree remarkable well in both

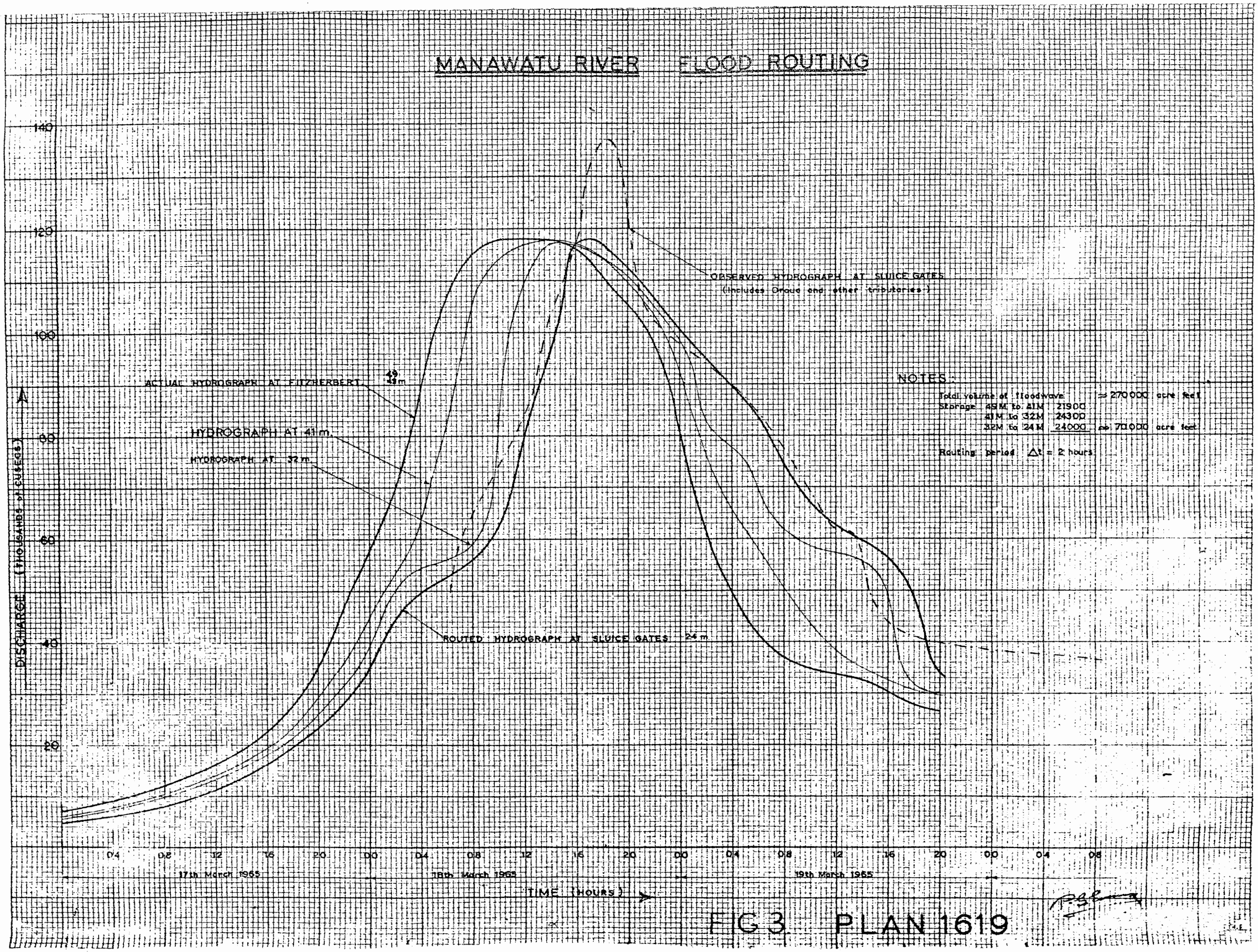

Figure 3

Routed and actual hydrographs, Manawatu River time and shape. The routed peak is some 20,000 cusecs lower which may be accounted for by the tributary flow as shown above.

NOTES ON METHOD USED

The basic equations for unsteady flow may be written as:

$$\frac{\partial Q}{\partial X} + \frac{\partial A}{\partial T} = 0 \qquad \text{Continuity equation}$$

$$\frac{\partial Y}{\partial X} + \frac{V}{g}\frac{\partial V}{\partial X} + \frac{I}{g}\frac{\partial V}{\partial T} = So - Sc - \text{Dynamic equation}$$

where $\frac{\partial Q}{\partial X}$ represents rate of change of discharge with distance

$\frac{\partial A}{\partial T}$ represents rate of change of area with time

$\frac{\partial Y}{\partial X}$ represents rate of change of depth with distance

$\frac{\partial V}{\partial X}$ represents rate of change of velocity with distance

$\frac{\partial V}{\partial T}$ represents rate of change of velocity with time

g is gravitational acceleration

So is the river bed slope

Sc is the water surface slope

The storage routing method assumes that the acceleration terms in the dynamic equation are small enough to be ignored. This is considered to be true providing that the channel slope is small (i.e. less than two feet per mile).

This criterion is met for all the river below 41^m and it appears from the Palmerston North hydrograph that the section

$49^m - 41^m$ may also be considered of mild slope. This is because of the comparatively slow and steady rise in the river which means that for an eight mile length of river over any two hour period that conditions are never very far from steady flow.

Neglecting wedge storage was a time saving simplification and the errors so caused were minimised by using short routing reaches. In this it is felt that the percentage of error involved in ignoring wedge storage is much less than that involved in the original calculations of storage volumes.

CONCLUSIONS

The storage routing method is applicable to the section of the Manawatu River investigated and should therefore be applicable to all similar rivers. The greatest source of error in the calculations would have been in the calculation of storage volumes at the various water levels. For further work it is recommended that volume calculations be based on cross sections at half mile intervals or less. The effect of tributary flow and how to handle it in the storage routing method could be a profitable study.

APPENDIX A

CALCULATIONS FROM STORAGE DISCHARGE CURVE

Obtaining the storage-discharge (S-O) curve is a matter of simple arithmetic and a lot of planimetry providing that satisfactory cross sections are available and that there are sufficient records to provide a series of flood profiles covering all discharges up to the maximum required.

Thus we have a graph of O cusecs and S acre feet. Now to a close approximation:

1 acre feet 12 cusec hours

and in this case $\Delta T = 2$ hours

$$\text{therefore } \frac{S \text{ acre feet}}{\Delta T \text{ hours}} \doteqdot \frac{S\,(\text{acre feet})}{2}\ 12 \text{ cusecs}$$

$$= 6S \text{ cusecs}$$

A table is drawn up as follows from the storage graph:

(1)	(2)	(3)	(4)	(5)
0	$\frac{0}{2}$	S acre ft	$\frac{S}{\Delta T}$ cusecs	$N = \frac{S}{\Delta T} + \frac{0}{2}$
10,000		2,400		
20,000		4,200		
30,000		6,000		

This is filled in as follows:

Column (2) = ½ x column (1)
Column (4) = 6 x column (3)
Column (5) = column (4) + column (2)

Then the graph of O - N is drawn using the figures in columns (1) and (5)

To use this graph a table is drawn up as follows and the inflow hydrograph information put onto it:

Time	Inflow I cusecs	$\bar{I} = \frac{I1 + I2}{2}$	N	$\Delta N = I-0$	Outflow cusecs
17/3/65					
06	2800		5800	graph	2800 *
08	3000				
10	3200				
12	3500				
etc.					

The assumption is made that at this point the inflow to the reach is equal to the outflow, i.e. conditions are steady.
* Therefore the initial outflow can be put down 2800 cusecs. Now from the graph the value of 0 correspondends to a value of N = 5800 which can be put down as shown. We now calculate the average inflow for the first period, i.e.

$$\bar{I} = \frac{2800 + 3000}{2} = 2900 \text{ and put}$$

this in the third column. Now using this value of $\bar{I}$ and the previous value of 0 we calculate ΔN as follows:

$$\Delta N = \bar{I} - 0$$
$$= 2900 - 2800$$
$$= 100$$

Thus we now have in the table:

Time	Inflow	$\bar{I}$	N	ΔN	0
17/3					
06	2800		5800		2800
		2900		100	
08	300		5900		2900
10	3200				

Now knowing the previous value of N - 5800 and ΔN = 100 we have the next value of N = 5800 + 100
= 5900
and corresponding to this from the graph we have the next value of outflow 0 = 2900. The cycle of calculations has now been set up and carries on quite simply to the finish.

$$\text{i.e.} \quad \bar{I} - 0 = \Delta N$$
$$N_1 + \Delta N = N_2 \text{ etc.}$$

Time	Inflow	$I = \frac{1I + 1II}{2}$ cusecs	N cusecs	ΔN ΔN = I-0	Outflow Cusecs
17/3/65					
06	2800		2800		2800 $49_m - 41_m$
		2900		100	
08	3000		5900		2900 ΔT -2hrs
		3100		100	
10	3200		6100		3000
		3350		350	
12	3500		6450		3200
		3700		500	
14	3900		6950		3400
		4100		700	
16	4300		7650		3700
		4650		950	
18	5000		8600		4300
		5250		950	
20	5500		9550		4700
		5950		1250	
22	6400		10800		5400
		8800		1900	

Time Hrs	Inflow Cusecs	I = (1I + 1II)/2 cusecs	N cusecs	ΔN ΔN = I-O	Outflow Cusecs
18/3/65					
00	7200	7700	12200	1500	6200
02	8200	8800	13700	1900	6900
04	9400	10000	15600	2100	7900
06	10600	11400	17700	2200	9200
08	12200	13200	19900	2900	10300
10	14200	15300	22800	3300	12000
12	16400	17700	26100	3700	14000
14	19000	20900	29800	4500	16400
16	22800	25300	34300	5900	19400
18	27800	31700	40200	8300	23400
20	35600	41300	48500	11700	29600
22	47000	52250	60200	16250	36000
19/3/65					
00	57500	63750	76450	18150	45600
02	70000	79750	94600	26450	53300
04	89580	97950	121050	34550	63400
06	106400	110850	155600	29150	81700
08	115300	116600	184750	11200	105400
10	117900	117950	195950	3950	114000
12	118000	118000	199900	100	117000
14	118000	117150	200000	-50	117200
16	116300	113550	199980	3350	117100
18	110800	108200	196400	6200	114400
20	105600	101800	190200	7800	109600
22	75000	89900	182400	13600	103500
20/3/65					
00	81800	71900	168800	20200	92100
02	62000	55650	148600	20850	76500
04	49300	44350	127750	21150	65500
06	41400	39200	106600	18900	58100
08	3700	36000	87700	14400	50400
10	35000	34400	73300	9500	43900
12	33800	33400	63800	4900	38300
14	33000	31500	58900	3600	35100
16	30000	28850	55300	3950	32800
18	27700	27250	51350	3150	30400
20	26800		48200		29500

$49-41^m$
ΔT=2hrs

DISCUSSION

Statement: R. Zander (Wellington Acclimatization Society)

It is not often that "river improvement" schemes have recreational advantages. However, I would like to report that one result of this scheme has been an improved wild fowl habitat.

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SEDIMENT MOVEMENT IN STREAMS

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SUMMARY

This paper presents a survey of the processes by which alluvial streams transport sediment. The differing modes of transport and the changes to be expected in bed profile with varying transport rates are described. The influence of these changes on effective channel roughness is demonstrated with an example showing a five fold decrease in friction factor with increase in velocity at constant depth. It is recommended that the Shields Diagram form the basis for calculations on channel stability and that predictions of sediment discharge based on published formulae be treated with suspicion. A better procedure is to make use where possible of the sediment rating curves prepared by the Soil and Water Division of the Ministry of Works for particular sites on particular rivers. It is concluded that the available techniques for predicting sediment discharge in alluvial channels can only give rough estimates of the true discharge.

INTRODUCTION

Streams and rivers, by virtue of the energy contained in the flow, have the power to transport sedimentary material. If a source of sediment is available, a stream will entrain the material and transport it, often over great distances. Possible sources include the surrounding country and, if it is an alluvial stream, the banks and the bed of the channel. It has been estimated[1] that sediment is removed from the land and deposited in a marine environment at a rate of 20×10^9 tons/year with rivers in Asia contributing 80% of the total. Some yields for various rivers are listed in Table 1.

Table 1 - Sediment Yield of Selected Rivers				
River	Location	Average Sediment 10^3 Tons	Annual Yield Tons/sq.m	Source of Data
Yellow	China	2,080,000	7,540	Ref. 1
Mississippi	U.S.A.	344,000	280	Ref. 1
Nile	Egypt	122,000	100	Ref. 1
Murray-Darling	Australia	35,190	85	Ref. 1
Waipaoa	Kanakanaia	12,160	19,930	Ref.1&2
Clutha	Clyde	525	113	Ref. 3
Buller	Woolfs	183	104	Ref. 3
Wanganui	Te Maire	365	424	Ref. 2

A knowledge of the amount of sediment a river may be expected to transport is important for many applications. Flood control schemes require expected water levels which depend on scour and deposition at downstream sections. Similar problems occur with irrigation channels and in the dredging of river ports. The economic life of reservoirs is directly related to the sediment deposition within the lake - it has been estimated that between 1935 and 1948 2×10^9 tons of sediment deposited in Lake Mead behind Hoover Dam.

The sediment transport capacity of a moving fluid is the maximum rate at which the fluid can transport a particular sediment mixture. It is assumed for this definition that a sufficient quantity of sediment is available to satisfy the transporting capacity. If this is not so, the flow will transport all that is available with the rate of transport being independent of flow conditions. Both situations can exist together in natural channels because of the wide range of particle sizes that may be present. The larger sizes will approximate to the bed material size and the transport rate will adjust to the capacity of the flow. This portion of the load is termed the bed-material load and its transport rate is prescribed by the local flow conditions. There is a continual interchange of such particles between the bed and the body of the stream. The finer sizes, termed wash load, usually remain in suspension and have no counterparts in the bed. Transport of this material is independent of the flow and depends only on the supply, i.e. conditions external to the flow.

One can now define an alluvial channel as one in which the bed is composed of sediment of the same type as that being transported. In such a channel the bed configuration and the flow characteristics are interdependent. An increase in local transport rate will result in scour while a decrease will cause deposition. In symbols

$$\frac{d}{dt}(f(B)) = g(B) - g(S)$$

where B is a mathematical description of the boundary

$\frac{d}{dt}(f(B))$ is the local rate of scour or deposition

g(B) is the local transport rate as a function of the bed geometry and

g(S) is the transport rate or supply into the region under consideration.

An alluvial stream in equilibrium would have g(B) = g(S). If an obstruction such as a bridge pier were placed in the stream the uniform flow pattern would be disrupted and the bed configuration B, would change accordingly. The greater velocities would increase g(B) and scour would result. As the scour hole enlarges g(B) would decrease until it again equalled g(S) at which time an equilibrium bed would have been established. Laursen[4] has considered this problem in detail. In general the solution of the above equation depends upon the establishment of mathematical relations relating the bed geometry, transport rate and supply rate to flow conditions and time. Such relations are unknown at present and recourse is usually made to model studies.

BED FORMS AND CHANNEL ROUGHNESS

For the case of alluvial channels in equilibrium some progress has been made with the physical mechanisms involved being at least partially understood. Here the transport rate is a function of sediment properties and flow conditions with the bed geometry being a dependent rather than an independent variable. The various types of stable bed that occur under different flow conditions are discussed below.

Firstly, at low velocities the sediment grains will be unaffected, the bed form remaining unchanged. This is equivalent to flow over a rigid boundary. As the velocity is increased a critical value (more correctly a critical value of the bed shear stress) is reached at which grain motion begins. This value depends on the bed shape, being greater for a flat bed than for a duned bed. At slightly higher velocities bed features, termed dunes, form. These are irregular haphazardly located sharp-crested features which move downstream. The details of the pattern change continually and the bed must be considered as a deformable boundary. It is an equilibrium state in the sense that average dune height, dune spacing and bed roughness remain constant. Some writers refer to the small regular dunes that form at low velocities as ripples. The mechanisms of formation and maintenance of both ripples and dunes would appear to be the same implying that any distinction between them, other than size, is not justifiable. Several explanations (e.g. refs 5, 6) have been given for the formation of these features. None are entirely satisfactory due mainly to the difficulty of expressing the particle and fluid interaction in definitive terms.

At still higher velocities the dunes disappear and the bed becomes flat again. At the transition point features called sand waves can form. These are essentially regions of flat bed with high flow velocity and low depth followed by regions of duned bed with larger flow depths and lower velocities. Higher velocities cause the formation of antidunes which are sinusoidal in form and are strongly coupled with the water surface. They usually occur in trains of up to twenty waves and move upstream, material being deposited on upstream faces and scoured from downstream faces. Antidunes are often accompanied by significant water surface waves which tend to grow in amplitude and then break.

As the bed form adjusts to changes in flow velocity so the roughness of the bed changes. On flat beds with no grain motion the only roughness is that of the sand grains. The friction factor can thus be deduced from a pipe flow resistance diagram. With a dune bed the roughness arises from the sand grains and from the irregular shape of the bed. The flow resistance in this case is greater and therefore the friction factor and Manning's n are increased. For a flat bed with grain motion the roughness elements are in motion and offer a different resistance; slightly less than stationary grains. Antidunes do not change the friction factor appreciably from that of a flat bed with grain motion unless wave breaking occurs with the associated loss of energy.

The dependence of resistance and friction factor for flow in an alluvial channel upon the bed form can be quite marked. Experiments have shown that friction factors can vary by factors of six or more. Figure 1a shows a reduction of approximately five times for flow in a laboratory channel as the velocity is increased at constant depth. The effect is, however, not confined to the laboratory. In figure 1b the results of measurements made on the Rio Grande River during the passage of a spring flood are shown. The observed six fold variation in friction factor is too large to be accounted for by the small changes in sediment size that occurred (0.35mm to 0.44mm), or the changes in slope, viz 7.5×10^{-4} to 10.0×10^{-4}. The evidence strongly suggests a dependence of friction factor on bed form. One notes also the possibility, when the roughness changes, of flows at the same slope and hydraulic radius but at different velocities. Change of bed roughness is also thought to be responsible for discontinuous rating curves.

Prediction of roughness is an important factor in design work concerned with alluvial channels. Einstein and Barbarossa[7] have suggested a method which, using

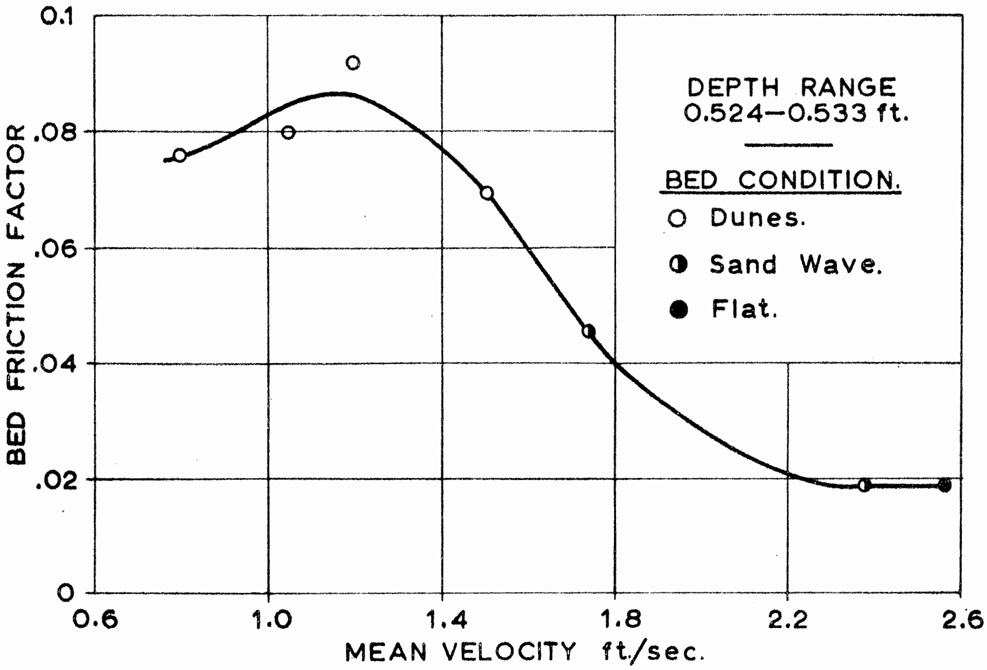

Figure 1 **(a)**
Variation of bed friction factor with flow velocity in a laboratory flume. Sediment size: 0.137mm.

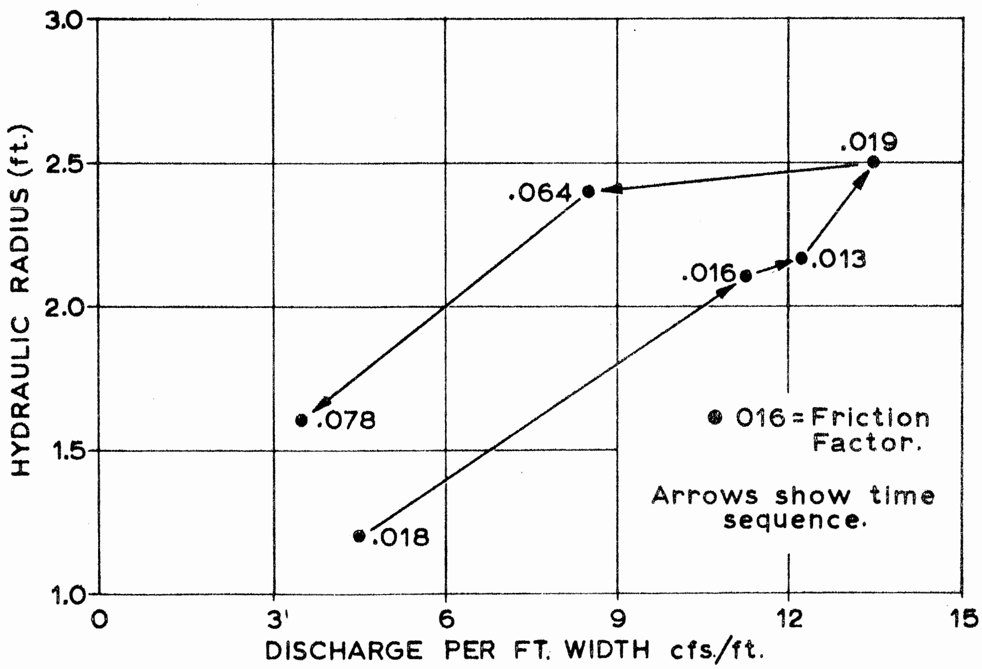

Figure 1 **(b)**
Variation of hydraulic radius and friction factor with discharge for Rio Grande River at Bernalillo, New Mexico, April-July 1952. Data from Ref. 9.

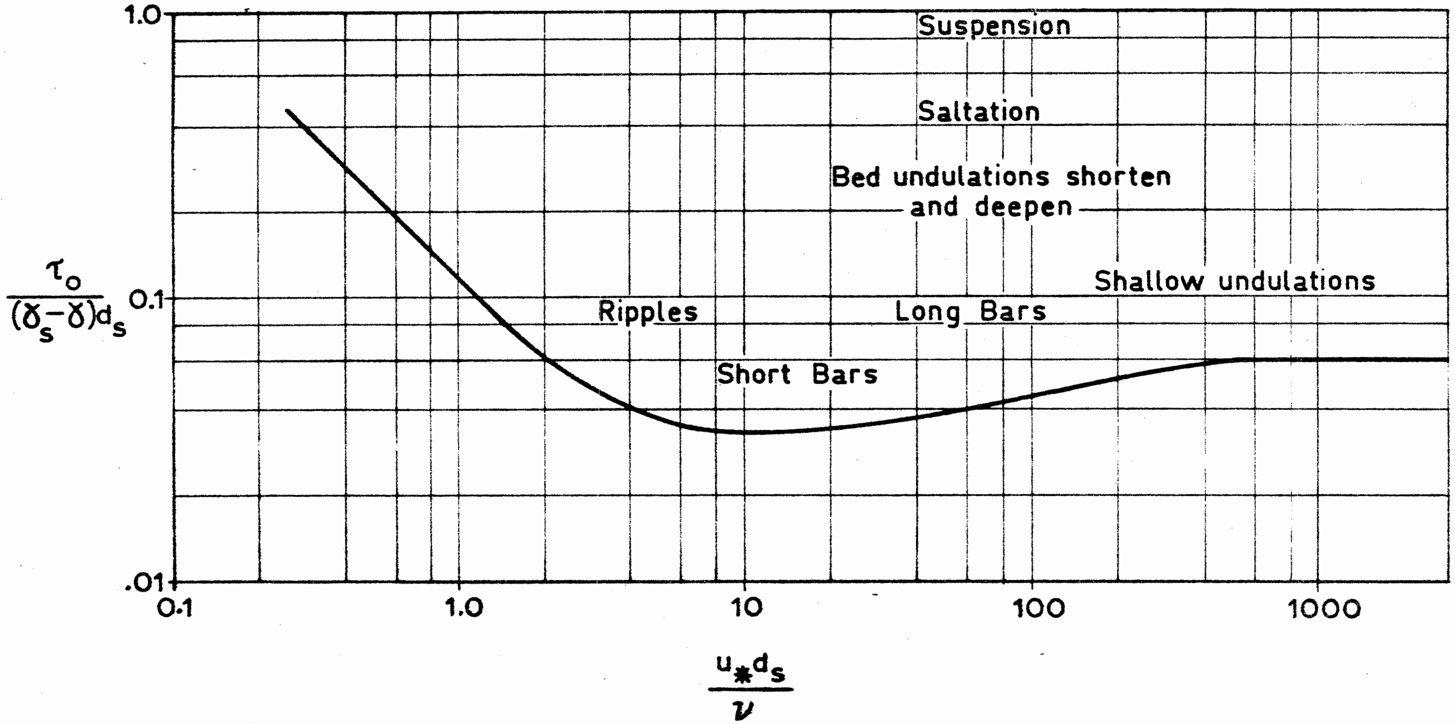

Figure 2
Shields diagram for critical shear stress.

the discharge, sediment properties, channel geometry and slope as basic data, predicts the roughness and thus a rating curve. The physical basis for their method is obscure and while some of the results are accurate others show serious discrepancies with measured values. Engineers are thus forced to rely on their own judgement and experience or on any available field data they have access to.

It is doubtful whether changes in roughness are important in streams with beds of silt or clay. This material is so easily moved by flowing water that dunes never attain a significant size. With very coarse material the sediment moves primarily as bed load and the bed roughness does not change radically. Consequently the multiple relationship between discharge, depth and slope will be of importance for intermediate sizes, e.g. fine sand, under ordinary circumstances or possibly coarse material under flood conditions.

GRAIN MOVEMENT

Certain problems require a knowledge of the critical flow conditions which will just initiate sediment motion. The most useful analysis in this regard was done by Shields who expressed his experimental results by the equation:

$$\frac{\tau_c}{(\gamma_s - \gamma)d_s} = f\left(\frac{U_{*c}\, d_s}{\nu}\right)$$

where τ_c is the bed shear stress when particle motion begins, d_s is the sediment size, U_{*c} is the shear velocity $(= (\tau_c/\rho)^{\frac{1}{2}})$, ρ is the fluid density, γ_s and γ are the specific weights of the sediment and fluid, ν is the kinematic viscosity of the fluid and f denotes function of. Shields' results are shown in figure 2 on a plot of

$$\frac{\tau_o}{(\gamma_s - \gamma)d_s} \quad v \quad \frac{U_* d_s}{\nu}$$

where τ_o is the bed shear stress and $U_* = (\tau_o/\rho)^{\frac{1}{2}}$. The Shields curve shows values of critical shear stress. At points above the curve particles will move; an indication of the bed forms to be expected is given on the plot.

Below the curve the particles will remain stationary. The diagram is strictly only applicable for incipient motion on the flat beds. Little is known about incipient motion on dune beds although some evidence suggests that motion first occurs at lower velocities in this case. Differences are small and probably of the same order as uncertainties in Shields' work. It is recommended that Shields diagram be used whenever an indication of the critical flow condition is required.

Once a grain is disturbed its motion is dependent upon the interaction of all the forces on the grain. These include the lift and drag exerted by the fluid, the grain's submerged weight and the inertia force due to the momentum of the grain. Turbulent motions within the fluid cause the lift and drag forces to fluctuate in magnitude and direction, even to the extent of reversing the direction of application. If the moment of the instantaneous lift forces on a grain about its point of contact exceeds the moment of the submerged weight about the same point the particle will start to roll. It will continue to do so until it reaches a position downstream where it is again stable. If the lift force exceeds the weight force at any instant the particle will be lifted from the bed and carried upwards. It can then either fall back to the bed at some point just downstream, i.e. saltate, or be further lifted by the turbulent flow and suspended. Its further motion is then governed by the turbulent pattern of the moving fluid and its intensity in relation to the weight of the particle.

Movement of sediment has been classified on the basis of mode of transport as bed load and suspended load. Bed load (rolling and saltation) is that portion of the total load that moves on or near the bed where both the transport and the flow pattern are influenced by the bed. Suspended load moves relatively far from the bed and is governed by the fully developed turbulence field. The above distinction is, in practice, a little meangingless in that material which is bed load at one time can be suspended load an instant later, since there is a continuous interchange of material between the two modes. Their sum represents the total load.

The vertical distribution of suspended sediment in two dimensional steady flow is determined by the balance between the rate of upward flow of sediment due to turbulent diffusion and the downward rate due to settling under gravity. The balance can be expressed as:

$$\frac{c}{c_a} = \left(\frac{d-y}{y} \; \frac{a}{d-a}\right)^z$$

where $z = w/kU_*$ and c is the concentration at distance y from the bed, c_a is the concentration at some reference level y = a, w is the settling velocity of the grain, k is a constant (usually equal to 0.4), U_* is the shear velocity and d is the stream depth. The equation applies to that fraction of the load with settling velocity w. Figure 3 shows curves, derived using this equation, of relative concentration of suspended sediment for several values of z with the reference level a = 0.05d. Experiments in the field and in the laboratory have shown close agreement between the form of the theoretical and the observed distributions(8).

As the ratio w/U_*, z is a measure of the effort required to transport the sediment divided by a measure of the transporting power of the stream. Coarse material will have high values of z and it is seen from figure 3 that this material will remain close to the bed. The finer fractions which have lower z values will be more uniformly distributed throughout the depth. The parameter z can also be used to judge qualitatively if appreciable quantities of sediment are being carried in suspension. When z exceeds 2 or 3 most of the sediment is moving near the bed. For $z \doteq 0.1$ sediment would be seen on the surface of the stream.

COMPUTATION OF SEDIMENT DISCHARGE

The suspended sediment discharge can be predicted from the distribution equation by evaluating the integral

$$\int_a^d cv \, dy$$

where c and v are the sediment concentration and fluid velocity at elevation y above the bed. The integral

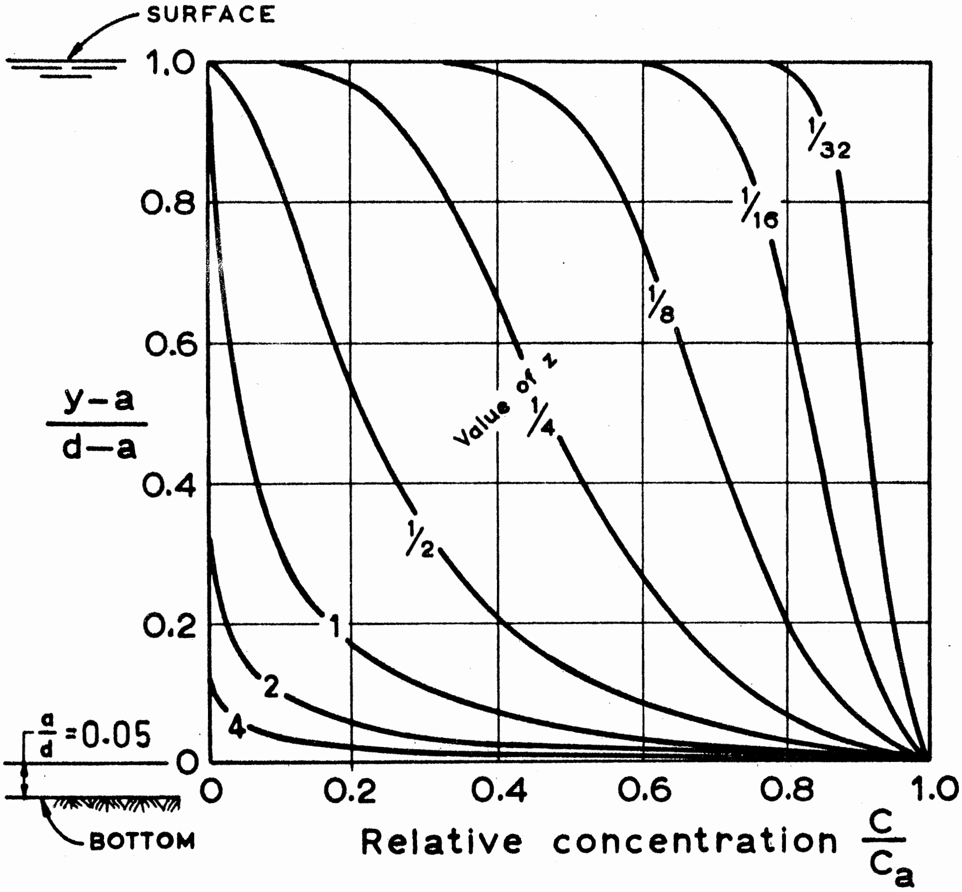

Figure 3

Distribution of suspended load in a flow.
(From Ref. 8).

cannot be evaluated precisely since there is no way of determining c_a. There are empirical methods based on bed load considerations for estimating c_a. River sediments are usually well graded and thus must be broken up into size fractions, the above integral being evaluated for each fraction.

There are no general theories for bed load discharge. Being empirical each theory is only appropriate for a limited range of conditions, viz. those under which the data upon which it is based was collected. In this sense all formulae are actually total load formulae. The early ones were termed bed load formulae because in the experiments upon which they were based suspended load was insignificant. More recent formulae do apply specifically to the suspended load situation.

Examples of sediment discharge formulae are given in the Handbook of Fluid Dynamics edited by Streeter. Most of them contain terms such as the bed shear stress, depth, and mean velocity. To express the sediment discharge g_s, in terms of the fluid discharge q, in such equations a relation between q and the depth is needed. The flow equation e.g. Manning's equation gives such a relation if the friction factor is known. However, the friction factor of an alluvial stream is, as noted above, not readily determined.

Comparison of sediment discharge rating curves, derived according to various formulae, with measured data shows a wide scatter of results. Figure 4 shows the results of some calculations by Vanoni on data from the Colorado River at Taylor's Ferry. The scatter in the experimental measurements themselves is indicative of the inherent difficulty of predicting the rating curve. Curves from the Schoklitsch, Shields and Einstein-Brown formulae are too flat at high discharges. They are thus perhaps more suited for situations in which bed load transport predominates. Curves from Duboys and Meyer-Peter formulae are too flat throughout the range while the Einstein Bed Load Function would appear to be too steep. The Meyer-Peter-Muller curve in this case approximates the correct slope at all the discharges shown. Based on this evidence

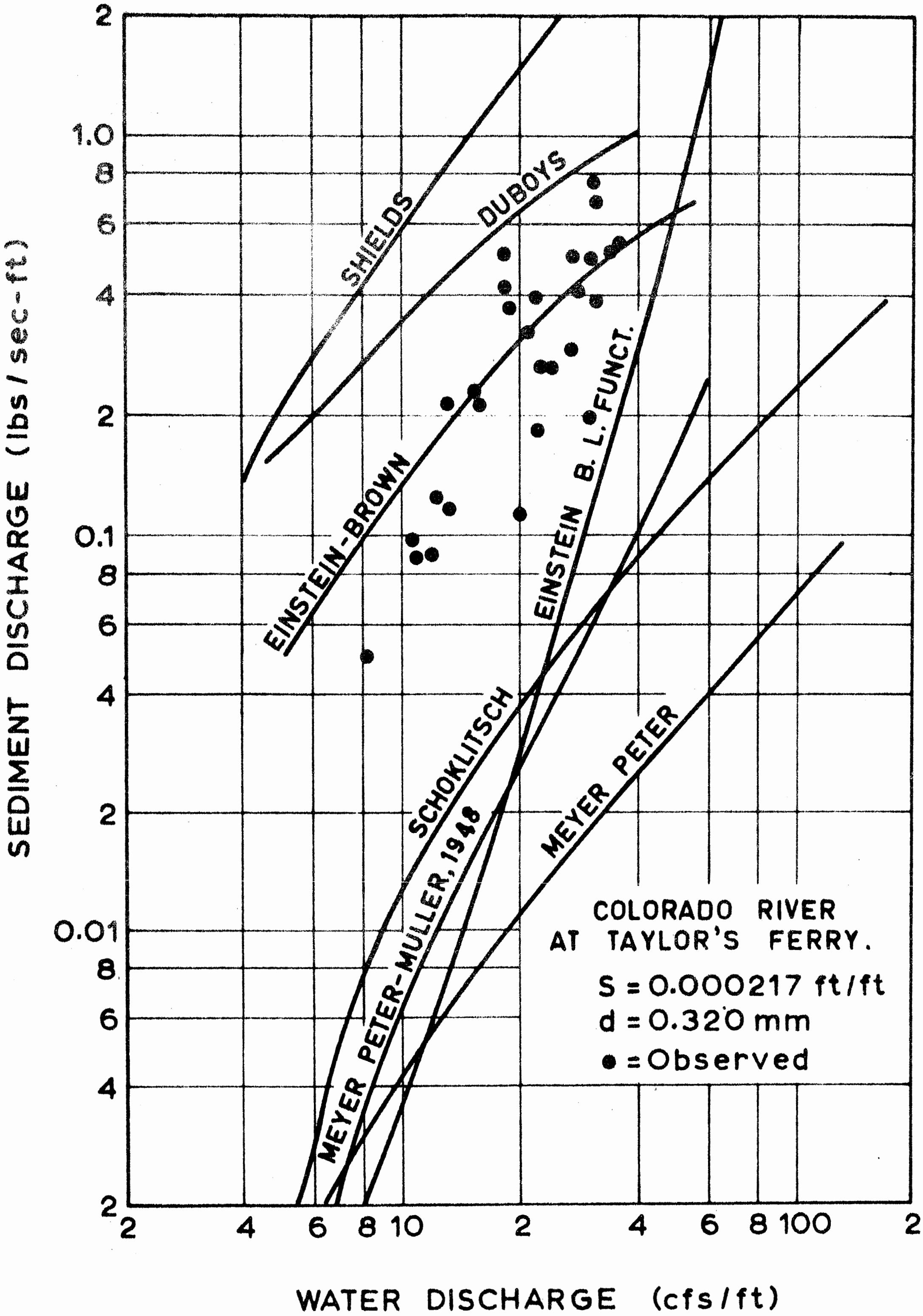

Figure 4
Sediment rating curves for Colorado River at Taylor's Ferry. (From calculations by Vanoni).

errors of up to 100% can be expected when using sediment discharge formulae, and calculated values can only be regarded as estimates. Comparison of results from several formulae will give an indication of their reliability.

Sediment rating curves on logarithmic graph paper can be approximated by straight lines of the form

$$g_s = Bq^m$$

where m is the slope and B locates the line on the graph. The mean concentration c_m in the flow is

$$c_m = \frac{g_s}{q} = B\, q^{m-1}$$

Since c_m is expected to increase with discharge, m must be greater than 1. Usually m lies between 2 and 3. Hence calculated rating curves with slopes near unity are too flat and should not be used particularly when the ratio of, or the difference between, sediment discharges for different flows in the same channel are required.

The Soil and Water Division of the Ministry of Works is determining by regression techniques on measured values, the relationship between g_s and q at numerous gauging stations throughout New Zealand. The results, which are listed in the Hydrology Annuals, are expressed in the form

$$g_s = B\, q^m$$

with g_s in tons/day and q in cfs. The relations are called suspended sediment rating curves and presumably do not account for bed load transport. For the 45 relations published in the 1965 Hydrology Annual values of m ranged from 1.20 to 5.54 (7 values less than 2 and 13 values greater than 3). An example is for the Esk River at Waipunga Bridge where

$$g_s = 4.67 \times 10^{-2}\, q^{1.56} \text{ tons/day.}$$

Two discharge formulae, Schoklitsch and Meyer-Peter can be applied without knowledge of the rating curve. They are respectively:

$$g_s = \frac{86.7\ S^{3/2}}{d_s} \quad (q - 0.00532\ \frac{d_s}{S^{4/3}})$$

and

$$g_s^{2/3} = 39.25\ q^{2/3}\ S - 9.95\ d_m$$

where d_m and d_s are the sediment size in feet and in inches respectively, q is in cfs/ft, S is the bed slope and g_s is in lbs/sec/ft. To compare with measured results the width of the gauging section, the river slope and the sediment size must be known. In Figure 5 the results of some calculations for the Esk River at the Waipunga Bridge are shown. The data used, obtained from the 1965 Hydrology Annual, was S = 0.007, sediment size 2mm. The latter figure was assumed from the description given of the bed material as "very fine shingle". The observed curve has been plotted for an assumed river width of 20 ft. This simply locates the line, larger widths moving the line to the left without changing its slope. Both derived curves approximate the slope at low discharges and are too flat at higher discharges. Indeed the slopes for q greater than about 40 cfs/ft are very close to one. Use of these curves in this region would be ill advised.

For determining sediment discharge in particular cases it is recommended that use be made of the Ministry of Works results if there are relations available that apply to the river concerned. If there are no such relations then the discharge must be estimated by using as many different empirical methods as practicable. The results must then be compared and evaluated. The final figure must always be treated as only an estimate with an expected error of up to say 50%.

SUMMARY

The problem of sediment movement in streams can be simply stated as follows. Fed into each reach of the stream is a water discharge and a sediment load which must be transported. The channel has no control over these quantities which are therefore independent variables. By changing its roughness the stream can adjust the depth

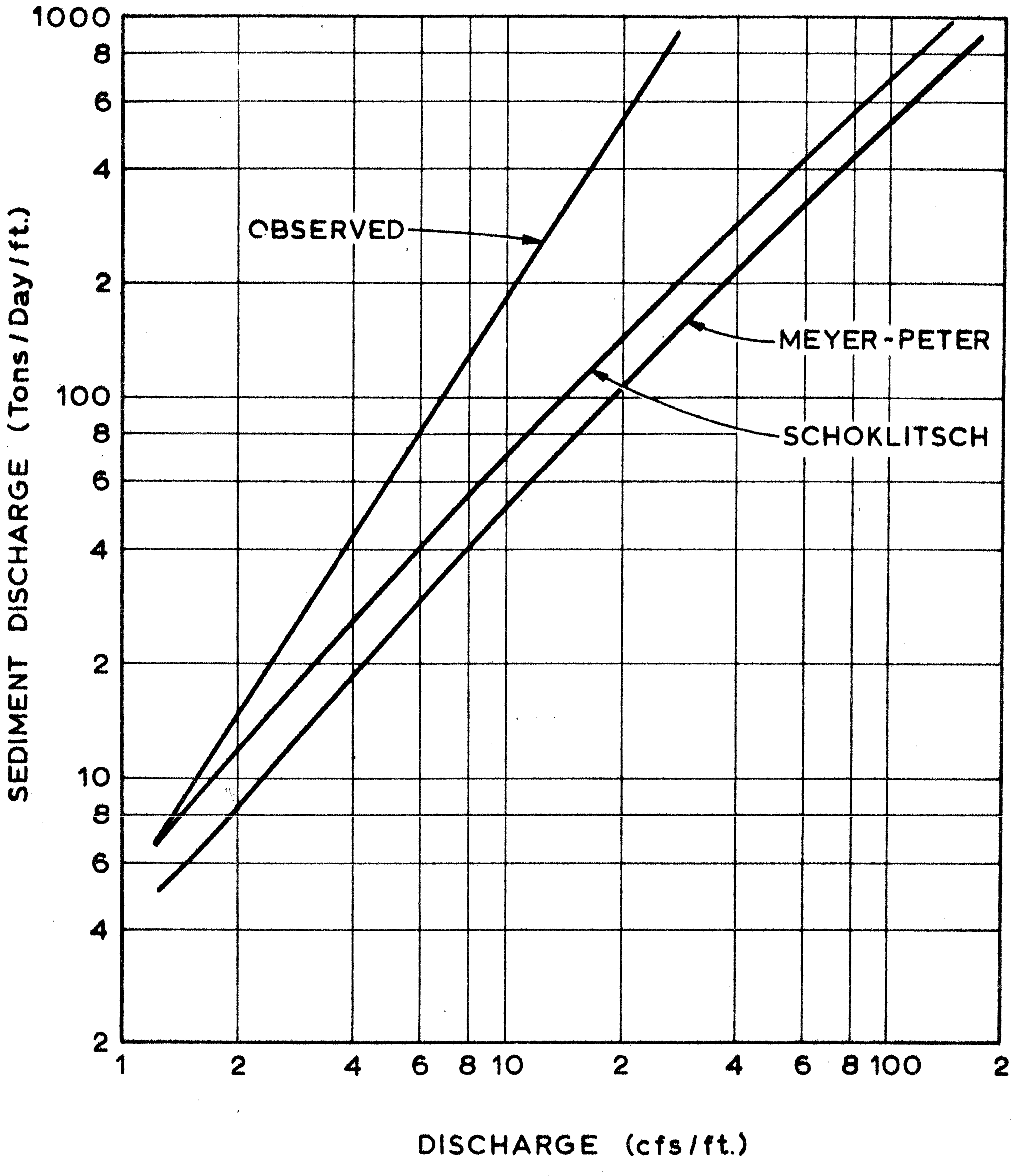

Figure 5

Sediment rating curves for Esk River at Waipunga Bridge.

and velocity of the flow together with the factors that govern the sediment transport capacity of the flow in such a way that the imposed water and sediment may be accommodated. To assure that a solution exists for all combinations of discharge and load the depth must be related to both these quantities. In alluvial streams this is achieved by variable roughness. To find a solution to the sediment transport problem the dependence of roughness on discharge and load must be known. At present there is no definitive statement of this dependence.

DISCUSSION

Statement: A. J. Gillies (Otago Catchment Board)

When Dr Sutherland referrred to rigid and mobile bed channels, was he referring to roughness effects in all mobile bed channels or was he referring only to sandbed rivers? Sandbed rivers are much less common in this country than shingle bed ones and there is a marked difference in flow behaviour between shingle bed and sandbed channels and this difference should be noted.

The changes of bed form with Froude number which Dr Sutherland has pointed out only occur in sandbed channels.

In gravel rivers the sediment moves as shoals and then only at higher flows. There is generally negligible transport, and hence change of roughness, at lower stages. Even at higher stages, changes in the bed form roughness in gravel rivers are largely marked by the overall grain roughness and boundary roughness effects.

Reply: A. J. Sutherland

Mr Gillies is quite correct in assuming that the remarks made in the section headed Bed Forms and Channel Roughness were concerned principally with sandbed rivers. The final paragraph of this section refers, perhaps not strongly enough, to this point. With very coarse material significant movement occurs only at high discharges when large quantities are moved and then deposited downstream.

The motion has the appearance of a gravel wave or shoal as suggested. With very little being known about such motion, either qualitatively or quantitatively, it should form a fruitful field for research workers.

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A NOTE ON SILTATION IN THE MANGAHAO POWER PROJECT

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Palmerston North

INTRODUCTION

The Mangahao Power Station is 63 miles from Wellington and obtains its power from the diversion of the Mangahao River through the main ridge of the Tararua Range. Although its generating capacity of 19,200 kw is small by today's standards, it was, when completed in 1925, the largest station in New Zealand.

The mean flow of the Mangahao River is about 150 cusecs. Low flows of 70 cusecs and peak flows of 1,700 cusecs have been recorded.

Fig. 1 shows a plan of the project and shows that water from the Mangahao River is stored in three dams. Details of these dams are given in Appendix A.

Siltation

Although normal erosion hazards in the Mangahao catchment are high, there was only a small build up of silt in the storage dams from 1924 to 1936. However, in 1936 violent winds from the south and southeast wrought fantastic devastation in a few hours. The forests of the Mangahao valley caught the full force of the storm and severe wind throw was experienced throughout the catchment, particularly on western slopes. All tributaries carried immense quantities of debris for some years after the storm [1].

To prevent silt accumulating in the dam, the no. 2 dam was flushed through a bypass tunnel for a short period each week. Although this was successful, there was always the

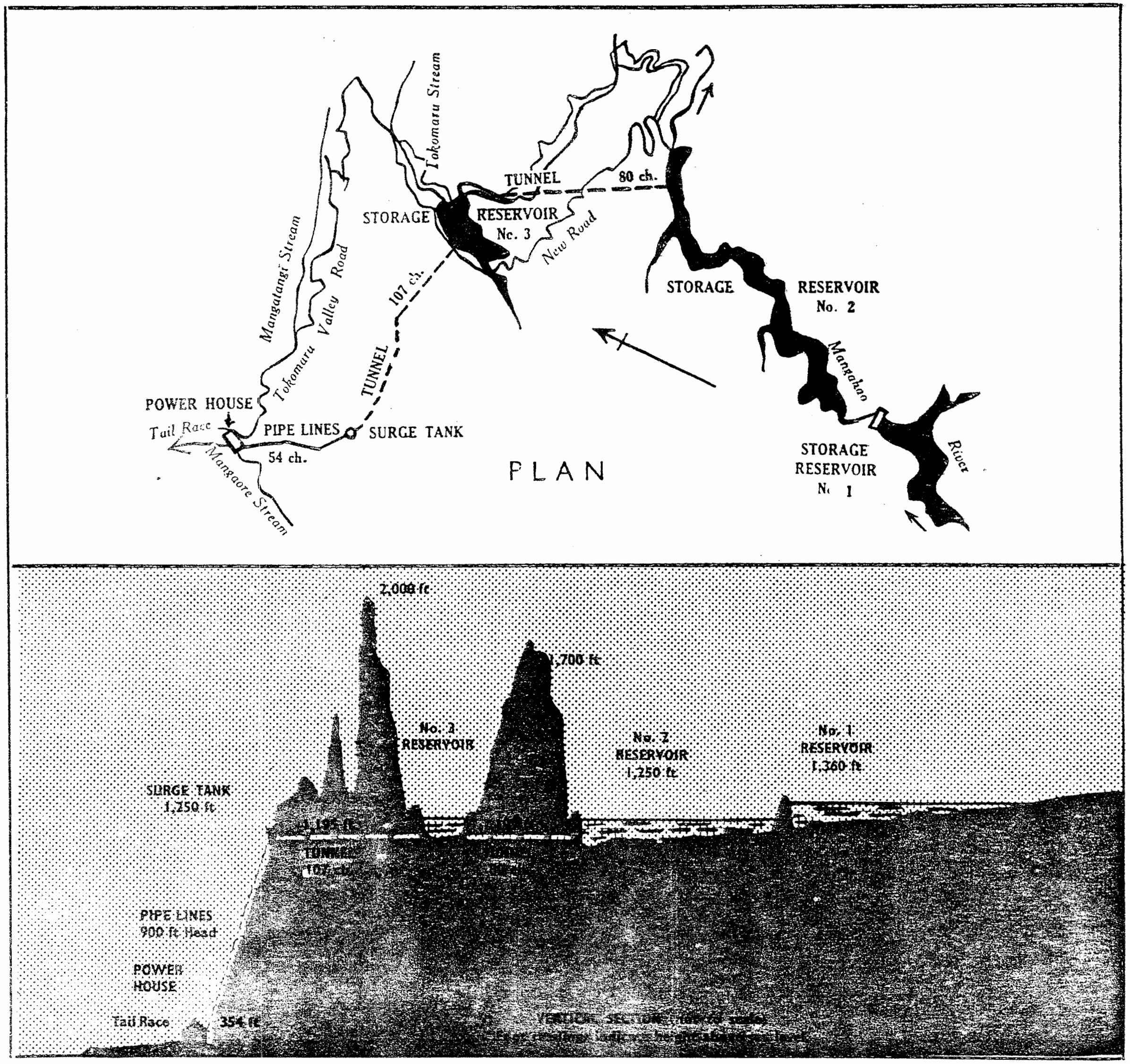

Figure 1

Plan and vertical section Mangahao Power Scheme.

risk that logs might become trapped in the tunnel between no. 2 and no. 3 dams. During the war electric power was in short supply and its generation was vital. In 1944 it was decided to cease the weekly flushing because of the danger of a blockage in the tunnel and the disastrous effects that this would have on the power supply of the North Island.

From 1944 to 1959 there was a fairly rapid build up of silt. Table 1 shows that no. 1 dam lost 1,262 acre feet of storage and that no. 2 dam lost 666 acre feet of storage between 1250' and 1220'. The total loss of 1928 acre feet of storage represented a loss of two days 18 hours of generating at full load to produce 1,250,000 units.

Table 1 - Storage Capacity of Mangahao Dams

No. 1 Dam -	Original storage:	3810 ac.ft at 1360'
	Capacity 1960:	2548 ac.ft at 1360'
No. 2 Dam -	Original storage:	1630 ac.ft at 1250'
		1263 ac.ft between 1250'-1217'
	Capacity 1960:	666 ac.ft between 1250'-1220'
No. 3 Dam -	Original storage:	620 ac.ft between 1246'-1212'
	Capacity 1960:	769 ac.ft between 1250'-1200

Even more important, the screen structure at the entrance to no. 1 tunnel (between no. 2 and no. 3 dams) was now nearly buried and the risks of complete blockage were high. On more than one occasion skin divers were sent down to clear debris from the screen, to allow water to flow to the no. 3 dam and the power house.

The removal of silt from the no. 2 dam was most important. This would not only give greater storage on that dam, but also allow free access to the tunnel which supplied the no. 3 dam and therefore the power house.

DESILTING

There was about 42 ft of silt above the bypass tunnel and there was some real doubt as to whether the gate could be successfully opened. However, as there was a small high-pressure leakage, it was reasoned that if it could be opened, the small flow could increase and lead to a break through.

It was realised that if the opening was successful, tremendous amounts of mud would be discharged downstream. However, the saving factor was the seven miles of deep ravine with many rock pools below the dam in quite uninhabited country. We consulted the Manawatu Catchment Board and received their encouragement and support.

Nos 2 and 3 dams were built up to 1,243 ft level and the gate at no. 1 tunnel was closed, isolating the no. 3 dam. On the 23rd January the gate was raised. Very little happened that day. However, the next day (24th January) at 11.05 a.m. after juggling the gate up and down, the blockage cleared and the dam began to empty. As the water receded a large vortex formed above the tunnel entrance. When most of the water was gone a large crater-like depression was left. A small tributary flow from Tramway and Blackwoods creek cut a channel down the central part of the mud plateau. As this channel deepened it brought down huge avalanches of mud which blocked the tunnel mouth until a head of water had built up, forcing the mud through the tunnel. By the 27th January 1969 it was estimated that 25% of the mud had been removed from the dam and priority was given to clearing mud and logs from around no. 1 tunnel entrance. This was done by sluicing and back flushing from no. 3 lake and winching timber up the bank. Eventually a clearance of mud and timber was made around the intake structure down to the invert level of the tunnel. About halfway through, the operation was held up by a flood which had the desirable effect of flushing the lower valley clear of mud.

From the 25th February it was decided to pond up the dam each night and flush during the day and spend the day disposing of timber. The flushing each day brought down considerable but decreasing quantities of mud. By 28th February it was decided to close down operations. The last two days were spent in clearing the lower basin of all timber and stumps which could be troublesome. After 28th February the dam was refilled and the normal operations of Mangahao was resumed.

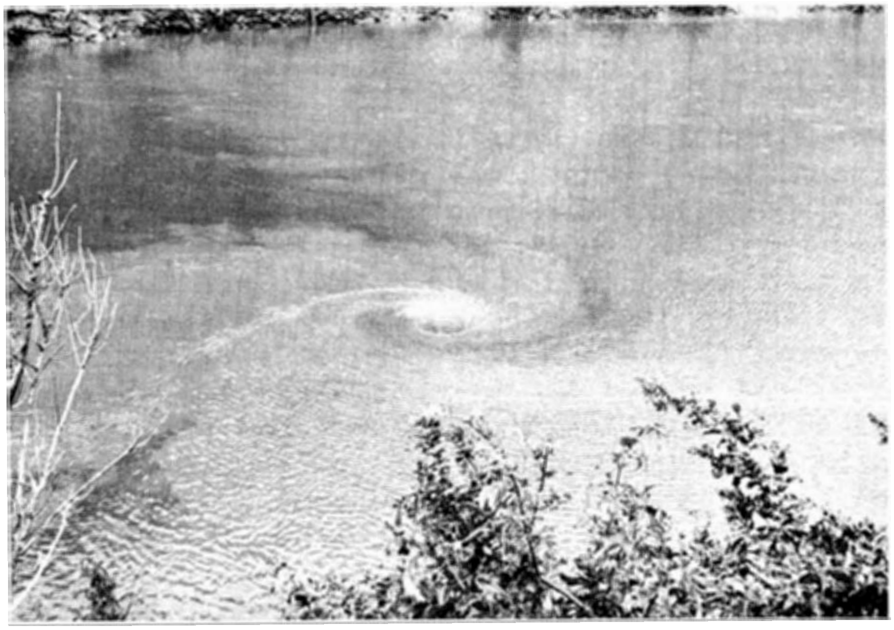

Plate 1: 24 January 1969, 11.35 a.m.
The vortex which formed as the lake level fell.

Plate 2: 24 January 1969, 12.28 p.m.
Most of the water stored in the lake has drained through the hole in the mud. River flow is now collapsing the sides and forming a crater-like depression.

Plate 3: 24 January 1969, 12.29 p.m.

Plate 4: 25 January 1969
The screened intake to the No. 1 tunnel appeared after the gate had been left open all night.

Plate 5: 28th February 1969
The silt has now been cleared from around the screens prior to refilling the dam at the conclusion of the operation.

RESULTS

The operations removed about 600,000 cubic yards of silt. This represented about 75% of the total accumulated sediment. As a result, there is now unobstructed flow into the no. 3 dam and the power house.

The silt removed from no. 2 dam was very fine. The coarsest particles were about 0.04 millmeters and there was an extremely high proportion of organic material.

The operation cost a total of $1,964 and the estimated annual gains are about $70,000. It is estimated that alternative methods of desilting would have cost between $100,000 and $200,000.

Appendix A - Details of the Mangahao Storage Dams

No. 1 Crest 1,360 ft. Bypass tunnel 8' diameter at 1269.5 ft. Gate 6' x 4'. Three tipping gates each 53'4" long and 10' high.
Disperser valve 1279' level 4' diam.
Original Storage 166 x 10^6 cu. ft. at 1,360' level.
Capacity in 1960 111 x 10^6 cu.ft at 1,360' level.
Catchment area 17,698 acres

No. 2 Crest 1,250 ft. Bypass tunnel 8' diam. 212 ft long at 1172.2' Gate 8' x 6'3".
Two tipping gates each 53'4" long x 10' high.
Original capacity 71 x 10^6 cu.ft at 1,250'.
" " 55 x 10^6 cu.ft between 1,250' and 1,217'.
Capacity in 1960 29 x 10^6 cu.t. between 1,250' and 1,220'. Catchment area 20,146 acres.

No. 3 Main level 1,255 ft. No provision for spillage or bypass. 1957 capacity 27 x 10^6 cu.ft between 1,246' and 1,212'. Capacity in 1960 335 x 10^6 cu.ft between 1,250' and 1,200'. Having regard to the different levels quoted the capacity has changed little.
Power house level 354 ft.

DISCUSSION

Q. What are the risks of the dam being refilled with sediment?

A. The chances are not high. The intake is now flushed each month and with forest regeneration there is less total sediment entering the dam.

Q. Did the Manawatu Catchment Board give the Electricity Department a permit to discharge this sediment into the river system?

A. (P. Evans, Manawatu Catchment Board) Yes, although 600,000 cubic yards is a lot of silt it amounts to less than one foot depth when distributed down the river channel.

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OPPORTUNITIES FOR MULTIPLE USE OF HYDRAULIC STRUCTURES

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INTRODUCTION

With the pace of modern life hydraulic (and other) structures are being built in such profusion, and the needs of people for such structures are becoming so complex, that a strong demand is arising for all structures to be put to as many uses as possible. At present, almost without us recognising it, many structures are put to more than one use. In this paper I am trying to make the distinction between multiple use of a structure built for a single purpose and a multiple purpose structure whose uses are foreseen at the planning, design and costing stages.

Possible uses for hydraulic structures include flood control, mining, domestic and industrial water supply, navigation, hydro-electricity, supply of water for stock purposes and irrigation, fish farming and recreation. Of these navigation and recreation may not need special structures but they can use a wide variety if they are available. Inland navigation and fish farming alone have not been extensively pursued in New Zealand. These different uses have generally two needs; the water must be in the right place, and available at the right time. The first requires structures to contain and guide the water; the second structures to store it.

Man's use of water in New Zealand has intensified rapidly since European settlement. Originally water was used as found without construction of major structures, but as time went on development was needed to make the best use of the water available. Structures tended to be built because they were needed, and the cost, whether in labour or in money, was a necessary evil. This tendency to regard cost as secondary is a natural concomitant of simple needs, it becomes significant when the user cannot meet it, or when there are alternative ways of satisfying the demand,or when there is obviously more than one use to which a structure can be put.

A tradition of building single purpose structures encourages a "catch as catch can" attitude to finance - if there is an opportunity for meeting a need we do it as cheaply as possible without consideration for others - which can be inimical to multiple use. The provision of services by a public body of some kind which covers its costs by means of a general rate is also no help to the multiple use of structures as people do not appreciate the capital costs concealed behind the annual charges. If a rate is to be charged then there is usually a poll of the prospective rate payers before the project is committed. If there are two prospective users, one of whom turns the proposal down by an adverse poll, then there can be difficulties in getting a multiple use project started. Unless one user is to subsidise others, this matter needs official policy consideration.

THE PAST

Some of the earliest large hydraulic structures built in New Zealand were dams and water races to supply water for mining purposes. These were often built by "grubstaked" labour at very little expenditure in actual money and I suspect that the actual return on the effort expended was often very low. I offer as a subject for a Doctorate in Economics the thesis that, "The main returns on gold mining in New Zealand were made with the minimum expenditure of capital, and that the return from capital and labour invested in mining dams and races was very low". Be that as it may the mining structures, whether races or dams, were gradually abandoned and in the dry Otago areas were in some cases eventually taken over to supply irrigation and stock water. Because most of the servicing structures were already built water could be made available at very low capital cost with consequent low charges to the users. The result has been that many farmers have a faulty idea of the real cost of the water supplied to them and object to meeting the costs of modern schemes where all charges have to be met. On the West Coast the old mining structures have sometimes been used to provide water power for timber mills and electrical generation.

Although in the past most hydraulic structures have been built for a single purpose, a great many have had secondary uses, and some have caused secondary detriments. Even flood control by stopbanking, an apparently one purpose development, may, when associated with the cutting off of river loops and the straightening of deep channels, provide facilities for recreation, as for instance the rowing course associated with the flood control scheme on the lower Ruamahanga. Such works might also provide opportunities for fish farming.

Unlike some of the large continental regions, in New Zealand reservoirs specially built for holding floods have not been widely used. The Taylor river near Blenheim and the Porewa Valley near Hunterville are the only projects of this nature known to me.

Flood control is often a secondary benefit of reservoirs built for storing water for other purposes, as any dam built to even out the flow of water retains high flows if they occur when the reservoir is not full. People downstream seldom realise the gain from this as they do not notice that floods are less frequent. They are also very ready to blame the controller of the dam if a flood is passed through. Hydro-electric examples of this secondary flood control function include the Taupo Gates, Matahina, Cobb Dam and Control works at Tekapo, Pukaki and Hawea. Except possibly at Taupo the design conditions for these nominally single purpose dams include space above maximum operating level to contain at least the full volume of a 1 in 500 or 1 in 1,000 year flood without the release of water at a rate greater than it would have been under natural conditions. This space is needed only when the flood rises above Maximum Operating Level, which in most storage lakes is reached for 25% of the time or less. This designed operational storage reduces the frequency of floods in proportion to the time when the lake is low, for flood water must be discharged over the spillway only when the lake is full.

For instance the Taupo flood of February 1958 raised the level of the lake over 2 feet in 3 days while only nominal flows were released down river. At this time natural high flows would have intensified a major flood already occuring in the lower Waikato.

At Matahina, where flood control capabilities are limited by the small ponding area, preliminary estimates of flood size are now thought to have been too generous. As a result, despite preconstruction studies that showed it to be much more economical to provide protection by stopbanking rather than prevention by ponding, the Electricity Department has been able to make provision for reducing major floods above 18,000 cusecs by up to 7,000 cusecs thereby reducing a flood of 18,000 cusecs from about a 1 in 20 event to one of about 1 in 30 years.

At Benmore the large new lake should reduce a 120,000 cusec inflow (a 1 in 1,000 year event) to 80,000 cusecs. As the chances of the 120,000 cusec inflow have already been reduced by the controls on Lakes Tekapo and Pukaki, and Aviemore lake adds its damping effect, there is thus a very small chance that floods past Waitaki will in the future exceed 70,000 cusecs (a size exceeded on at least four occasions between 1878 and 1964). The biggest flood of which we have authentic record, that of February 1967, was reduced from an estimated uncontrolled 92,000 cusecs to 42,000 cusecs past Waitaki. It so happens that the Waitaki is not a river where floods have caused catastrophic damage so this gain in control has no great significance, though it is a convenience to farmers and others on the river.

The Hawea Control Works is a case where timing of the needs of different potential users did not synchronise. In the late 1940s and early 50s when it became obvious that the lake would have to be controlled for electricity purposes there was some correspondence regarding the possibility of incorporating provisions for flood control in the structures. Four feet of extra storage would have been needed for this purpose. It would have cost £50,000. As the contribution of Hawea to floods down river is limited to an experienced 9,000 cusecs and forecast long term 13,000 cusecs (less than 10% of floods in the lower Clutha) no money was made available for this purpose. In consequence only the standard provision was made from Electricity funds for containing a two day 1 in 500 year flood with continuous outflow up to 11,000 cusecs. In practice floods occurring while the lake is below maximum control level are retained at no expense to the land lower down the river and a 1 in 50 year event will probably be extended to a 1 in 200 year event or even rarer.

Though it was obvious that the Hawea Flat would respond to irrigation, this was not wanted by the farmers at the time the Hawea Control Works was being built and, though belatedly finance was provided for the rudiments of an intake for irrigation water, the opportunity for building the most economic form of intake was lost.

On the other hand, when the Rangitata Diversion Race was started in 1938 to provide water to irrigate the land between the Rangitata and Rakaia rivers, the opportunity was seized for utilising water not needed by irrigators by passing it down the 300 feet high terrace at Highbank through a hydro-electric power station into the Rakaia river. Besides contributing to the cost of building the race the Electricity Authorities pay a royalty for the use of water that would otherwise have been wasted.

Other cases where structures built for specific primary purposes have proved of recreational value are:

(a) The head pond of the Kourarau power station in the eastern Wairarapa which has become an important centre for wild birds, both for sport and for sanctuary:

(b) The Manorburn dam built for irrigation, which is a shooters' resort and, in cold weather, is nationally known for its skating:

(c) Water supply reservoirs in many areas, notably round Auckland, have provided some degree of flood relief.

To sum up conditions as they stand in New Zealand today: with the major exception of the Rangitata-Highbank Race, hydraulic projects have nominally been single purpose developments. Secondary services have been developed at no cost to the secondary beneficiary. On balance, it does seem that the primary developers of these one purpose projects have, despite some secondary nuisances caused by their works, been tolerant of secondary users and the New Zealand Electricity Department in particular has co-operated with these users in a generous way, at times at cost to the electricity consumer. A case might be made out for the beneficiaries to make some contribution to the capital cost of the works they use.

MULTIPLE USE

Turning now to the future. The passing of the Water and Soil Conservation Act of 1967 has provided a means by which the possibilities of making full use of proposed hydraulic structures can be examined. Believing as I do that the fullest benefit should be obtained from the expenditure of public monies, I hope that the National Water and Soil Conservation organisation set up under the Act will be able to ensure not only that all the ramifications of a proposal are fully investigated but its full capabilities are exploited. So that this can be accomplished it is essential that applications for approval of projects involving water use are initially complete and are submitted in ample time for full examination by the organisation, which should do its best to ensure that proper evaluation has been made of possible secondary uses. The interdepartmental committees that have examined developments in the Mackenzie Country and the Clutha are steps in the right direction. To this end techniques suited to New Zealand conditions should be evolved for evaluating the benefits of a structure and equitably allocating the costs between possible users. There are several published overseas models for this. Power may be needed to speed on the work of a reluctant user or some means devised whereby his fair share of the cost is eventually charged to him.

When considering opportunities for multiple use of a structure we need some idea as to the requirements of potential users and an examination of their compatability, a matter that is often overlooked by enthusiastic proponents of particular schemes.

The erratic manner in which water flows is a major difficulty facing the planners of multiple purpose structures. In many streams and rivers high flows are more than 200 times low flows and though in general it is possible to forecast the season of high flow, the scatter in individual years is very large. This means that even for single purpose use simulation studies are needed to compute the effective good that can be achieved with economy. The mass curve technique has been in use for many years in estimating volumes of storage needed to even out flows so that shortages are acceptably rare. This has mostly been done in town water supply and hydro-electric studies, but it is arithmetically tedious and has usually been confined to studies of annual mean flows. In the hydro-electric field in New Zealand the technique seems to have died out about 20 years ago with the partial substitution of statistical methods.

If the multiple use of hydraulic structures is to be intelligently investigated simulation of flow and demand on a basis much finer than the annual is needed. (Two years of the same mean flow can, because of different patterns of short term flow, give widely different useable outputs). The period has to be as long as practicable. To complete the work, which is essentially trial and error, in reasonable time computer assistance is essential. At present the only effective action known to me in this field is in the Ministry of Works, and in the New Zealand Electricity Department, though more theoretical studies are believed to be going on in the universities.

HYDRO-ELECTRICITY

In recent years the most spectacular hydraulic structures built here have been for hydro-electric purposes. If water cannot be stored then it usually cannot be used to best advantage and one of the most delicate planning operations is to match the installed generating capacity with the water that can be made available. For this reason it has been practice to select for hydro-electric development the rivers with most even flow. Only at small stations such as Mangaohao and Cobb has this not been done and, relatively speaking, these are two of the most costly hydro stations in the country.

For many years it was postulated that sufficient storage should, if possible, be provided to avoid other than rare (one year in 10 or more) water shortages if the power stations were planted to match the system load factor on the assumption that 85% of the water could be used. In average to wet years water was expected to run to waste, but in dry years it would all be needed. The use of this 85% utilisation factor has lead to the claim that the remaining water is freely available for alternative use. This is not so, and the relations of dual demands in dry years should be examined numerically before such a secondary use is approved.

Figure 1 shows how the annual flow and water needed for power can vary in a river with a large lake but no other control. Dotted on is the output that would be available if 85% of mean annual flow was assumed to be achievable, and the water that might be used for other purposes is also shown. The calculations were done on a daily basis and the wide variation in annual output can be seen from years having almost the same mean flow. Also the small proportion of years in which the nominally unneeded water is completely available for other uses is shown.

To obtain a nominal 85% of utilisation of the Waitaki water through power stations operating to match the system load with a deficiency once in 20 years, it has been computed that 1,100,000 cusec days storage should be provided in the upper lakes. This is 29% of the annual discharge from the lakes or 25% of the water passing Waitaki Power Station each year. As the computations were done on annual flows the volume of storage needed is probably under estimated and deficiencies could occur more often. Similar computations have shown that for the Clutha about 1,150,000 cusec days are needed - 18% of the annual flow past Roxburgh - if a 1 in 20 year shortage is to be avoided. So far only 640,000 cusec days of storage have been provided in the Waitaki and 900,000 in the Clutha.

The stations on the Waikato are proportioned to utilise more than 85% of the flow past them and the volume of storage in Taupo is not sufficient to meet needs. The result was that for many years the North Island, dependent mainly on the Waikato stations, suffered power cuts that were due more to shortage of water than inadequacies in the amount of plant installed.

As the electrical system has become larger and more complex, the interconnection between generating stations and between the Islands has enabled advantage to be taken of the fact that floods and low flows in all rivers do not coincide.

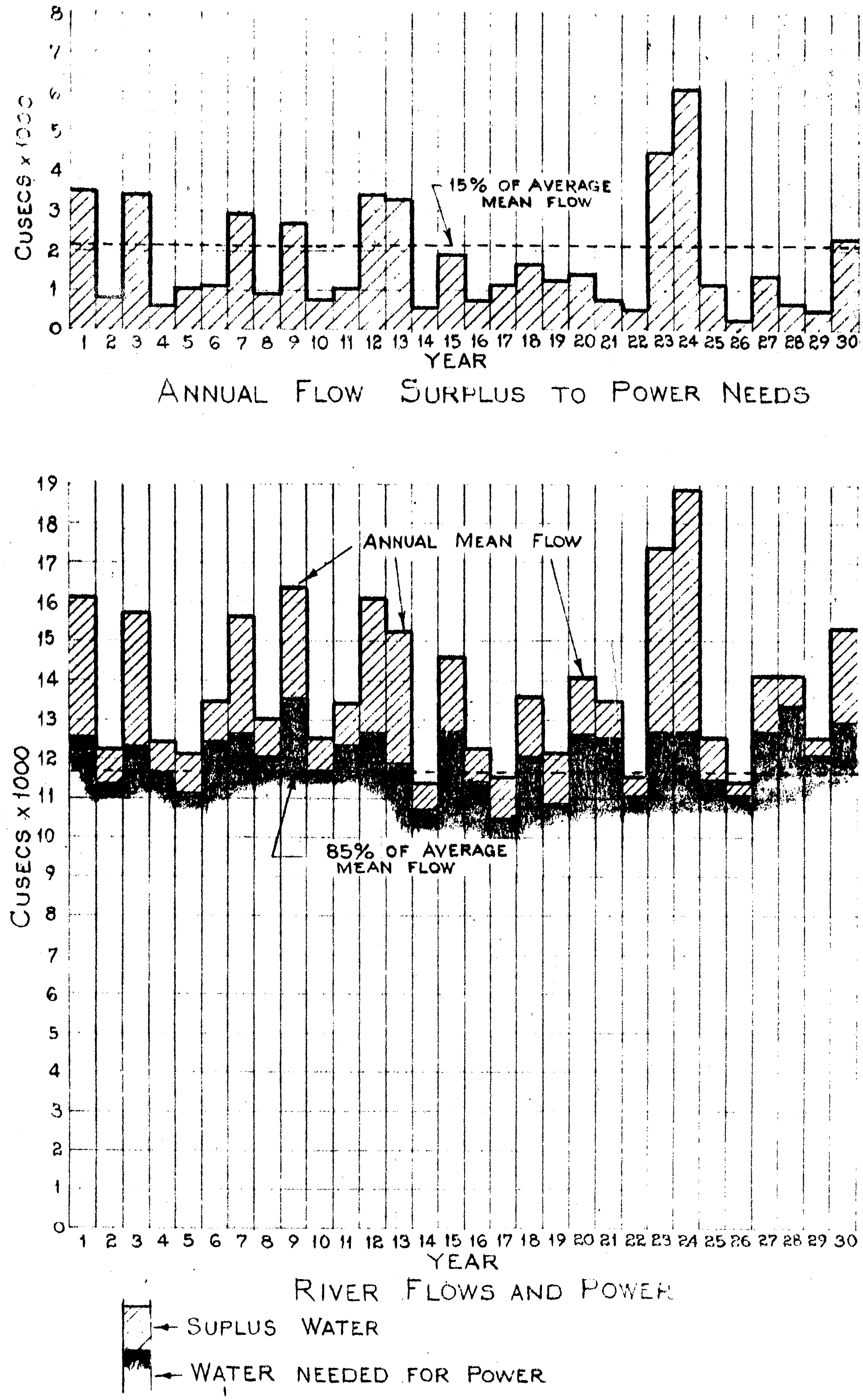

Figure 1

River flows and water needed for power generation

In addition, the construction of thermal generating stations has enabled an effective extension of the water storage system by using stored fuels to run the steam stations more in times of drought. These two developments justify the reduction of the proportion of water stored. However, water, once its storage facilities have been provided, costs almost nothing, whereas fuels not only have to be stored but cost money to buy. The computation of the most economical balance between water storage and fuel consumption is extremely complex and very tedious to work out, even with modern computing facilities. Work on this in New Zealand is by no means complete and it is possible that water storage is at present under-valued in official thinking.

When it comes to comparing the benefits of using a hydraulic structure for electrical generation with some other purpose an initial difficulty is to assign a value to the electricity generated. The New Zealand Electricity Department is constrained by law to charge at a rate that covers the total cost of producing all the electric power plus an amount towards the cost of providing for the continuing growth of the load. Charges are not related to the cost of power from individual stations or to the real worth of the power produced and, from the fact that so many users of energy have freely changed over to electricity, it is at present probably under-valued. However, for want of anything better, it is convenient to value electric power at the rate at which it is sold by N.Z.E.D., that is at about $23.5 a kilowatt peak load plus 2.7 mills (o.27 cents) a kilowatt-hour for each unit sold. About 8% of the power generated by the department is lost during transmission to points where the retail organisations take it over so should not be included in comparative calculations. The marginal cost of generating kilowatt-hours by thermal means is greater than the selling price (2.7 mills) so that from a strictly economic point of view the generation of great blocks of thermal power should, with the present cost structure, be avoided.

PUMPED STORAGE

A specialised form of hydro-electric development is pumped storage electrical generation. This is being developed in quite a large scale overseas but so far has not been used in New Zealand. Thermal power is generally less flexible to operate than hydro-electric and, despite the fact that the marginal cost of generating power can be quite large in steam and is essentially nil in hydro generation, situations arise in large thermal systems where it is cheaper to keep a steam station running than to close it down for a few hours. If this surplus power can be used to pump water to a high reservoir for return through a water turbine to generate electricity at times of peak demand not only will most of the surplus power be used, but the need for installing peak thermal generating capacity will be materially decreased.

As the New Zealand generating system is still predominantly hydro-electric, there is no strong case at present for pumped storage, but the situation will probably change as the proportion of thermal (especially nuclear) power increases. Even now there are times in the North Island when the presence of a pumping station to use "dump" power would be an operating convenience.

The economics of pumped storage are complex and can only be studied properly when there is a very thorough understanding of the financial, thermal, and electrical operating system. The calculations are tedious and are practical only with computer support.

Pumped storage stations are most likely to be found economic when they can be sited near large centres of load. They lessen the need for gas turbine stations, over whom they have the advantage that the marginal cost is that of the "dump" power adjusted for pumping efficiency, whereas gas turbine marginal costs are high. On the other hand they are not suited to assisting the system by extra running when water supply is short and storage lakes are low.

Pumped storage generation may be operated in conjunction with normal hydro-electric generation and a situation as at Benmore, between the large Benmore and Aviemore lakes, is an obvious possibility. However, the remoteness of Benmore from a load centre makes its early development unlikely. On the other hand it is more likely that sites near cities with little water, but present or potential upper and lower reservoirs suitably close together, will be first developed for pumped storage. Theoretically no water need be wasted from a pumped storage station, but usually a flow of four or five cusecs in a 300 or 400 MW station is needed to make up for evaporation and leakage. It is not essential that fresh water be used and sites where sea water can be pumped into a reservoir can be acceptable.

Because the levels in reservoirs may fluctuate widely and rapidly it is not likely that pumped storage stations will often fit in with other non-electrical uses, but town water supply storage may on occasion be profitably associated with pumped storage and cases where this could eventually be profitable may exist near Wellington and Auckland and Dunedin.

FLOOD CONTROL

Up to now it has commonly been regarded as too expensive to provide a volume of flood storage big enough to (say) halve the potential peak flood and it has been found best to build stopbanks which though long, are usually fairly low and not unduly difficult to design or expensive to build. If, however, suitable holding ponds are available for other purposes the provision of extra capacity for flood retention may be quite cheap. A third, long term, method of lessening floods is by providing porous country draining into the rivers. Natural vegetative cover to the ground is almost always more or less favourable to the retention of rainwater but development by animals, human and others, almost always encourages the quick runoff of water, thereby increasing floods and enhancing periods of very low stream flow. This matter is receiving the attention of soil conservators and others, but the improvements they make in the ability of country to absorb water are very slow to take effect and at present all we can hope for is that they will slow down or stop the increase in floods that the development of the country has hitherto encouraged.

Development of cost-benefit methods for evaluating flood control proposals has until recently not gone very far in New Zealand, partly one suspects because in some areas they would show that the benefit of improved production from the land protected would not nearly outweigh the cost of protection.

The fact that a dam for hydro-electric or irrigation water storage or water supply is usually not full means the bulk of the floods are in fact retained even if no special provision is made to reduce a flood occurring when the dam is full. The benefit and any detriment of this should be assessed in the planning of new structures. In the past this has not been done and the effect of a lot of flood supression has not been allowed for in the accounting. It should be in the future.

If a dam is built for other purposes and flood storage facilities are added this is done most usually by heightening. The consequent area covered by water in the flood range is very much larger than if a smaller structure had been built for flood control only so that the extra height on the dam may be quite small. The provision of 20,000 cusec days on a lake of 10 square miles needs a range of 6 ft whereas the same volume behind a lower dam on the same site giving a lake averaging 1 square mile would need a range of 60 ft. In costing, however, it must always be recognised that the addition of height to a dam really means increasing its base so that the gain is not as great as it first appears.

WATER SUPPLY

Water supply for industrial or domestic use is a specialised service, demanding high standards of purity. Water for this purpose may come from a great variety of sources and the money available for securing sufficient in quantity and quality may be more than is usual for other uses. Frequently it is pumped from underground aquifers or streams but where only limited surface water is available large dams and pipelines are needed. The special needs for purity make it difficult to fit this use into normal multiple purpose systems.

FARM WATER

The use of water for farming takes the main forms, domestic supply, stock water, and irrigation water in ascending order of magnitude and firefighting.

Domestic needs are small in quantity and have in the past been met from streams, tanks, stockwater races etc.

It is probable that often the standard of purity has been low and it is also permissible to speculate that the general health of country people is due in part to their inoculation against a wide variety of germs acquired from their domestic water.

Over much of the South Island and the eastern side of the North Island ranges, the streams are too widely spaced for stock to make full use of the available pastures. To remedy this elaborate systems of water-races have been built in many areas and one or two regional piped systems have been installed. The quantity of water needed is not great, about 1 cusec to 4,000 acres for race supply, or perhaps only 5% of that if a piped system is used, so the return on the extra water is often very high. Indeed, the benefit-cost ratio for money expended is usually much higher than for the more elaborate irrigation systems. Till now, stockwater has usually been taken from suitable streams but situations are arising where it might with profit be possible to bleed from hydraulic structures built primarily for other purposes. The proposed hydro-electric development in the Mackenzie Country is a case in point. If multiple use is to be considered there, the relative cost and benefits to be gained from water race, or the vastly less water-wasting piped system, should be assessed as the water wasted could be put to profitable use in generating electricity.

The water demand of irrigation is much larger than for stock. It is usually accepted as 1 cusec per 100 acres for about half the year. For large areas the demand can be very large and if there are alternative uses to which the water can be put the most economical methods for irrigating should be practised and no more water used than is actually needed. In different parts of the country water is taken directly from large streams or rivers, for example the Rangitata Diversion Race and the Tarras Race, or it may be pumped as at Ripponvale. Where natural flows are low in the irrigation season large storage reservoirs may be needed. Headworks can be costly and the possibilities of joining with other users in the multiple use of structures should be explored. Combined hydro-electric and irrigation use seems attractive in many areas but the problem of operation in dry years should be thoroughly investigated. It may well be that the use of say 100 cusecs for irrigation would increase the annual output of 10,000 acres by 30,000 ewe-equivalents, but the frequency with which dry years could make the 100 cusecs of value to both irrigation and power, should be examined and the effect on the economy evaluated if either has to go without.

NAVIGATION

Generally New Zealand rivers are not suited to navigation. From earliest times the Waikato and Lake Wakatipu have had a certain amount of traffic and the Wanganui a lesser amount. In the early days boats plied on several other lakes, but as land access has improved commercial navigation on inland waters has become relatively more expensive and less popular until today there are only a few isolated farms that rely on boat access for their existence. With this lack of interest it is not easy to see navigation being an effective unit in many future multiple purpose hydraulic structures. The water will be there in acceptable depths, but in few places does it seem likely that commercial use could be made of it. Pleasure navigation is in a different class and is discussed under recreation.

FISH FARMING

Fish farming has not so far been practised on a commercial scale in New Zealand. Our waters are relatively cold so that food would not grow so fast and yield such a harvest as is reaped in some of the more tropical countries. However, there is no reason why it should not be practised in suitable waters that can have fertiliser added to them. I am told that it would best be done in tanks specially built with controlled water inflow and outflow and probably it would be associated with the sea or artificial canals rather than lakes and rivers.

MINING

Mining has already been mentioned as being the earliest industry to build major hydraulic structures. Its uses of water are manifold, from providing motive power for machinery to excavating and sorting materials. As a direct source of motive power, mining is unlikely to use water very much in the future and as a sorting medium water is specialised and likely to fit in with storage dams rather than conveying structures. Here again an economic study of the alternative is needed before multiple use is embarked on.

INDUSTRIAL HEAT

Thermal stations have to dissipate very large amounts of unusable heat. Usually, over two thirds of the available energy is lost in this manner. Hydraulic structures supplying cooling water are often one of the most costly of the civil engineering works associated with stations of this type and any economical opportunity for using this low grade heat should be exploited. The fact that this is not often done probably points to the economy being very marginal but opportunities for fish and salt farming are possible in certain New Zealand areas. District heating does not seem practical in our open planned towns.

RECREATION

Of all the uses to which hydraulic structures can be put recreation is the most difficult to evaluate and discuss because it is a pastime. As technology develops and more and more people spend more time on recretation, so the value of water space will increase.

Apart from the provision of sports grounds and botanical and scenic gardens, features already existing are generally used for recreation though much money may be spent on developing them. This may be seen in the amenities associated with the skiing fields, the hot springs at Rotorua, the lake-side resort of Queenstown and the marina springing up at Benmore. This tradition for expenditure not to create opportunities can have a bearing on the financing of multiple purpose projects.

The main recreational activities now associated with inland waters are fishing, boating in various forms, swimming, bird shooting, bird watching and biological studies, painting and photography and picnicking. All these started with natural waters and their practitioners take their opportunities where they find them. Having found them they are, not unnaturally, reluctant to lose them, and they hope that others, such as tourists, will also have opportunity for enjoying the facilities. Construction of hydraulic structures usually makes conditions better for the more mechanical activities, but conditions for the more biological branches may often be made less good. They will always be changed in more or less subtle ways. Because they are largely emotional it is hard to put a value on the benefits of such betterment or detriment though attempts are being made overseas. Those with these recreational interests are in these matters essentially conservative in outlook and, since on the whole they belong to the more communicative section of the community, they are often extremely vocal. Because their emotions are involved they are not interested in numerical values. The current opposition of the sporting-fishing fraternity to proposals for fish farming is very typical and the attitude to power development in the Waitaki and Clutha is also true to pattern; where fishing has been improved it is accepted as a right, where changes are expected development is opposed as being retrograde. The maintenance of 900 cusecs down the Tongariro river for recreational purposes means the loss of about $2,500,000 a year in electrical power, the fuel to generate which will have to come from overseas at an annual cost of about $1,000,000 a year.

When large scale hydraulic developments are being considered recreational interests must be allowed for and the most difficult decisions are involved in striking a balance between the numerically accountable benefits and the emotionally argued demerits.

MUTUAL ACTION

Multiple purpose structures imply multiple responsibilities - responsibilities for meeting costs, constructional, or operational, or social, as well as for using the benefits. The opportunity for multiple use can be properly assessed only if these costs, responsibilities, detriments, and benefits can be evaluated. In the past this has not been done comprehensively. The point I want to make is that New Zealand techniques for doing this should be developed and the data thus obtained used when rights and cost are being allocated. I understand that at Lincoln work is in progress on developing them and it is to be hoped that it soon comes to fruition in a form that can be used by the National Water and Soil Conservation organisation.

In applying modern numerical techniques for evaluating projects there will still be ample scope for argument and disagreement on benefits and costs but by attempting to put figures on as much as possible there is a reduction in the area wherein arguments have to be carried out on the, "it is: it isn't" basis. Most of the economic potential uses of a structure are amenable to this numeration; flood control, stock water and irrigation, electrical generation, etc. being thus treated. It is in the recreational uses that obscurity is likely to continue to reign, but if the "best" economic solution to a proposed development is worked out and then the cost of more socially acceptable proposals, there is a fairly clear statement of what these could cost the country. Where the extra cost should lie may be debatable; for instance, should some of the storage available in Taupo be removed from the electrical use for which is was built and applied to flood mitigation? If so, should the electricity consumer be compensated by the benefitting land occupier downstream or by the Government, or should he have to carry the cost himself? Many other examples can be quoted but the point is clear, if multiple use is to be made of any structure then, even if all the cost is charged to a single user, the cost to all the beneficiaries should be known so that the country as a whole knows where capital and annual benefits are being distributed, whether equitably, or inequitably.

When it comes to providing finance for multiple use structures (without which it is not possible to build them), it is reasonably easy for the contribution from electricity to be assessed. Flood control, irrigation and stockwater can also be assessed. They usually qualify for government subsidy, but problems can arise if the potential beneficiaries turn the project down. Does this mean that the development should go on with or without provision for the rejected use? If the former, who pays? Recreational interests, particularly fishing and game shooting, nearly always oppose proposed developments on the grounds that a detriment will be created. In fact this may or may not be true but any proposed change can be argued to be detrimental, and first arguments are almost always emotional. Where a recreation benefit is created who should pay for it? The principal user as a public service? The sportsman through licence fees? Or the government through a special contribution? This matter needs informed public discussion.

POSSIBLE MULTIPLE PURPOSE PROJECTS

To conclude I append a list (Table 1) of possible projects containing hydraulic structures that can be considered as presenting opportunities for multiple use. This list is not meant to be exhaustive, nor does the presence of a project in it mean that I necessarily expect it to be either economically or socially acceptable, but all have had mention somewhere. Neither are the comments exhaustive. Both the list and comments are meant to be provocative and to stimulate discussion and the suggestion of further subjects.

Most of the developments include electrical generation as one of the opportunities for development. This is an acknowledgement of the place that hydro-electric power plays in our developing civilisation and its likely continuance into the next century. The opportunities mentioned here for pumped storage are unlikely to be taken up within the next thirty years but should be considered. Irrigation is most discussed in the South Island where it has been the prime reason for one existing multiple purpose project and could be so for at least two other possibilities. Flood control is included in most developments listed. As discussed above, a water storage structure automatically decreases the frequency of floods of a given size even if it does not necessarily reduce them when they occur.

The northern Thermal Stations are unique in the list as involving saltwater in reasonably enclosed areas. There seems no biological reason why fish should not be farmed in the warmed cooling water from suitably sited thermal power stations and considerable work has been done overseas on the possibility. The use of low grade heat for evaporative purposes such as salt or freshwater production may also be worth considering.

Table 1 - List of Some Possible Projects Containing Opportunities for Multiple Uses of Hydraulic Stuctures

Name	Uses
Northern Thermal Stations	Electrical Generation, Fish Farming, Industrial Heat
Kopuriki-Wheao Power Projects	Hydro-electricity, Forestry, Flood Control
Taupo Control Extensions	Hydro-electricity, Flood Control
Wanganui Power Project	Hydro-electricity, Flood Control, Navigation
Otaki Power Development	Hydro-electricity, Flood Control, Pumped Storage
Esk Valley Development	Road improvement, Flood Control, Forestry, Hydro-electricity, Industry, Farm Water
Mohaka Power Development	Hydro-electricity, flood control
Clarence-Waiau-Hurunui Power Development	Hydro-electricity, Pumped Storage Flood Control, Irrigation
Karamea Power Development	Hydro-electricity, Flood Control
Wairau-Buller Power Development	Hydro-electricity, Flood Control
Taramakau-Grey Power Development	Hydro-electricity, Flood Control, Pumped Storage
Rakaia North Canal	Irrigation, Hydro-electricity
Lake Stream, Ashburton-Rangitata Development	Irrigation, Hydro-electricity, Flood Control
Upper Waitaki Power Development	Hydro-electricity, Flood Control Farm Water, Fish Farming
Great Moss Swamp Development	Hydro-electricity, Irrigation
Clutha Power Development	Hydro-electricity, Flood Control Farm Water, Recreation, Pumped Storage.

When the Rangitaiki was first being considered for hydro-electric development, a preliminary study was undertaken of the relative costs of providing significant flood storage in the head ponds of the power stations or of stopbanking the lower river. No special flood routing procedures were considered and it was concluded that stopbanking was much the cheapest. As a result nothing more was said about the multiple use possibilities and the power and stopbanking works were carried out independently. Further detailed study has shown that Matahina and Kopuriki can make a significant though small reduction in floods downstream, and if Kopuriki is built now, a saving of $100,000 could be made in stopbanking. This is not enough to advance the power station in the planning programme. The small Wheao project upstream includes a new canal cut through the pine forests which would provide significantly improved fire fighting facilities.

Investigation has shown that Wanganui Power Development is of marginal economic value and presents formidable design problems. If built the large lake would enable flood peaks in the lower Wanganui to be reduced by a third or more, and it would provide better access to farm land that is at present almost outside economic reach. In addition the Wanganui Scenic Board has said that it would welcome the lake as enabling it to develop and police its extensive reserves. The lake would inundate the rapids existing down the river and so make canoeing less interesting but would make boat travel through the gorge much easier. The Wanganui is an example of how there has been a lack of co-operation in considering such possible multiple uses. Though they could not provide much financial support, at present there is little potential secondary users could effectively do to show that they support a proposal. (Opposition can much more easily be publicised through the public press.)

The Esk Valley proposal is a complex matter inspired by the wish to cut out the Devil's Elbow hill road north of Tongoio. An alternative route further up the Esk cuts out most of the hill but involves a series of big fills. The valleys upstream of these might be used for flood retention to protect the vineyards now spreading over the valley floor flooded in 1938. It has been suggested that the water impounded might be passed through a small hydro-electric station, say 6,000 KW, and that marginal areas could with advantage be planted with trees. Water might also be used for a paper mill at the mouth of the river and some taken to water the flats of the Napier inner harbour raised during the 1931 earthquake.

The Taramakau-Grey development with its new 170 square mile head pond would, besides supplying one of the biggest blocks of hydro-electric power in the country, allow a reduction of at least a third in the floods through the Grey harbour. By diversion of the Taramakau into the Grey the ruling flow past Greymouth would be increased and the flushing effect on the bar would improve the channel to this very difficult port. The lake would, besides inundating much waste land, also affect some well farmed flats and the local communication system.

The north Rakaia canal development has been, like the Rangitata diversion race, suggested by irrigation interests. It would also provide opportunity for developing a block of hydro-electricity. At least 300,000 acres of irrigable land could be commanded by a race taken from the Rakaia below the gorge, and a potential increase of 800,000 ewe-equivalents a year in farming output is forecast. The race at its upper end would have to take 3,000 cusecs and this flow in winter could be turned over the edge of the terraces through a power station and back to the river, thereby generating 50 MW or more at times of peak demand.

Similar possibilities exist in diverting and damming the Clarence-Waiau-Hurunui river systems. It is hoped to start field investigations in the next few years into the possibilities of hydro-electricity in this region. The power produced is unlikely to be very cheap, but combined with the provision of farm water and flood control, an economic system might be developed. The Lake Heron-Upper Ashburton-Rangitata diversions in South Canterbury and developments associated with the Great Moss Swamp, Sutton Stream, Maniototo and Strathtaeri in Central Otago have similar possibilities but on a smaller scale.

Completion of the Clutha Power Development would provide not only the biggest block of hydro-electric power remaining in the country (some 1600 MW), but in its extreme form suppress the worst of the flooding in the lower valley. This version would inundate large areas of land developed in varying degrees and involve the movement of over 2,000 people. The benefits it would provide in supplying farm water at higher levels would probably be balanced by the need to replace amenities and developments on the inundated land. An extensive preliminary investigation into the possible effects of this power development is in hand. If these are shown to be beneficial to the country as a whole it is clear that a further big research effort will be needed to sort out the details.

CONCLUSION

This paper may be summed up as a plea for closer examination of all the uses of proposed major hydraulic structures. It recognises that difficulties arise from the fact that those who might benefit from the development do not all feel the need at the same time and may hang back in the hopes that a primary user will push on, foot the bill, and allow secondary users free use of the amenity. It also recognises that proposals may create detriments, which may be real or imaginary, particularly to recreational interests. However, its main thesis is that these difficulties can be greatly lessened, if not resolved, by proper field investigation of all possible uses, by study of the effect of variations in flow by simulation and statistical means, and by proper economic evaluation of all the benefits and costs. It recognises that a fair allocation of costs between the potential users may be difficult and that it may be desirable, even though not equitable, for a primary user or the government to subsidise some of the secondary users, but the plea is made that this be done consciously rather than through ignorance. It welcomes the setting up of the National Water and Soil Conservation organisation as providing a mechanism that should be able to ensure that the facts regarding full use of a proposed structure be collected and examined, and it hopes that this body will be able to assist in the co-ordination of work in time as well as space.

Reviewing the past, the paper shows that multiple use of hydraulic structures has been far wider than was planned and notes that the New Zealand Electricity Department has, while creating some detriments, a good record in providing (often unconsciously), facilities for flood mitigation and in co-operating with, notably, the irrigation and sporting interests.

The paper finally presents an incomplete list of projects that might be built with conscious attention to multiple use, together with brief notes on some of the schemes (Table 1).

ACKNOWLEDGEMENTS

I wish to thank the organisers of this conference for the invitation to present this paper, and the Chief Power Engineer, Ministry of Works, for permission to prepare it. The facts presented have been collected from a variety of sources too wide to mention individually, but I thank those who have helped, often unconsciously, in the collection of data and its evaluation, and especially those who have discussed the subject and read and criticised this paper. Any views expressed are my own. They are not necessarily those of any official organisation with whom I may be associated.

DISCUSSION

Statement: C. T. Pugh (N.Z. Electricity Dept., Wellington)

Although this paper contains a number of contentious issues and many points need further consideration, the New Zealand Electricity Department supports this paper. The Department does co-operate, as far as it can, in flood control, in maintaining flows for stock water and boundaries and in providing public ammenities and recreational facilities. However, we must remember that our New Zealand rivers are very different from overseas rivers and it is not realistic to think that schemes such as those in the Tennessee Valley and in the Snowy Mountains can be applied to New Zealand.

On most New Zealand rivers power generation is likely to be the primary use. Secondary users are unlikely to initiate multi-purpose schemes but it is most desirable that they have facts and figures ready for the inclusion of secondary uses of hydro-electric power schemes at the time when hydro power development takes place.

Statement: K. F. O'Connor, Grasslands Division, D.S.I.R. Lincoln

The Timaru Herald of the 16th August, 1969, carried this statement:

> "... Mr McKenzie (General Manager, N.Z. Electricity Department) said that the N.Z. Electricity Department had been given the right to use the water in the Mackenzie basin but broadly it was the department's responsibility to ensure that property owners were not worse off because of it."

If it is the department's responsibility to ensure that property owners are not worse off, whose responsibiltiy is it to ensure that the community is better off and not just that the present property owners are no worse off?

Reply:

In this respect I hope the Water and Soil organisation will take up the matter. The interdepartmental committee is collecting facts on the multiple-use programme in the upper Clutha but there is the problem of reluctant users.

UPSTREAM ABSTRACTIONS OF WATER AS A FACTOR LIMITING DOWNSTREAM DEVELOPMENT

D. G. Reynolds

Farm Advisory Officer
Fairlie

One cannot but agree that a discussion such as this is timely, even perhaps a little late. Already in some back country areas the distribution and use of water and rights to it is causing some distress and confusion. Whatever the legal and practical solutions to the use of water it should be realised that farmers and those associated with land consider that there is a right to use water in any way that the land requires. To a considerable extent the resource of water is looked upon as part of the asset just as much as the land itself. Any reduction of property potential by alienation of water must inevitably have a damaging influence on the desirability of land and hence its marketability and capital value. This in time will have a direct bearing on the ability of the asset to attract money for development.

We must remember that agriculture today is facing increasingly stiff opposition in atracting what it considers to be a necessary share of the national financial cake for development. If as a result of these discussions we do anything for the future which damages the inherent productive capacity of land both physically and financially we will be doing no lasting good for the agricultural scene in New Zealand.

Canterbury forms an ideal example of a possible conflict in demand for water and I want to put the present state of its agriculture and its possible 20 to 30 year development into perspective. Firstly the definition of upstream I take as meaning all that country lying from the low downs to the main divide. Within this territory we have an amazing range of altitude, climate, soil, vegetation, aspect and present and potential use.

Rather than spending time discussing these one can generalise by saying that the land within these boundaries is being used to only about 25% or 30% of the capacity which we consider feasible with existing knowledge. This figure itself varies within the region. For instance farms on the wet downs have achieved 75% usage and parts of our high inland basins are only running at about 10% or less. For the purposes of brief discussion I want to divide the upstream area into three classes - high country, foothills and downs. Downstream are the plains and cities.

Any consideration of manipulating water for the future must take into account the eventual integration of the different systems of farming from mountain top to coast. This is already becoming apparent to a small degree. Its present affect on the efficiency of farming systems is very marginal. When stock concentrations are three or four times their present levels though, the importance of this will be more obvious.

In the high country ,the past 10 to 12 years has seen a remarkable increase in development and of our appreciation of the part this land can play in the future. Indeed knowledge and use have come so quickly that many of the concepts and practices put forward as recently as 5 to 10 years ago are already out of date or at least questionable. Amongst these I would list the practice of land retirement as a means of improving damaged country. There is evidence accumulating quite rapidly that intelligent use can be as effective or more so that non use.

Production in terms of meat and wool must be considered to increase at least ten or twenty fold as management techniques for handling different classes of country under high production are evolved. The practicality or significance of cash cropping should be discounted in terms of overseas markets and trends of production.

The implications of these increases in terms of the use of water resources could be considerable. The social ethics of damaging this potential for any immediate or future downstream development must be debatable.

Taking the Waitaki Catchment as an example it can be assumed that present water usage in the area amounts to 40,000 million gallons per year or 200 cusecs for the production from 400,000 stock units and a human population of 800. If we assume a dry matter production of 10,000 lbs per annum over 80% of the present used area, then in situ water usage for agriculture will increase over 10 times to 3,000 cusecs. This will include human population increase to 10,000.

Tourism and hydro-electric power production are the other two major enterprises in the area. The first mentioned makes little measurable impact on the quantity of water arriving downstream. Power production, however, by the creation of artificial lakes covering between 50 or 60 square miles reduced stream flow by 250 cusecs alone if we assume a 60 inch evaporation rate which has been measured at Tara Hills. Other losses in power production are not significant. Assuming the present average stream flow of the Waitaki at Kurow is 12,000 cusecs we can expect it to be reduced by 3,250 cusecs when these combined uses become effective.

A factor of power production is the variation in daily flow which in the case of the Waitaki is considerable. Each day at Kurow, flows fluctuate between 5,000 and 15,000 cusecs as power demand requires. When constant supplies required are above the minimum flow, obviously some extensive system of ponding will be necessary.

The same principles apply to the foothills and downlands as the high country. The implications though are far more serious. The major river systems are not used to nearly the same percentage of their productive potential as the minor waterways.

Taking another small case study gives us some insight into this. The upper reaches of the Opuha, Opihi and Tengawai catchments cover some 350,000 acres and at present allows production from 610,000 stock units. There are 2,700 people living in the area. The water flow from the district at present averages 340 cusecs.

If we allow for a production from 80% of this area of 10,000 lbs dry matter and the consequent increase in stock and population, we can deduce a total reduction in water supply to downstream areas. The theoretical requirement is 910 cusecs for this level of production.

Within the next few years Timaru city intends tapping some supply and it can be expected that Temuka will also require water additional to present supplies.

The acceptance that all areas must be allowed to develop to their maximum would seem to mean then that the major river systems will have to receive much more use than has so far been considered. When a quick approximation of downstream development over the next 20 - 30 years is done ,this becomes more obviously realistic and suggests that the intensive development of the major river systems could be closer than we realise.

Figures for both the high country and foothills are based on average flows and rainfalls. From information supplied by the South Canterbury Catchment Board and the Meteorological Service it is obvious that there are wide variations. For instance rainfall figures for Fairlie in the last 20 year period vary from 20 to 35 inches and in the previous 20 years between 14 and 39 inches.

Stream flows from the Opihi, Opuha and Tengawai rivers indicate lows which are only 30%, 25% and 30% respectively of the average flows.

Coulter made this comment which I quote: "Over a 20 or 30 year period the month to month and season to season trends are quite large. There may be fairly appreciable departures of the same sense in a run of a few years, but on the whole these are not very significant in New Zealand, except where the utilisation of the water resource is running close to its average amount". (Coulter pers. comm.)

As though variables in availability are not enough, it's as well to remember that consumptive use is also a variable. Maximum demand could conincide with minimum flow. This introduces the question of ponding or other storage. The cost of this and who is to bear it then becomes a nice point which can be left for others.

Initially at least then, variations are obviously going to be of major significance rather than overall supplies.

Downstream areas comprising the coastal downs, plains and urban areas can be expected to increase production and population density at an ever increasing rate.

In the agricultural sector there are 2½ million acres in Canterbury extending from the Rangitata to Culverden at present carrying six million stock units. With full irrigation and consequent development it can be expected that water requirements for agriculture could expand to 10,000 cusecs. In the urban sector the present usage of 60 cusecs could expand to 150 cusecs at least over a 30 year period.

This supports the previous suggestion that the minor water sources can expect to be fully utilised within a comparatively short period and make the greater use of the major rivers quite vital.

In the long term the major rivers themselves will have scant flows remaining, (working on average mean flows) Working on low flows there is approximately 60% of requirement available. The implications of this must be an engineers paradise - or nightmare, and just to add spice to the exercise combined high flows are 50 times greater than requirement.

SOCIAL

It needs little imagination from the foregoing exercise to see that sooner or later there will be a conflict of demand for the resource of water. This must have repercussions on the social evolution of rural communities.

It is becoming commonplace in modern society for rural communities to receive the thin end of the wedge - particularly where population densities are not high. There are three reasons for this. One is the lack of significance of a minority group and the second is their decreasing economic significance. A further aspect is their non-demanding nature. While this may be true for the majority of the world one cannot but question its allowable applicability to New Zealand.

The Agricultural Production Council some time ago laid down a necessary rate of agricultural development for our national well-being. More recently the National Development Council has updated this. The trend is for a rapid increase in the development of secondary industries and the degree of orbanisation of our population. The most optimistic prediction of national development, however, still shows agriculture as contributing well over 50% of our export income for the next 30 years at least.

It is obvious that the agricultural sector must be provided with all the ammenities necessary to keep it in a healthy viable state. This will not be easy in the face of declining political significance and contribution to the Gross National Product.

I emphasise this because I believe the social well-being of rural populations to be finely balanced at present and at a stage where it could improve or decline. If agriculture is to thrive it must attract, hold and use, a fair share of the country's intellectual resource. To do this it must be made attractive socially and economically.

Economically the last 15 years have seen a big improvement in parts of the rural sector and Government has necessarily encouraged this at some slight material cost to other sectors of the community to improve our export income.

Socially, matters have also improved. But not as much as they should. Agriculture today faces the same spectre of comparative isolation that it did 20 and 24 years ago.

I say this in spite of the massive improvements in roading, public servicing, radio, television and extension services. Adequate and comparable educational facilities are a very real problem and contribute probably more than anything else at present to a rural stigma. Any social group depends on sufficient numbers to be self-generating in terms of new ideas, optimism, resiliency and interchange with other groups within the country. Conditions of work must be such as to allow this social coherence to take form and give expression. There are many areas in New Zealand where these "sufficient numbers" are barely achieved, and this combined with conditions of work and the problem of education, go together to create what I believe to be the main social problems of rural communities.

The implications of these facts for the utilisation of water resources must be obvious to all of you. Any arrangement which does other than encourage any part of the rural scene in terms of economic significance, population growth and all forms of servicing, must be ruthlessly avoided. The alternative must be a planned obsolescence of parts of the countryside, and at the start of this paper I emphasised the inter-relationship of different land classes for their full effective utilisation.

LEGAL

Prior to the Water and Soil Conservation Act 1967, the right to take or discharge water was governed by the Common Law. With regard to water flowing in a stream or natural watercourse, only riparian owners (i.e. those whose land adjoined the water) had a right to take and use water. "Use" of water in this context is divided into two classes:

(a) ordinary use such as the use of water for domestic purposes and for watering stock;

(b) extraordinary use which includes all other usage.

The distinction between the two types of use was important as a riparian owner had the right to take and use the water for ordinary uses on his riparian property and in the exercise of this right could exhaust the water completely. The extent to which a riparian owner could use water for extraordinary purposes is uncertain and decisions of the Courts have varied considerably. In this country the chief extraordinary use of water is by farmers for irrigation, and whether irrigation was lawful or not depends on the type and extent of water usage. Generally it may be said that an extraordinary use of water by a riparian land owner is lawful if it does not interfere with the rights of other riparian proprietors either above or below him.

It must be emphasised that a riparian owner had no right whatsoever to take water and use it for purposes not connected with the riparian land.

Underground water fell into two classes. Where it was flowing in a defined stream or channel it was subject to the same rights as a surface stream. Where the water was merely percolating through the ground, however, the owner of the land above had an absolute right to take and use as much of the water as he wishes, without considering any other persons under whose land the water might later percolate.

The Water and Soil Conservation Act 1967 vested all rights to water in the Crown. The existing Common Law water rights no longer vest in the Riparian owner but in the Crown. However, it remains lawful for persons to use water for certain purposes, in particular for domestic uses, stock water and fire-fighting, in other words for their "ordinary" use.

The Act also provides that any use of water lawfully happening before the 9th September 1966 and which is notified to the Regional Water Board by the 1st April 1970, is authorised by the Act to the extent that it had lawfully been happening. These closing words are of the utmost importance, since they mean that a notification of an existing use of water does not necessarily authorise that use under the Act.

The Regional Water Board, which administers the Act at a local level and must issue directions of the Water Allocation Council, has no authority to reject a notification of an existing use of water. It is under a statutory duty to receive and record such notification.

But if notification is of a use which was not lawful under the Common Law then the individual concerned may find his right to the usage of water questioned at a later date either by the Regional Water Board or by another individual with a conflicting interest, and may be deprived of, for exampled, his irrigation supply. Because of this it is likely that there would be cases where, although the use was happening before the 9th September 1966, it would be better for the person concerned to apply for a new right rather than merely notify the existing use.

It is on this question of whether a use which has been notified and was lawfully happening that the Common Law rules relating to water will remain of importance as a basis on which a notified use of water can be challenged in the future.

Any use of water begun after the 9th September 1966 must be the subject of a final application to the Regional Water Board. All local body use of water must of course be registered.

So much for the present legal situation. Now what effect does this have on the farming scene? In the meantime obviously very little,if any. One cannot help feeling, however, for the freehold owner who is gradually losing his control over what was once purchased as part of the freehold. One would imagine that riparian owners would be entitled to some financial return for the loss of their common law rights. It is no argument to say that a farmer or land occupier is not using the water. The point remains that it was there as an asset for future exploitation prior to the Water and Soil Conservation Act. Those private persons who provide over 50% of the mortgage finance in land might well consider moving their investment elsewhere if such questionable practice is allowed to continue.

Obviously the Act is intended to provide a basis for the future manipulation of water for the benefit of all. Such an objective is most laudable. The method of achieving it though is no so acceptable. It is time that landholders pressed for some clear cut statement of intent as to the future security of the assets they pay money for in good faith. Remarks made in the section on social implications now come into sharper focus.

As far as Canterbury is concerned there would appear to be enough water for all provided the major river systems are used. The point at issue will be who is to pay for this more costly water. One would imagine that those with Riparian rights should have no costs to bear greater than if they had exploited their own riparian resource.

For the future those administering the Act have a clear cut duty to re-assure the farming community on several points. One would be the guarantee that no ordinary use of water will be interefered with for 999 years,and secondly,that in view of the arbitrary alienation of extraordinary use,that all those with rights before the Act have some preferential treatment for their possible future requirements. An overall reassurance to the farming community generally,would be to guarantee any requirement for future development where this existed naturally before,or give compensation for its loss.

On a broader issue some long term definition of freehold land would be worthwhile. The stage has now been reached where a freehold owner can have his land management dictated by Soil Council, has no right to oil, minerals, or water and is powerless to prevent the passage of roads, rails and power lines. Just where is it going to stop?

CONCLUSION

Using the two examples of upstream conditions is by no means necessarily indicative of the remainder of Canterbury nor for that matter is Canterbury indicative of the rest of New Zealand. It does however, suggest that there will be numerous cases in New Zealand's immediate future where conflicting requirements for available water will occur. It would seem that the task of water planners is not going to be simple. Economists tell us that we must earn money and willy nilly we have little option in the future but to earn a large proportion of this from agriculture. Obviously agriculture will be greedy in its use of water, to say nothing of the quality of residual water when it has passed through farming lands. This factor may be more important than actual supplies. In this context also due regard must be given to the requirements of tourists and sportsmen and our native fauna and flora.

Possibly there will have to be some radical changes in our concept of how land and water is to be utilised and inevitably this will create some degree of social disturbance. There is also a distinct danger that some individuals will suffer financial loss, as is happening now. This is a very wide subject, the morality and legality of which requires much careful consideration. Obviously nobody who is building a future for his family should be unreasonably disturbed. What is necessary for the community must be compensated for or paid for. Any other course of action is to me unthinkable.

In so far as our present agricultural production is concerned it does give us a rather unbalanced view of that which is likely to occur in the future. The upstream areas have, and are at present providing, a relatively small proportion of our total annual farming production. This will not always be the case. Already we have the knowledge that these upstream areas can be the equal of the more coastal areas in terms of dry matter production per annum. Methods of utilisation are changing rapidly and it needs little imagination to see that this can become a fact in a very short time. There would seem to be little doubt that upstream areas if allowed uninhibited growth cannot but have a marked effect on downstream development.

Early planning for future growth will cause the least disruption to social groupings. Where water has to be manipulated it will be done far more cheaply, and efficiently in terms of water use, well ahead of requirement.

ACKNOWLEDGEMENTS

I am indebted to the organisations and individuals for some of the facts and figures presented in Appendix A and to Mr J.H. Main of Oamaru for legal advice.

APPENDIX A

750,000 gals water to produce 10,000 lbs D.M. (Lobb, 1968)

1 sheep = 1,200 lbs D.M. per year
1 cusec = 1 cubic ft per second
1 cubic ft = 6.25 bals
1 cusec = 375 gals per minute
1 cusec = 22,500 gals per hour
1 cusec = 540,000 gals per day
1 cusec = 197.1 million gals per year

Upper Waitaki

400,000 stock units
800 people
1,770,000 occupied acres
440,000 25% waste and marginal use

1,330,000 acres

Waitaki stream flow at Kurow 12,000 cusecs (Waitaki Catchment Commission)
Per person 20 gals per day = 7,000 per year
City usage 80 gals per person per day

Plains Rangitata to Culverden = 2½ million acres
600,000 acres immediately irrigable
1,000,000 acres eventually

24 million sheep - 1 cusec per ½ million = 50 cusecs
Comestic country = 5 cusecs
55

1200 lbs D.M. per sheep per year (S.U.)
Mackenzie County Downs
350,000 acres - 610,000 S.U. and 2,700 people
Est. 80% highly improvable 280,000 acres

	Aver	Low	
Opuha at Skipton	170	58	Cusec flow - ex South Canterbury Catchment Bd.
Opihi at Rockwood	120	24	
Tengawai at Cave	50	15	

Lake Benmore 30.5 square miles
Waitaki 10 ? " "
Aviemore 12 ? " "

Evaporation Tara Hills 60"

Ex R. J. Bellamy (Ministry of Works, Belfast)

	High	Low	Mean
Waimakariri	118,000	1,190	1,200
Hurunui	30,200	400	1,800
Waiau-uha	46,200	1,000	2,000
Selwyn	7,800	16	90
Rakaia	144,000	3,000	4,500

Ex South Canterbury Catchment Board

North Ashburton	24,000	70	
South Ashburton	33,000	136	
Rangitata	88,000	1,220	4,500

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FORMULATING A WATER POLICY

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INTRODUCTION

Prior to, and for some time after the passage of the Water and Soil Conservation Act, it was stated that this Bill was intended to be the fore-runner of a number of complementary Acts which would amplify in greater detail the broad principles outlined in the 1967 Act.

Two years have passed without any further legislation materialising. This has left the Regional Water Boards, who have been entrusted with the responsibility of implementing the main provisions in the legislation, in somewhat of a quandry as to how some parts of the Act were intended to be interpreted. This is especially so in view of the very generalised and all embracing terms in which it has been written, and the radical departure from the previous system of common law rights and preferential rights under the Mining Act.

This paper attempts to review some of the problems Regional Water Boards are confronted with in formulating their water policy and briefly mentions other aspects which it is thought could influence the direction and application of this policy.

After a perusal of the Act, one is left with the impression that compared with hydro electricity, industrial municiple and local authority use, there is very little direct encouragement for the application of water for agricultural purposes in the Act, or an appreciation of the problems associated with such a use. This impression is strengthened by the lack of any general provision in the Act to reimburse Boards for the heavy costs of investigations connected with this aspect of the work. Lack of such provision could well frustrate its purpose.

From what is known of the effect of the legislation to date, it would probably be fair comment to state that the majority of all existing rights which have been registered to date, and the majority of applications and objections for the use of natural water, concern consumptive use for agricultural purposes.

Since there is only limited time to present the paper, discussion has therefore been limited to these aspects of water policy formulation, and consideration of the purely restrictive and administrative functions of the water policy has not been included.

WATER POLICY

As the word policy has several popular as well as scientific connotations some qualification is desirable as to what sense this term has been used in the paper.

Water policy as hereafter discussed, concerns the inter-related actions adopted or pursued by a government or semi-government agency to allocate and develop the nation's water resources. From the National Authority's first information bulletin[(1)] the purpose of the new Act is to:

> "Centralise the control of all matters concerning natural water so that a national policy may be developed for the conservation and wise use of natural water."

Policy does not, however, just happen. Both impulse and direction are needed to give it shape and form. By the very way the legislation has been constructed with a complex infra structure of delegated and sub-delegated responsibilities, a unified national water policy may be difficult to achieve without more concise definition as to how certain aspects of the legislation are supposed to be interpreted.

This observation may be dismissed as being premature, but already certain trends are evident, and unless there is some clear-cut direction from the Authority the planning aspects of the legislation may well be ignored if it is expedient or politic to do so at the grass roots level.

Absence of specific direction from the Authority concerning the planning aspects of the legislation has resulted in each Regional Water Board creating its own local water policy. This may have a great deal to commend it, provided these activities are co-ordinated. But co-ordination comes from the top, not the bottom, and lack of such co-ordination gives every encouragement to go it alone.

The outcome may well be eighteen or twenty five slightly or greatly different local codes of practice. This could well result in neighbouring water boards having very different approaches to the resolution of the same problems and a great waste of already over committed resources of manpower and effort.

Since this paper is an attempt to deal with policy at the Regional Water Board level, it is probably pertinent to review briefly the Regional Board's responsibilities and examine what appears to have generally happened so far.

The duties conferred to imposed on Regional Water Boards within their respective regions can be summarised briefly as:

1. Promoting the protection of local authority water supplies.

2. Planning projects for water conservation and the most beneficial use of natural water.

3. Recommending standards of quality for lake waters and minimum acceptable river and stream flows.

4. Investigating regional water resources.

5. Examining the effect of damming, abstractions, diversions and other factors affecting the volume, quality and availability of natural water.

6. Receiving notices under Section 21(2) of the Act, i.e. lawful uses and making a register of these.

7. Allocating water rights on receipt of applications under Section 24(1) of the Act.

By now most, if not all, Regional Water Boards have:

(a) Established some form of machinery to deal with their responsibilities and have allocated various duties to their executive officers to administer these responsibilities.

(b) Registered or are in the process of registering such existing rights as have been notified.

(c) Received applications for new rights and have made some degree of progress in processing them.

(d) Adopted conditions for the granting of water rights.

As far as the author is aware there has not been much progress by most Boards towards implementing their other responsibilities such as planning projects for conservation of water, determining what is the most beneficial use of water in their region and recording all significant resources etc. Therefore such progress that has been made so far has been of a strictly pragmatic nature.

THE RELATIVE IMPORTANCE OF WATER ALLOCATION

The resolution of water rights has long been considered to be primarily a legal one. The new Act has, however, made significant changes. The right to use water and the right to impound water is a right to a definite physical quantity which has to be measured and distributed or stored and later utilised. It is subject to evaporation, percolation, seasonal and annual fluctuations and if it is to be beneficially used must be available at specific times and locations.

Although New Zealand is generally acknowledged to be a humid country, there are parts which are exceptions to this.

The premise for example, that was the guideline for the United Kingdom's water policy (another humid country):

> "There is in this country ample water for all needs. The problem is not one of total resources but of organisation and distribution."(2)

is not generally applicable here. The exceptions to this premise are on a scale sufficiently large to demand a realistic evaluation of the water resources of at least critical regions, particularly for consumptive use purposes for agricultural applications.

Redistribution of water is seldom economically possible for agriculture, except when it is heavily subsidized because of the generally low added value which is returned by water used for that purpose.

Despite its needs, agricultural use is at a profound disadvantage compared with industrial or local authority usage both socially and economically.

Careful planning to make the best possible use of this resource when it is scarce should, it is considered, precede allocation. The reverse could, however, well be the case, first because of the pressures placed on the Regional Water Board to allocate rights; secondly the influence of previous practices which do not appear to have been adequately considered when the legislation was drafted.

These practices concern the intrinsic value which scarcity and the establishment of priority rights has given to water in those areas where a legal right has been acquired under the Mining Act.

Although from Roman times onwards the waters of rivers and streams in most western countries have been considered to be public rather than private property, personal appropriation of water has become firmly entrenched in those water-short areas of this country which are also mining districts. These rights which are generally long term but terminating ones, except in special cases, have generally been renewed by the Warden on expiry with much the same established priority of right.

This has given these rights very substantial monetary values which are recognised and assessed by the Valuation Department. These rights may be valued at upwards of tens of thousands of dollars and such rights have been sold quite recently for quite substantial sums.

There appears to be nothing in the legislation to compensate for these rights if on expiry they are not renewed in full. But if they are renewed on the present basis, is this the most beneficial use when others in the same area are deprived of even stock water?

And what for example is going to be the reaction of the owner of these rights, if when they expire and a new right is applied,for, the Regional Water Board grants a short term right in their place for only some of the water?

One paramount consideration by the National Authority and by all Regional Authorities should be the need to ensure that any settlement made should be a just one where there are competing demands. It would be unrealistic and idealistic to imagine that all decisions can be based solely on technological grounds. But since water is no longer allocated by law, but by discretionary bodies, it would appear that the only tangible safeguard that a body has of clearly establishing its impartiality, is to base its decision fairly on the best technical information it can assemble. The need for skilled technological data collection and analysis is therefore stressed. This data would also be of greater standing if it were drawn up according to a recognised uniform code of practice.

DIVISION OF TECHNICAL RESPONSIBILITIES

The Act Requires that certain service functions be carried out regarding the registering of rights and the maintenance of records. It also requires Boards to carry out certain technical functions,such as the promotion of works and projects to conserve water,and the collection and analysis of technical data. Probably by accident rather than design these closely parallel the existing Clerical, Conservation and Engineering sections of a Catchment Board.

There are basically two aspects of water policy: water allocation and water development.

Water allocation has already been considered in some detail. The service responsibilities are primarily administrative. Data Collection and analysis calling for special skills in hydrology, and the determination of the effects of withdrawals for consumptive purposes on the downstream occupiers, are largely engineering skills.

Water development (i.e. the expansion of the water use sector) involves soil conservators and engineers. Both are involved in the storage of what would otherwise be wasted water. Their relative contributions depend only on the size of the project and the technical difficulties which may be encountered. Regulating water by a variety of watershed management practices is almost wholly the prerogative of the conservator. These activities can have a marked effect on the quality and quantity of overland flow as well as on groundwater recharge. This work therefore is of considerable significance to the water allocation problem in prolonging the duration of sub-surface runoff. Base flow which undoubtedly denominates the critical yield of an unregulated catchment is, however, largely a function of the underlying geology and hence is normally independent of both engineering and conservation practices.

In a field that obviously needs very close technical collaboration and effort it may well be to the Regional Water Board's disadvantage to continue to divide its technical effort in this field into sectional interests.

SECTIONS 14(3)d AND 20(5)c OF THE ACT AND ALLOCATIONS TO COMPETITIVE USES

In several places the Authority is directed to "use water to the best advantage of both country and the region", to "promote the best uses of natural water", and in Section 20(5)c of the Act, the Regional Water Boards are directed "to promote the most beneficial uses of natural water".

The use of such terms removes the interpretation of the Act from equitable facts to disputable opinion. Is it social opinion, where hardship is a factor which is to be considered, or is the intention a comparison based on a cost benefit analysis, or is it a combination of both?

The Act has been described by Davis[3] as imposing a town planning control over water usage. Is the use of generalities such as these going to be any more successful in the long run than the interpretation of terms such as "amenities" have been in the Town and Country Planning Act? Is this a case where the desire to cover any and every eventuality has really resulted in nothing being effectively controlled?

Hard won experience has shown that an appeal is not only a challenge of the Regional Water Board's decision, but also of the technical opinion on which that decision was based. Anyone who has had experience of legal proceedings is only too well aware, to his sorrow, of the confusion a skilled cross-examiner can achieve if he is given good opportunity to exploit or challenge an opinion.

One cannot help but compare for example the detail with which the Soil Conservation and Rivers Control Act defines the issues which are to be considered in classifying for benefit under that Act, with the generalities and lack of definition in the Water and Soil Conservation Act.

In the interests of all those whose task it is to administer the Act at the grass roots level, serious thought should be given to clarify and adequately define these terms, to make the task of comparison a little more foolproof than it is.

THE INFLUENCE OF WATER DEVELOPMENT ON REGIONAL POLICY

Water development, particularly if combined with realistic multiple water use projects, could have a profound effect on regional water policy.

To any overseas visitor from a country, where sufficient water for agriculture is just not available, it must appear to be little short of a macabre joke that the country's biggest rivers flow through much of its driest country practically untapped on their way to the sea.

It is also staggering to contemplate the snow melt water which cannot be stored, flowing to waste past the turbines and generators and the land not far away lying arid and undeveloped because the existing tariff system makes no provision for low cost irrigation pumping. This is an even more bitter situation when it is recalled that certain selected industries can command preferential rates for electric power.

In New Zealand up until now, any multiple use projects of the waters from our rivers seem to have happened accidentally rather than been planned from the start. The proposed Maryburn scheme, for example, when first displayed made no mention of irrigation. Absence of suitable dam sites made power canals attractive to develop necessary head. Belatedly irrigation was added.

Is it fair to enquire if a properly conceived multiple use project would have exploited the potential of a greater area?

Are these the kinds of problems the Regional Water Board is expected to study with its meagre resources, or are these questions, and this type of planning, the prerogative of higher echelons?

THE COST OF ADMINISTERING THE WATER POLICY

A vast amount of work is involved in collecting and analysing data where there are conflicting or competing demands. As competition grows keener, so will the need for more comprehensive and better data become more necessary, if fairness and impartial judgement is to be the basis of the country's water policy.

One of the more unrealistic assumptions which appears to have been made when the Act was drafted, was that implementation of the Act would proceed slowly and that the Board's existing staff would have no difficulty, apart from recording existing rights, in coping with the added burden.

It can only be supposed that this opinion was never referred to the operating agencies for their comments. Anyone who has had experience of the constant clamour over the cost of Board's administration would know that Boards never have had, or are ever likely to have, a reservoir of untapped staff resources with the necessary skills to deal with these problems.

The Act proclaims that it is a national policy not just a regional one, and why should the ratepayers alone in the region be asked to bear the whole burden? Nor is it fair to demand that the first with a request should have to bear the major cost of an initial investigation. Some areas have far more problems than others and therefore investigational costs in these areas must be much greater than the national average.

The Otago Board for example has already had 250 applications for new rights and most of these are from areas where there are long histories of water shortages and water disputes. Surely Boards should be encouraged to solve the water problem on a skilled and scientific basis and not on the easiest expedient.

Is it also intended that finance for water development planning work, undertaken as a direct result of the Act, should be paid for directly out of fees, or is this to come from some other yet undisclosed source? And what about the actual work itself? How is this to be financed if the benefit it produces is conferred on an offsite recipient?

Finally, to convince those who still think that an effective water policy is possible at only nominal cost and minimal initial effort over the whole range of conditions prevailing in this country, I suggest that we should undertake a systematic investigation of each region's requirements by a research study based for example on the P.P.B.[(4)] approach.

For those who are not up with the trends, P.P.B. is the trade name for Programming Planning and Budgetting, first introduced in the U.S. Defence Department in McNamara's era, and is the latest system of expenditure analysis.

P.P.B. is an attempt to express in precise policy goals in terms of more specific definable functions; to cost these properly and so to try and make a reality of the idea that such a thing as a range of policy opinions really exist in quantifiable terms.

The range and variation of conditions in New Zealand makes an amorphous approach to the problem unsatisfactory to the Regional Water Boards with the problems.

RECAPITULATION

There are a number of aspects of the Act which appear to need resolving if Regional Water Boards are to be reasonably successful in formulating a water policy. In summary these are:

1. The need for better definition in the Act of some of its more abstract requirements and a more precise expression of its policy goals.

2. The need for greater overall co-ordination to avoid unnecessary duplication of effort and to give consistency in the method of assessing benefits.

3. The need for a properly co-ordinated technical approach to the multiple use and water development concepts.

4. The need for nationally contributed finance as well as user finance for the Water Boards' activities, and the provision of finance for development purposes.

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CRITERIA FOR WATER ALLOCATION, USE AND CONSERVATION

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INTRODUCTION

The title of this paper was given to me and I take it to mean, "The Critical factors on which the Allocation, Use and Conservation of Water (in any region) will depend". Before discussing these I think it necessary to make some brief comments on water administration.

The Water and Soil Conservation Act 1967[1] created an administration to:

(a) promote a national policy in respect of natural water,

(b) control conservation, allocation, use and quality of natural water and,

(c) to prevent flood damage and soil erosion.

The administration is headed by the National Water and Soil Conservation Authority, assisted by three councils dealing with Soil Conservation and River Control, Water Pollution and Water Allocation.

With some exceptions, the sole right to dam rivers and streams or to divert or take natural water or to discharge water or wastes into natural water or to use natural water is now vested in the Crown, but it is the intention of the Act that as far as possible natural waters should be controlled locally. To do this, the country is, or will be, divided into 21 water regions. Many of these catchment districts existed before the Act was passed. Each region will be administered by a Regional Water Board, which when the region coincides with a catchment district, will be the Catchment Board.

Subject to the overall directions of the Authority and the three councils, each Regional Water Board is required, inter alia:

1. to promote the protection of water supplies and recommend schemes for water conservation,

2. to investigate and collect data on the resources of natural water in its region,

3. where no underground water authority exists to exercise the functions of an underground authority as far as the National Water Authority directs,

4. within its region to grant to an applicant, on such terms and conditions as it may think fit, the right to dam any river or stream or to divert or take natural water or to discharge any natural water or waste into natural water or to use natural water,

5. to report to the authority as to the demand and availability of natural water within its region.

The Authority may direct a Regional Water Board to promote the protection of the water supply of a local authority in an adjoining region and may, if it considers it necessary, expressly delegate functions, rights, powers and duties to a Regional Water Board. The Authority also deals with applications by the Crown to take water, and natural water required by the Crown may, by Order in Council, be declared water of national importance. However, generally the administration of the water resources of a region is in the hands of the Regional Water Board, and it is the Board which will have to decide the principles to be used in allocating the water it controls.

Fundamentally these will depend upon:

1. The quantity of water available.

2. The quantity of water needed.

3. If water is short, which users should have priority.

4. What conditions should be applied to a "Right" to use or discharge.

WATER AVAILABLE.

Taking the country as a whole, the water available depends upon the rain which falls on it. This varies from as little as 12" per annum in Central Otago to as much as 200" in the Southern Alps and South Westland, but in most parts is between 25" and 60" with an average of about 65".

Toebes[2] has estimated that this average rainfall was used, or not used and returned to the atmosphere or to the ocean, in the following way:

Used beneficially by vegetation in transpiration		15"	
" " " hydro-electric development		00.50	
" " " industrial water supply	.007"		
" " " urban water supply	.010"		
" " " rural water supply	.021"	0.04	
Used for irrigation		0.14"	
Total beneficial use			15.70"
Returned to atmosphere without beneficial use		11.00	
Returned to ocean without beneficial use		38.30	
Total non beneficial use			49.30
Total rainfall			65.00"

The total returned to the atmosphere is 26" and the total returned to the ocean is 39". Of the amount returned to the ocean only 0.70" is used beneficially for various purposes. Thus theoretically there is still 38.30" available for beneficial use. However, because much of this falls in isolated places where it is not needed and because storage on a large scale is often not practical, only a small amount of this surplus will ever be used, or indeed will ever be wanted.

WATER NEEDED

The demand for water depends, and will depend, on land use and population. Present land use in New Zealand is:

Occupied Farm Land	Acres (millions)	
Improved grassland	18.4	
Tussock and other native grass	13.0	
Total Grassland		31.4
Land in field crops, gardens etc.	1.4	
Plantations	0.9	
Fern, scrub & second growth	5.7	
Sturdy bush	2.7	
Barren and unproductive	1.9	
		12.6
Total Farmed		44.0
Other Land		
Cities and Boroughs	0.4	
National Parks and Reserves	5.1	
State Forest	9.8	
Waste land, mountains, bare rocks, waste surface rocks etc.	7.1	
		22.4
		66.4

(Source: N.Z. Official Year Book 1962)

The areas of parks, state forest and waste lands are more or less constant but the areas occupied by cities and boroughs are increasing. Although the area of farm land will decrease slightly it can be anticipated that cultivated and improved grasslands will increase and that more water will be needed for rural supplies and irrigation.

More water will also be needed for urban supplies to cater for the growth in population and the increase in the consumption per head.

However, Toebes' estimates show that taking the country as a whole, the amount of our rainfall collected, managed, and used beneficially, is very small. Although water supplies will be inadequate in some areas, there are still ample to take care of most of our future needs.

CONTROL OF SUPPLIES

If, in any water region, the supply of natural water (i.e. water in streams, or in aquifers or in natural lakes) is not sufficient to meet demands in all seasons of the year, supplies will either have to be restricted or water which runs to waste in wet periods will have to be stored. Alternatively, surplus water from outside the region will have to be brought in. In such a situation the Regional Water Board will have to decide:

1. How will demand be restricted?

2. Who should have first call on the available water?

3. Can water be stored or is water available from other parts of the same region or from adjoining regions? Whether anyone is prepared to pay for storage or bringing water in?

1. Restriction on demand - Ideally each Regional Water Board will have sufficient information about its water resources and the anticipated demands of its region to be able to allocate water use in the best manner. However, until this information is available the boards can only use their knowledge and judgement. In some regions it

will be apparent that water will always be plentiful and all reasonable demands can be met. In others it will be equally obvious that demands will have to be restricted. This can be done by allocating the available water to meet demands either in full or in part. In some extreme cases the supply may be refused or rationed in times of shortage, by restricting the time and quantity of water used.

Restricted allocation, rationing or refusal of supply in part or full could mean that potential water users would have to move to other regions. In some cases boards will need to see if the cost of storage or of bringing in extra water can be justified.

2. Who should have first call on the water available? The 1967 Act states that it is lawful for any person to take and use any natural water reasonably required for his domestic needs and the needs of animals for which he has any responsibility, and for fire fighting. Thus there can be no control over such uses. However, the amount of water used will be small and generally will not affect water allocation. Those who were lawfully using water when the Act was passed will have next call on the available water. After these requirements have been allowed for, the Regional Water Board will then allocate the remaining water. Decisions of the Regional Water Board on the granting of rights are subject to appeal and each application for a right will need to be considered on its merit.

It is not possible or indeed advisable to set an order of priority of allocation which could be applied to all regions. However, in general it would seem reasonable that after allowance has been made for future domestic supplies for boroughs and towns and community supplies for animals, existing users should have some priority. The demands for new supplies either for industry or for agriculture should then be considered and allocated to give the most beneficial use to the region.

3. Who should pay for the cost of extra water? The right to use water is vested in the Crown. The Crown does not make any charge for water taken but the cost of taking and delivering water to the place where it is used and the cost of discharging it after use have to be paid by someone.

If a landowner is given a right to dam a stream and divert water to his land, he will have to pay the cost of the dam or other works. He will also have to provide the labour to control the flow on and off his land. If the Crown or some local authority obtains a right to take water for an irrigation scheme or a rural water supply, and delivers water to landowners, the owners are charged for this water.

The charge suggested for some of the mid Canterbury irrigation schemes, which incidentally would not meet the cost, is $1.20 per acre foot of water. In addition, the landowners would have to provide the ditches, banks and other works to distribute the water and provide the labour to control its distribution. This charge of $1.20 per acre foot is equal to $0.0044 per 1,000 gallons. Generally landowners claim that this charge is more than they can afford to pay.

There are many urban water supplies provided by local authorities, in which the water is collected and delivered through pipes to houses and factories and the cost is paid either by rates or by charges for the water used. For such supplies large dams and extensive works may be required and water may be piped considerable distances. Costs will vary but $0.30 per 1,000 gallons ($81 per acre ft) would generally be accepted by domestic users and most industries. In such a supply the water is delivered onto the user's land through a tap and ready to use.

These examples show that urban users are able or willing to pay a much higher charge for water than are agricultural users. Thus it might be practical to supplement urban water supplies from the more distant sources and to make the users pay for this. It would be more difficult to do this for rural supplies. This is a factor which could influence water allocation.

While a Regional Water Board would not normally act as a water supply authority, it might in some cases do this.

CONCLUSIONS

In summary, the criteria for Water Allocation, Use and Conservation in any water region are:

1. The amount of water available in the region and the surplus water available in adjoining regions.

2. The present demand and the anticipated demand for water for various purposes.

3. If water is short, the ability of willingness of users or potential users, to pay the cost of storing water in dams or reservoirs and bringing extra supplies considerable distances.

4. The use of the available water to give the most benefit to the region and the nation.

DISCUSSION

Q. The Water and Soil Conservation Act 1967, section 20, clause 6, states: "Every Regional Water Board shall have due regard to recreational needs and the safeguarding of scenic and natural features, fisheries and wildlife habitats and shall consult the appropriate authority controlling fisheries and wildlife where they are likely to be affected". Who determines whether or not fisheries and wildlife values will be affected?

A. The Department of Internal Affairs has a representative on the Water Allocation Council who watches this aspect. On a regional level advice is sought from the local acclimitization society.

Statement: Prof. J. R. Burton (Lincoln College)

"When the Water and Soil Conservation Act was put forward many people were under the impression that this would provide a national water policy. However, it now appears that the Act is more concerned with the control of water. To this end the control of water has been taken out of the hands of 12 government departments and put into the hands of 17 unwilling regional water boards. In the absence of a national policy these regional water boards must now create their own policies. That is instead of having one policy, it looks as though we are going to have 17 different regional policies."

A. The Ministry of Works (acting for central Government) cannot direct policy for all New Zealand. The regional water boards must do this. In addition, the Act is only two years old and although some amendments will be necessary, we must give the Act time to work.

Q. Assume a situation of two adjacent water regions, one rich in water, one poor in water. (For example Lake Tekapo alongside South Canterbury). What guidance would the Water Allocation Council give and what guidance would the South Canterbury Regional Water Board expect on the question of South Canterbury receiving Lake Tekapo water?

A. There is provision in the Act for the Authority to supplement the water resources of one region by calling on the water resources of an adjacent region.

Statement: R. D. Dick

"Local people want the control of their water but they also want some guide lines as to how this should be controlled."

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WATER AND SOIL CONSERVATION ACT 1967: N.Z. Statutes 1967(2): 1015-1047

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RIVER DRAINAGE AND EROSION CONTROL FOR KAIKOURA

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INTRODUCTION

This paper deals with the Marlborough Catchment Board's proposals for controlling flooding, drainage and erosion over the Kaikoura Scheme Area which is bounded by the watersheds of the Hapuku and Kahutara Rivers on the east coast of the South Island. It contains the catchments of the Kowhai River and the Mt Fyffe streams which are Sandy's Creek, Floodgate Creek, Middle Creek, Waimangarara River and Harnetts Creek. The total scheme area is 46,610 acres.

This intensively farmed land has special problems due to its proximity to the Seaward Kaikoura mountains which rise to over 8,000 feet at a distance of approximately 10 miles from the sea.

Solutions to the problems of flooding drainage, erosion and deposition of debris over farmland are proposed and some of these proposals due to the unusual nature of the problems could be considered unique.

HISTORY

Kaikoura was settled by the Maoris over one thousand years ago and the first European settlement took place about 1840. The plains area was subdivided into 40-50 acre units where dairy farming was established.

The great flood of 1868 with its catastrophic effects first made the settlers conscious of the flooding threat and resulted in the formation of the Kaikoura River Board in 1877.


Mt Manukau
Mt Fyffe
Waimangarara R
Harnetts Ck
Floodgate Ck
Luke Ck
Middle Ck
Kowhai R.
Town of Kaikoura.

The River Board's activities were initially directed in preventing the Kowhai River breaking its north bank and flooding the adjacent farm land and the town of Kaikoura. Although a degree of protection was achieved, this work was not permanent and failed to give protection against the larger floods.

Since 1923 there have been approximately 30 recorded floods and the commercial section of the town has been flooded on 12 separate occasions. In 1950 the south bank of the Kowhai River came under the control of the River Board and in 1962 Lower Floodgate Creek was included in the Board's area.

It is probable that throughout the period of Maori occupation fires frequently escaped into the forest, scrub and montane grasslands of the Seaward Kaikoura Mountains. These fires along with more recent disturbances to the vegetation by the white man's domestic and wild animals and his use of fire, have led inevitably to the highly modified forms of vegetation and soil erosion present today.

Pastoral occupation dates back for more than a century, at one time including what is now Mt Fyffe State Forest. Now, the Snowflake Run is the only run covering an extensive area of the Kowhai catchment. Unauthorized burning was reported here in 1937 and 1945 and in the 1940s representations were made by the Kaikoura River Board to the Soil Conservation and River Control Council to have the run closed. This was due to the severe erosion that was occurring in the upper catchment.

The present lease is a Pastoral Occupation Licence with a stock limit of 2,000 dry sheep from November to March.

At the beginning of 1966 Kaikoura came under the control of the Marlborough Catchment Board and a comprehensive scheme was prepared for the area mentioned above.

DESCRIPTION OF THE CATCHMENT

(a) Geology - The basement rocks of the Kaikoura area are the Jurassic greywackes of the Mt Fyffe ridge and

Upper Kowhai catchment separated by the Kaikoura (Hope) fault from the Upper Cretaceous and Tertiary rocks of the Kaikoura Peninsula. These rocks also form the basis of the low hills immediately south of the Kowhai River and underlie the late Pleistocene gravels of the Kaikoura Plain which is formed from the coalescing fans of the Kowhai River, the Mt Fyffe streams and the Hapuku River.

All of these rivers and streams excepting the Hapuku and two of the five major Mt Fyffe Streams are actively building up fans on gradients ranging from an average of 100 feet per mile for the Kowhai River to a maximum 400 feet per mile for the Mt Fyffe Streams.

The scheme area lies within a region of much past and recent tectonic activity and evidence within the catchment suggests that recent earthquakes have had an important effect on the rate of erosion. The basement rocks are extremely shattered and much major and minor faulting has occurred throughout giving rise to a very rapid rate of natural erosion.

(b) Topography - The scheme area comprises a floodplain of about 17,000 acres inland for 3 to 5 miles from sea level to about 500 feet above sea level, rising steeply and abruptly on to the Seaward Kaikoura range with summit peak altitudes between 5,000 and 8,500 feet. The upper catchment is characterised by extreme steepness of slopes with streams, largely without stable gradients. Gorges, waterfalls and precipitous bluffs are common throughout.

Table 1 shows the proportion of slope classes in the upper catchments and the floodplain.

The area/altitude distribution is shown in Fig. 2. Taken on the basis of the whole catchment, the area most subject to natural erosion (i.e. above 4,500 feet) is approximately 5,000 acres, which represents only 8.5% of the whole catchment. It does, however, represent 25% of the Upper catchment.

(c) Climate and Hydrology - The close proximity of the Kaikoura Plain to the sea has resulted in a

Table 1 - Slope Classes in the Upper and Lower Catchments

Slope Group	Range	Upper Catchments: Kowhai	Upper Catchments: Mt Fyffe Frontal	Lower Catchment: Floodplain Peninsula and Fernleigh Hills	Total and % of Catchment	
A	0-3°	-	-	8916	8916	20%
B	4-7°	81	973	6429	7483	17%
C	8-15°	68	503	2471	3042	7%
D	16-20°	79	256	587	922	2%
E	21-25°	284	195	1117	1596	4%
F	26-35°	2946	1570	936	5452	12%
G	35+	12453	3896	356	16705	38%
	Total	15911 ac.	7393 ac.	20812 ac.	44116 ac.	100%
		(36%)	(17%)	(47%)		

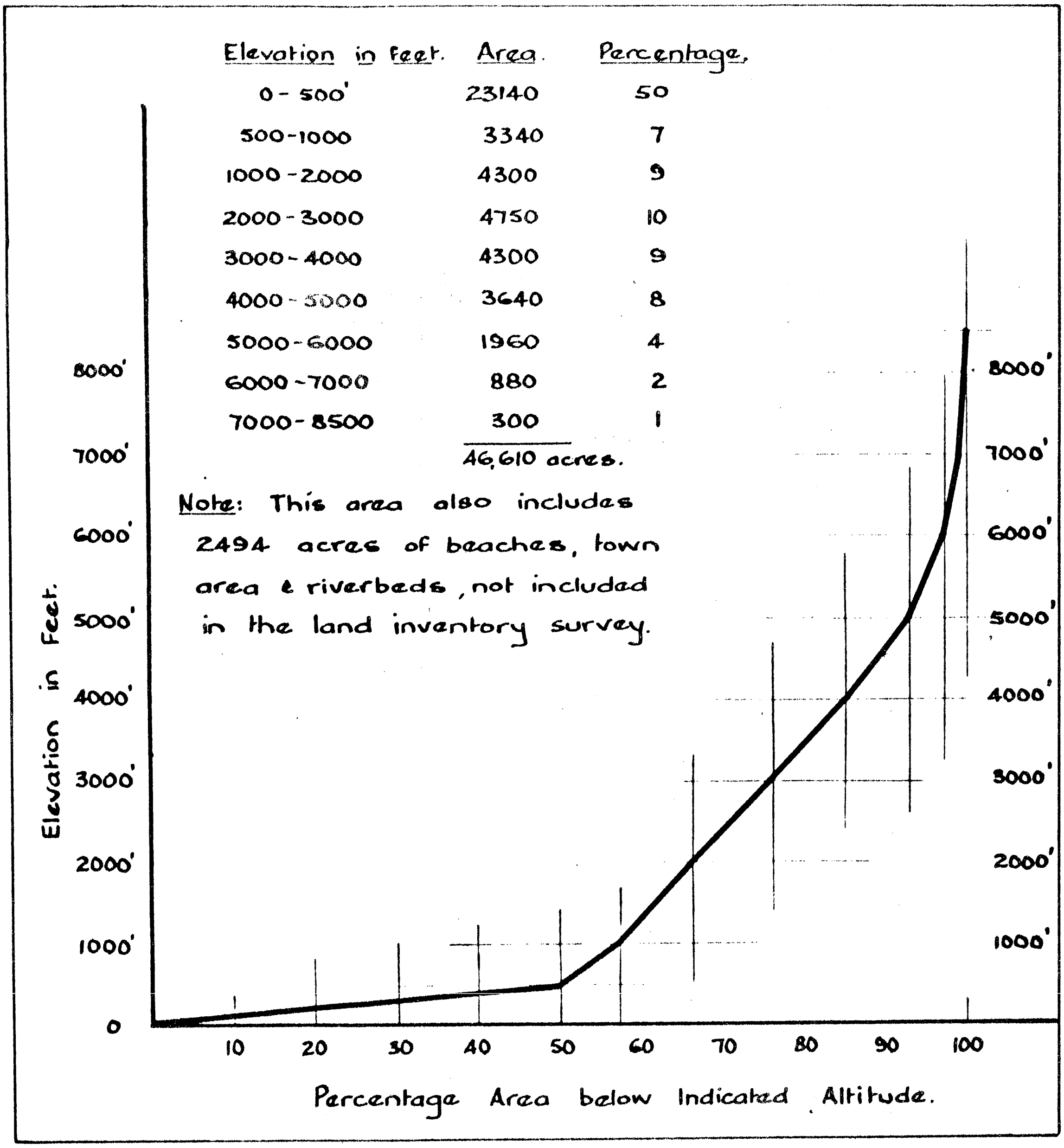

Figure 2

Area Altitude Distribution

reasonably mild climate despite the existence of high mountains which rise to over 8,000 feet a few miles distant. Temperatures observed at the Meteorological Station on the Kaikoura Peninsula seldom reach freezing point and often rise into the 80s during summer months although the climate is more severe closer to the mountains, where frosts occur on more than 40 days a year. At high altitudes frosts are severe.

Rain falls on about 130 days each year and averages 33 inches per year on the Peninsula, increasing to 55 inches per year at the base of Mt Fyffe. It is suspected that annual totals increase considerably with altitude on the south face of Mt Fyffe, and reduce in the Kowhai catchment due to the sheltering effect of the same mountain, but there are no records available to support this statement. High intensity falls from storms originating in the Tropics are experienced and when these rains fall onto catchments covered with soft snow, runoff is greatly increased.

Snow falls at any time of the year and during winter the mountains are covered down to 4,000 feet for 4-6 month periods.

(d) Vegetation - Before the arrival of the Polynesians the Upper Catchments of the Kowhai and Mt Fyffe were probably covered with undisturbed mixed hardwood - podocarp - broadleaf forest to an altitude of about 4,500 feet. As 90% of the upper catchment area is below this latitude the extensive protective effect of this forest cover can be appreciated.

From the time of arrival of the Polynesians to the present day widespread modification of the vegetation has occurred, especially since the mid-nineteenth century when the white man rapidly promoted extensive biotic changes with fire and sheep-grazing together with the full range of noxious animals.

i. Alpine and upper montane grassland - the main species present are Chionochloa flavescens and Ch. pallens and swards of these associations are all strongly modified. Celmisia spectabilis is often associated with the tall tussocks and tends towards dominance in strongly modified swards.

Poa caespitosa dominates the final stage of deterioration to bare rock and scree. Of the 110 plots sampled on the Seaward Kaikouras (and the overall finding would approximate the same in the Kowhai and Mt Fyffe areas) 81% showed very strong modification. None were unmodified. The general condition of these swards from the point of view of soil protection is extremely unsatisfactory. What is more disturbing is the fact that 59% of the plots on which trend is recorded in the scheme area are downward trending, 41% at present exhibiting stationary trend, while there are no upward trends in condition. (Wraight pers comm)

ii. Forest and Scrubland of the steeplands - the forest and scrubland of the steeplands may broadly be described as mixed Hardwood - Podocarp and Hardwood - Broadleaf forest, with large areas of Manuka scrub and mixed scrub hardwood stands. Short manuka scrub favours drier faces which have been burnt repeatedly. On Mt Fyffe the vegetation is a complex mosaic of forest and scrub types.

In general the watershed condition of the forest and scrub cover in both the Upper Kowhai and Mt Fyffe catchments is not good but varies widely from extremely bad to reasonably good on localised sites. Widespread areas of fine running shingle exist below the canopy with total absence of regeneration. Most of this damage is caused by wildlife, principally goats. The overall trend within the forests is downward (Wardle, pers comm).

(e) Soils - The 17,000 acres of alluvial flats and fans comprise about 4,500 acres of deep silt loams (Waimangarara and Taitapu soils) which in areas of low relief suffer from impeded drainage, grading to 5,500 acres of more shallow Waimakariri silt loams and gravelly sand near the Kowhai River and adjacent to the Mt Fyffe streams. Encompassing the Waimakariri gravelly sands on the steeper fan areas of the Mt Fyffe streams is the Hapuku soil series which covers 7,000 acres.

The soils of the alluvial flats and fans are high in natural fertility and in most seasons a well distributed rainfall may be expected. Of the total area of these soils approximately 11,000 acres, including 3,000 acres of poorly drained soils, are subject to flooding, scouring and sediment deposition.

Hill soils of the Peninsula, south of the Kowhai River and at the foot of Mt Fyffe cover about 5,000 acres and 50% of this area comprises low to moderate fertility Hundalee and Kahutara hill soils. The other 50% comprises moderate fertility Jordan and Medina soils and Puhipuhi hill soils.

The remaining 22,000 acres of the scheme area comprises steepland soils to be found in the upper catchment areas of the Kowhai River and Mt Fyffe streams. 38% of this area is covered by Alpine and Kaikoura soils which invariably occur together as associations. Wraight (pers comm) reports that from 4,500 feet upwards there is no discernible change in either the type or range of soil profiles encountered. His preliminary soil analyses show that these soils have a higher fertility than similar soils on grewacke ranges elsewhere. Erosion is severe throughout. The other 62% of the steepland soils are Patutu soils which developed beneath mixed scrub - podocarp - Broadleaf forest up to altitudes of about 3,500 feet. These soils are of moderately high fertility but, as with the Kaikoura and Alpine soils, have suffered serious erosion under the conditions that have pertained in the upper catchments.

(f) Erosion - All the elements necessary to create a profound state of both natural and accelerated soil erosion are present in the Kaikoura scheme catchments. These comprise:

i. A lengthy history of seismic activity

ii. Basic rock formations of an easily disintegrated type

iii. Frequent high intensity rains

iv. Above 3,000 feet considerable diurnal variations in temperature leading to severe frost lift.

v. Extensive and lengthy interference with the vegetative cover by man through his use of fire and domestic and introduced animals.

It is not surprising therefore that soil erosion of most types is present on an extensive scale throughout all the steeplands and that its intensity is, over large areas, classed as extreme or severe.

Sheet erosion is extensive over all of the steeplands, the intensity being mainly severe to very severe. Extreme sheet erosion is not yet extensive although the potential for this is very great under present conditions.

Gully erosion occurs, at present, mainly in the Kowhai catchment and is mapped over large areas as extreme in intensity. Although small in extent on Mt Fyffe, the areas of gully erosion are critical and of high significance in relation to debris discharge.

Scree erosion is very extensive throughout the steeplands, often descending to low altitudes. Many screes on Mt Fyffe occur beneath the forest canopy.

The rapid rate at which accelerated soil erosion in the upper catchments is progressing is due mainly to past influences of man's occupation which have resulted in the present condition and trend of the vegetation, described as extremely unsatisfactory over large areas.

It is reasonable to assume that, given adequate control of wild animals, regeneration of the forests should progress satisfactorily. Wraight (pers comm) has suggested that the swards of the montane grasslands at present in a fair to good condition (roughly 50% of swards sampled) have the capacity for improvement by natural regeneration providing pressure from grazing animals is drastically reduced. Without control of wild animals, restriction of sheep grazing to low altitudes and the prevention of fires, the alpine and montane grasslands and the forested areas will undoubtedly realise their full potential for accelerated erosion which, in these catchments, is extremely high.

(g) Land Capability and Present Land Use - Table 2 shows that nearly 16,000 acres or 36% of the scheme area is Class VIII land located in the upper catchments of the Kowhai and Mt Fyffe. This class includes large areas of Kaikoura, Alpine and Patutu soils, often in the severely and extremely eroded categories. At the land capability unit level the survey pinpointed the areas on the alluvial floodplain currently effected by floods and drainage problems and defined these areas in terms of soil types.

Of the 11,000 acres of floodplain vulnerable to damaging overflow, yet capable of high productivity, 3,000 acres suffer varying degrees of impeded drainage. Although the proposed river and drainage works will relieve these problems within a short time interval, the ultimate security of these works and therefore of the floodplain is closely related to the manner in which the Class VIII land is managed and treated in the future.

A survey of the lower catchment to obtain data for the economic report showed that about 50% of the 20,000 acres (approximately) comprises predominantly dairy farms while the balance is dominantly made up of sheep and/or beef cattle fattening units.

Butterfat production per cow at an average of 320lb approximates the New Zealand average, while butterfat per acre, averaging 122lb is well below the New Zealand average. These facts indicate that in general dairy farms in the scheme area are understocked, which in turn is probably due in no small measure to problems of flooding and impeded drainage.

(h) Wildlife - Chamois, deer, wild pigs, goats and possums are all present in sufficient numbers to adversely modify the vegetation and contribute to the pattern of accelerated erosion.

Huttons Shearwater (*Puffinus huttoni*) breeding grounds

Table 2 - Summary of Land Capability by Areas

Land Capability Class	Area Lower Catchment (ac.)	Upper Catchments (ac.) Kowhai	Upper Catchments (ac.) Mt Fyffe	Total	% of Scheme Area
IIW 1	589			589	
IIW 2	20			20	
IIW 3	1467			1467	
IIW 4	1441			1441	
IIW 5	1103			1103	
IIS 1	493			493	
IIS 2	408			408	
IIS 3	416			416	
IIS 4	74			74	
Total II	6011	-	-	6011	14
IIIe 1	541			541	
IIIe 2	15			15	
Other III	1392			1391	
Total III	1948	-	-	1948	4
IVS I	510			510	
IVS 2	517			517	
IVS 3	3035			3035	
IVS 4	218			218	
Other IV	885	149	307	1341	
Total IV	5156	149	307	5621	13
(III+IV)e 1	3145	24	1041	4210	15
(III+IV)e 2	138			138	
(III+IV)e 3	1823		446	2296	
Total (III+IV)	5106	24	1487	6617	15
VI	1947	159	177	2283	5
VII	633	3927	1271	5831	13
VIII	2	11652	4151	15805	36
	20812	15911	7393	44116	100

were discovered by Harrow (1965) in the Kowhai catchment and an area of 2,500 acres in the upper portion of the Kowhai catchment has been gazetted as a Huttons Shearwater Reserve. It has been suggested by Wraight (pers comm) that the Shearwaters' nesting habit of deep burrows in the loose, friable, high altitude soils under snow tussock may be the cause of much accelerated erosion, while the excreta enrichment of the sites may also lead to preferred browsing by deer, chamois and goats which in turn increase erosion rates. Bell (pers comm), however, considers that all the accelerated erosion is caused by the higher animals and that the Shearwaters improve the soil condition. Further research is obviously necessary to elucidate the exact part played by these birds in the local environment.

THE PROBLEMS

As mentioned earlier the problems consist of flooding, poor drainage, erosion and deposition of debris over fertile farmland. An area of approximately 11,000 acres is subject to flooding by the Kowhai River and the Mt Fyffe streams and although it is unlikely that all this area can be flooded at any one time, the steepness of the land and the ability of the rivers to change direction many times even during one flood makes almost all of this land vulnerable.

The Kowhai River is likely to overflow its banks anywhere between the Bluff and Ludstone Hills, and the Mt Fyffe streams can spill water off their fans anywhere below their gorges.

As no efficient channels exist to carry water and debris to the sea, and as flood overflows are frequent, gravel deposition over farmlands is a continuous threat. Not only gravel originating from high country erosion is deposited over cultivated land but also due to the slopes in the order of 200 to 300 feet per mile on the Mt Fyffe fans, the scouring effect of overflows and subsequent deposition is considerable, with many guts being formed where the surface cover has been weakened by farming operations.

An area of approximately 8,000 acres is vulnerable to this type of debris movement and deposition.

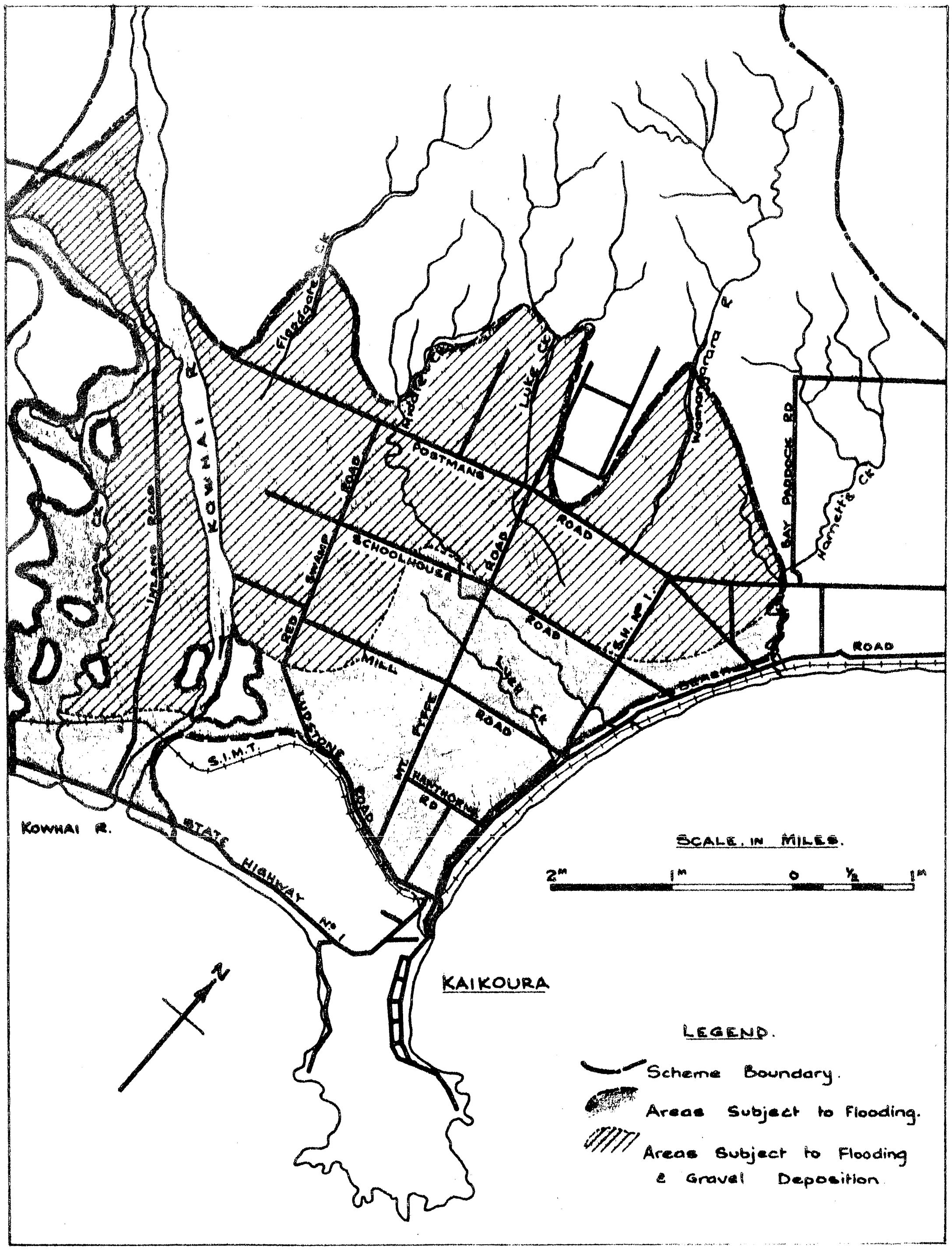

Figure 3
Areas subject to flooding and gravel deposition

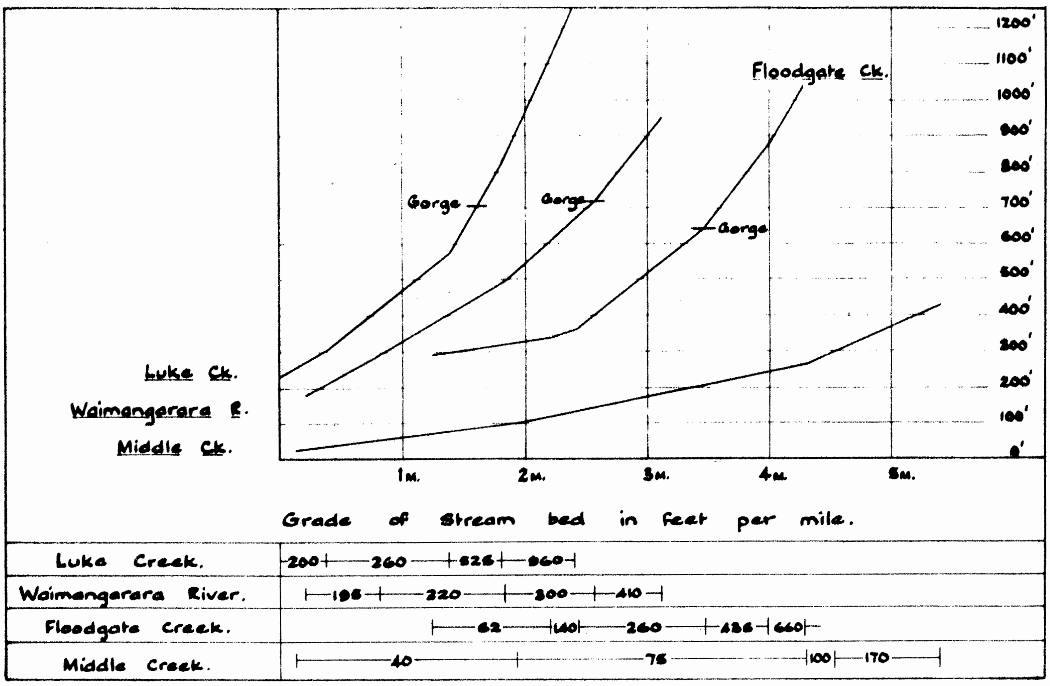

Figure 4
Mt Fyffe Streams, Longitudinal Sections

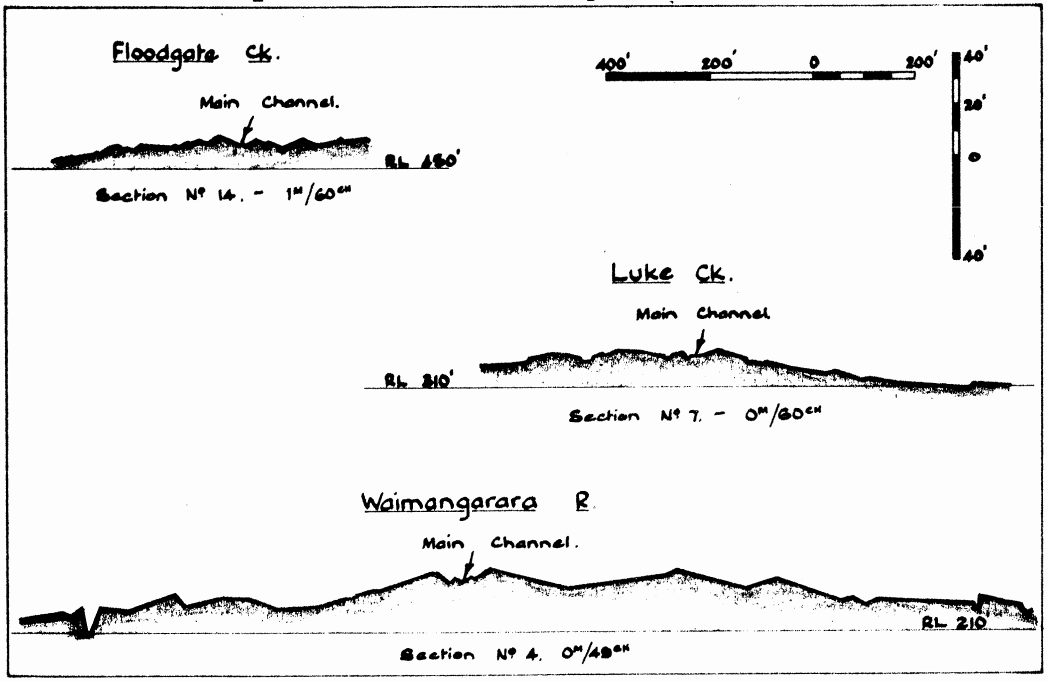

Figure 5
Typical cross-sections

The gradient of all rivers and streams is so steep that in most cases a precarious balance is maintained between the frequency and force of flood flows and overflows, bed material, size and vegetation. Minor changes in any of these factors can trigger off dramatic movements. This very problem requires the utmost care with any work done in these areas.

The amount of gravel movement within the streams is difficult to determine, however, a survey carried out on the Floodgate Creek fans has indicated that the estimated rate of erosion is likely to be in the order of 80 inches every 1,000 years.

By world standards this appears to be very high when compared with the Himalayas at 39 inches every 1,000 years, the Rocky Mountains at 8 inches every 1,000 years and the Alaskan Mountains at 31 inches every 1,000 years.

Although these figures give some idea on the degree of erosion on this catchment, no firm conclusions can be drawn from this data until further measurements are obtained.

Nearly 3,000 acres of good land suffers from impeded drainage, Although several miles of open drains have been dug in the past, most are not properly constructed and very little maintenance is carried out.

Drainage operations are further obstructed by frequent flooding which causes silting up in some places and uncontrolled scouring of drainage channels in others. The long term effect if present trends continue, will be a deterioration of the conditions described above.

Flood peaks and frequencies will increase as a result of higher runoff from more severely denuded upper catchments, with a consequent increase in the amount of debris transported and deposited over farmlands.

Although farm production has increased over recent years due to better farm management and technical developments, eventually a stage must be reached where the limitations placed upon good farmland by flooding, debris flow and impeded drainage will be severe enough to reverse the trend.

Land lost to agriculture as a result of gravel deposition or topsoil erosion is lost, if not for ever, for a large number of years and neither the farmer not the country as a whole can afford such loss.

INVESTIGATION AND DESIGN

(a) Surveys - A total of 231 miles of theodolite traverse and levelling was carried out in order to establish 86 concrete bench marks over an area of 30 square miles, 222 permanent reference cross sections across streams and rivers, and numerous trial traverses along proposed diversion lines. In addition bed material surveys were carried out by sieve analysis, Photographic Methods and the Maximum Rolling diameter method at 20 and 40 ch. intervals on most creeks and rivers in the scheme area.

Painted boulders to determine the rate and mode of gravel movement and scour chains attached to heavy concrete blocks were also installed at intervals to measure scour and deposition of gravel.

A land inventory survey which includes the mapping of soils vegetation, topography and types and extent of erosion has been carried out for the whole of the scheme area and a land capability plan has been prepared.

In order to collect economic data, personal interviews of some 90 farmers and others in the scheme area were carried out and information on flood losses, production and expected production, if limitations were removed, was collected.

Special surveys were also carried out by outside agencies such as the Department of Scientific and Industrial Research and the Forest and Range Experiment Station.

(b) Design flood discharges - Measured flood records are not available due to lack of suitable recording sites.

The probable flood discharges, shown below, have been calculated by using empirical methods based on rainfall runoff relationships and in particular the Soil Conservation and River Control Council's Technical Memorandum no. 61.

Due to the comparatively small size of the catchments and the resultant short time of concentration peak discharges are caused mainly by short duration high intensity storms.

Protection works on the Kowhai River have been designed to accommodate floods of up to 100 years return period and the channel dimensions have been determined from the two year dominant discharge. The Mt Fyffe Floodway has been designed for a 20 year flood but sufficient freeboard has been provided to accommodate floods in excess of this figure without overflow.

Table 3 - Flood Discharges in Cusecs

River or Creek	Area Sq.Miles	Return Period 2 yrs	20 yrs	50 yrs	100 yrs
Kowhai R.	26.75	13,030	27,600	32,690	37,000
Sandys Ck	1.5	192	456	536	
Floodgate Ck	1.55	600	1,310	1,545	
Middle Ck	2.00	730	1,540	1,810	
Luke Ck	2.00	1,100	2,400	2,840	
Waimangarara R.	3.25	1,650	3,500	4,100	
Harnetts Ck	3.85	420	995	1,160	

OBJECTS OF SCHEME

The objects of the Kaikoura scheme can be briefly stated as follows:

(a) The prevention of flooding.

(b) The prevention of gravel deposition over farmed areas.

(c) The control of erosion within the catchments and on the steep fans and farmed land.

(d) The stabilisation of all river and stream channels within the scheme area.

(e) The provision of adequate drainage.

RIVER CONTROL WORKS

(a) Kowhai River - This is the largest river within the scheme area and requires the most extensive river control and training works.

The river slope varies from 82.5ft/mile at the lower end to 126ft/mile at the gorge and the river is perched precariously on the top of the fan where it issues from the hills so that side overflows easily occur as a result of debris pile ups which form islands in the river bed. Because the river bed is extremely mobile during floods and the position of the channel changes many times with marked changes in bed levels, works that do not protect an adequate depth of bank can be destroyed by being undermined or overwhelmed with gravel.

The object of any control work in this river must be to safely contain the design flood within the river channel, while at the same time transport efficiently the massive bed load that would occur during a flood of that size. The work must therefore be of sufficient strength to produce downcutting of the river to develop a stable and efficient dominant channel. Horizontal alignment must be correctly selected to induce degradation of the bed and to reduce the cost of the protective works. At present the bed is basically straight and protection of a straight channel is very costly so a controlled meander pattern with protective works concentrated on the outside of the curves was designed.

The Henderson equation $S = 0.64d\ 1.14\ Q - 0.44$ * (Henderson 1968) was used to justify the design of a meandering channel.

* Where S = slope: d = median particle size in feet: Q = dominant discharge.

Proposed Works - The proposed channel will have rock armouring placed against high control banks located on the outside of all bends. The banks will be dozed up from the river channel. The quarried rock will be placed six feet below and at least five feet above present bed level and light osier type willows will be planted amongst the rock.

Channel dozing will be required to align the river and to form flood berm areas opposite the armoured control banks. In major floods these berms, which are outside the active channel, may receive flood water so they will be stabilized with suitable planting.

To assist with the control and alignment of the channel, cruciform type permeable groynes and heavy edge planting will be used.

The armoured control banks around the outside of bends will be built with wide tops at a height of 8' 6" above present bed level. These banks will therefore act as stop-banks with considerable freeboard to allow for changes in bed and water levels. Behind these control banks a system of echelon stopbanks with heights of up to 6' 6" will be designed to return overflow water to the main channel as soon as possible, so that the transporting power of the river is not reduced to any great extent. This will prevent deposition of material and the formation of islands.

The area between the echelon banks which is now covered with manuku and broadleaf will be cleared and replaced with productive species, which will also have a retarding effect on any possible overflows.

(b) Mt Fyffe Streams - The larger two of the Mt Fyffe streams, Luke Creek and Waimangarara River, have no defined channel off their active fans below Postman's Road and during heavy storms their floodwaters spread over the formed area down slope causing much damage by flooding, deposition of gravel, top soil erosion and silting up of drains. Floodwaters ultimately reach the sea via overland flow, drains and small watercourses.

Floodgate Creek before its diversion into the Kowhai in 1961 used to overflow above and below Postman's Road and its floodwaters after being collected by Lyell Creek would overflow at the lower reaches and flood the commercial section of the town.

Middle Creek and Harnetts Creek have reasonable outlets to sea but Middle Creek has insufficient capacity at the lower end.

The Mt Fyffe streams carry excessive bed loads and material which ranges from silts to boulders is transported on to the fans where it gets deposited as the gradient flattens out.

However, it is certain that most of the coarse material that reaches the farmed areas originates from the reworking of older deposits and by degradation of stream beds rather than being directly transported from the upper catchments.

The combination of slope, discharge, quantity and size of bed material make it economically undesirable to transport the bed load to the sea so the following objectives must be provided for:

i. To retain coarse gravel material on the fans;

ii. To ensure stability of the fans and avoid reworking of materials that have been deposited on the fans by previous floods;

iii. To collect and dispose of floodwater carrying quantities of silts and sands in a way that will avoid unnecessary flooding and instability of flood channels;

iv. To improve the stability of existing channels and to provide training and protection works where required;

v. To provide for overflows of floodwater down existing channel when floods exceed design figures.

Proposed Works - After several methods of dealing with the problems were carefully considered, it was decided that the Board should aim at retaining the coarse gravels and boulders issuing from the Mt Fyffe catchment on the fans while disposing of the floodwaters into the Kowhai River via a $4\frac{1}{2}$ mile long floodway along the foot of Mt Fyffe.

In order to hold the gravels on the fans a system for spreading the water over areas prepared specially for this purpose has been devised. This system provides for low netting fences attached to lines of Poplar trees planted on contours, supported by belts of willows. This method has been tried on a small scale in Kaikoura in the past by farmers with very encouraging results. At present the Marlborough Catchment Board is carrying out experimental work with this on a fairly large scale at Floodgate Creek.

It is proposed that 150 acres on the Waimangarara reserve, 50 acres on Luke Creek and 50 acres on Floodgate Creek fans will provide enough gravel storage at moderate depths to last for over 100 years at the present rate of erosion.

The floodway which has been designed as a non-eroding no-silting channel by the tractive force method, will be constructed downstream of the gravel retention area along the foot of Mt Fyffe and it will carry the "gravel free" waters of the Waimangarara River, Luke Creek, Middle Creek, Floodgate Creek and Sandys Creek safely into the Kowhai River. It will have a gradient of between 5 and 7 ft per mile with depths of up to 10 ft during design floods the width varying from 120 ft to 200 ft at the waterline.

The design capacity of the floodway will increase from 3,500 cusecs below the Waimangarara River to 9,200 cusecs below Floodgate Creek but a freeboard of 2 ft will accommodate much larger floods.

To cope with super design floods and eliminate any danger to floodway stopbanks, provision will be made for overflow control where the floodway crosses the existing beds of the Waimangarara River, Luke Creek and Floodgate Creek. By cutting the floodway into the fans at these points provision can be made for the spillway lip to coincide with existing ground level on the downslope side thus ensuring safe overflows without the risk of scouring. The existing riverbeds below the floodway will be treated to cope with minor overflows which are only likely to occur once in 20 to 30 years. Where the floodway cuts into fans the incoming water must be safely dropped into the channel and rock and rubble spillways will be used for this purpose.

The steep sideslope along the line of the proposed floodway (1 in 20) means that only one bank on the lower side will be needed as the original ground profile on the upslope side will contain the water within the floodway without flooding adjacent land.

Due to the larger _in situ_ material below the Floodgate Creek fan where the floodway crosses an old Kowhai River overflow, a steeper and more stable channel can be established, capable of carrying some of the Floodgate bed load into the Kowhai River.

To avoid interfering with water supplies to farms below the Floodway, provision will be made for low flows at Middle Creek, and other small streams intersected, to continue below the floodway. The Middle Creek channel, during storms, will be required to deal with surface flows below the floodway and minor stopbanking at the lower end will be required to accommodate these flows. It is expected that the effect of such a large quantity of relatively debris-free water, carried by the floodway into the Kowhai River, will have the extra benefit of helping to transport some of the Kowhai load to the sea, thus encouraging the degradation of this river so that a well entrenched safe channel will develop much earlier.

(c) Miscellaneous Stream Works - The scheme also contains proposals for the reconstruction of various other streams and creeks in the scheme area and this work mostly consists of minor stopbanking, clearing, minor diversions, realignment and other work of this nature as required.

Drainage - The Kowhai River and the Mt Fyffe Streams

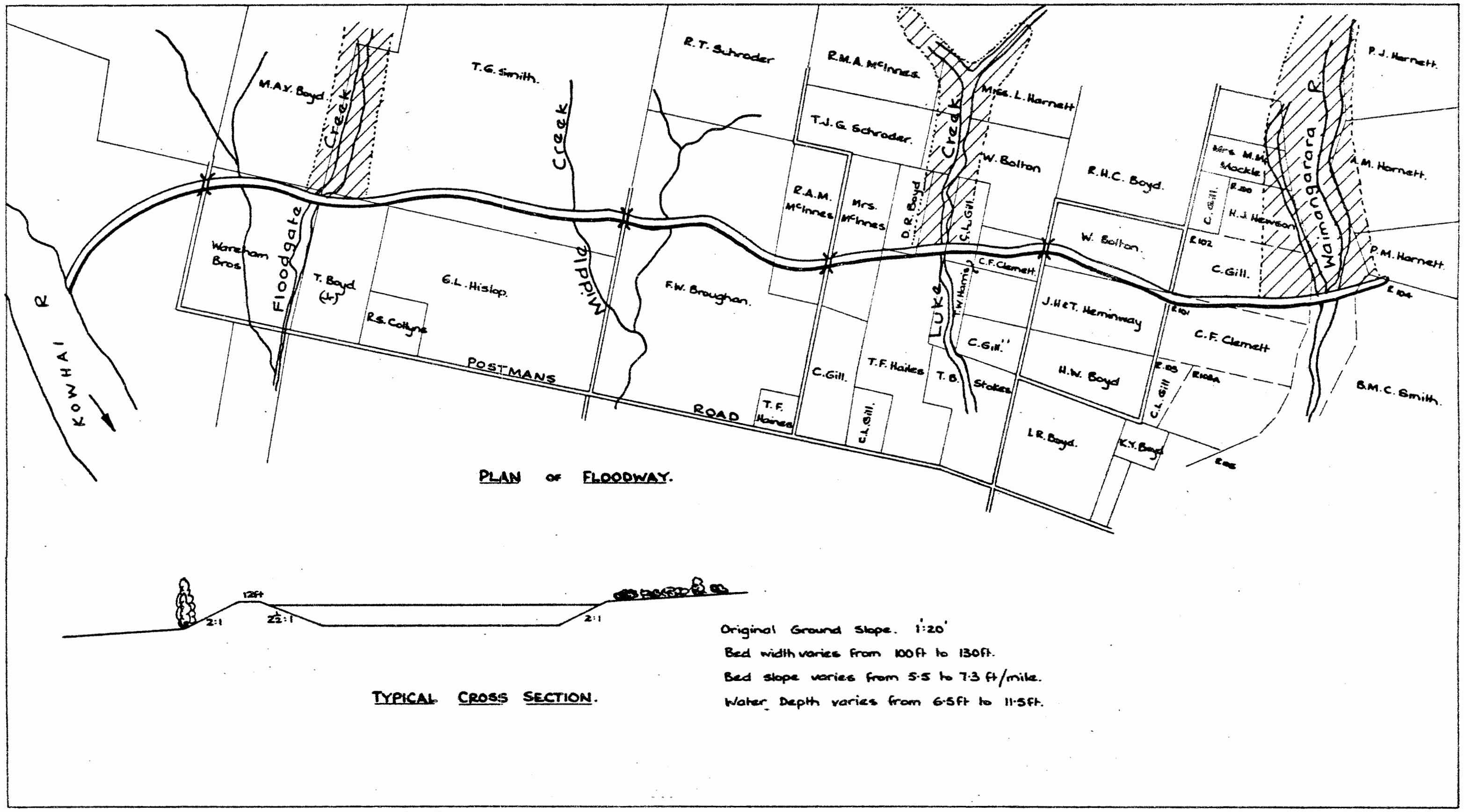

Figure 6
Proposed Mt Fyffe floodway

have a high porosity which causes most of the low flow to disappear underground. Some of this water eventually appears as seepage below the fans and it creates drainage problems. Also flood overflows carrying gravels, sands and silts fill up drainage channels causing continuous maintenance difficulties.

At present there is no overall control of the major drains and no rural drainage rate is collected by the County Council.

It is proposed that main drainage channels totalling about 30 miles be completely reconstructed as public watercourses. This work will involve excavation, battering and clearing.

On the steeper drains undue interference could cause uncontrolled degradation and erosion so initial work must be carefully carried out and drop control structures provided where required.

A small flood and drainage pumping station will be required to lift drainage and surface water over the Kowhai River stopbank between the Ludstone hills. At present the bed of the Kowhai River is higher than the surrounding farmland. However, if degradation of the river bed is successful, this pumping station will not be required for very long.

EROSION CONTROL WORKS AND SOIL CONSERVATION

Proposals for Upper Catchments - From the description of the upper catchments and their present condition and trend it is evident that immediate and energetic measures are necessary to arrest and slowly reverse the widespread soil and vegetation degration now taking place. To achieve this the following measures are proposed:

(a) Retirement from domestic grazing - All land in the upper Kowhai catchment at present used for depasturing domestic stock must be retired from grazing and the lessees involved assisted by run conservation plans to provide equivalent off-site grazing.

This involves the Lynton Downs Pastoral Occupational Licence of the 6895 acres Snowflake Run, where 2,000 dry sheep are run from November till March. The temporary tenancy of another small run of 2,000 acres, because of the nature of the lease, does not require any off site grazing provision although a conservation fence may be required.

(b) Statutory Protection of Retired Run Country - On withdrawal of domestic stock and upon the surrender of the leases all land in the upper Kowhai Catchment should be declared a Soil Conservation and Rivers Control Reserve. The purpose of this is to ensure that the long term control of the upper catchments of this river will be under direct statutory control of the Soil Conservation and Rivers Control Council, thus providing a form of direct local control which is essential for the implementation of the conservation proposals.

The Marlborough Catchment Board has a local establishment with personnel and equipment close at hand capable of organising and carrying out work, patrolling, and handling emergencies in the area while other agencies are remote.

As considerable work is proposed on the State Forest Reserve on Mt Fyffe, the same considerations apply, but statutory protection for State Forest land is already at a high level and given the necessary delegation of authority from the Minister of Forests to the Soil Council, a change in tenure is probably unnecessary.

(c) Noxious Animal Control - Much more intensive control than at present is necessary in the upper catchments and the success of any catchment rehabilitation programme of the nature proposed depends on the extent to which noxious animals are reduced or eliminated. It is also apparent that a control programme of the nature proposed cannot succeed unless considered in relation to the adjacent catchments of the Kahutara, Clarence and Hapuku rivers. Control must be applied over virtually the length of the Seaward Kaikoura Ranges to ensure permanent relief in the scheme area.

The Forest Service would be required to accord priority in animal control operations to this whole area with an intensive initial campaign to drastically reduce populations of goats and deer from the immediate catchments of the Kowhai, Mt Fyffe and Hapuku, with progressive and continuous pressure on the surrounding catchments.

Priority attention should also be accorded to possums to ensure adequate control in the critical areas.

The methods of control to be employed are the function of the agencies concerned but it is apparent that improved access and hut accommodation would almost certainly be necessary.

(d) Hutton's Shearwater - It has already been stated that the exact influence of this bird as an environmental factor in the upper catchments is uncertain and it is recommended that the Hutton's Shearwater and its habits be fully investigated by the appropriate agency.

(e) Revegetation of Mid-altitude Eroded Soils - As indicated by Wraight(pers comm) full recovery of large areas of depleted vegetation and degraded soils cannot be expected, even with the removal of all domestic stock and noxious animals and given fire protection. The trend on these sites is inevitably downward unless some restorative measures are applied in addition to the fire protection and grazing control.

Analysis of the land inventory survey shows that the Mt Fyffe frontal catchments comprise some 1,100 acres of Kaikoura and Alpine soils of which it is estimated some 750 acres are treatable in terms of vegetative restoration. Of this some 400 acres are below 3,500 feet. The precise nature of the conservation treatments will vary with the site characteristics of each situation but would largely comprise aerial treatments of seeding and fertilizers. Hand planting will be necessary on certain slips and screes together with mechanical retarding structures of an elementary type. Precise specifications will be dependent on the results of extensive trials to be conducted in the first three years of the scheme.

It is generally agreed that oversowing techniques should prove feasible and successful up to 5,000 feet. The fact that the soils are generally deep, with a high proportion of fine material, a good moisture holding capacity and a higher than usual fertility for greywacke-derived soils, supports this statement. In addition the climate is probably much less severe than on inland ranges due to the moderating coastal influence.

In the Kowhai catchment the land inventory survey shows a total area of Kaikoura and Alpine soils of 8,500 acres of which some 2,500 acres would be beyond treatment. According to Wraight's data it is probable that some 50% of the balance, or 3,000 acres, will be showing a downward trend and will require revegetation treatment. It has been assumed that of this more than half will have a chance to slow recovery without artificial assistance. For the purposes of the scheme some 1,200 acres of high altitude soil, comprising areas on the north face of Mt Fyffe, and in the Snowflake and Orange Grove stream catchments, have been selected for treatment. In addition 200 acres of screes will be planted at lower altitudes, more especially where these descend to the Kowhai River.

Should later vegetation studies indicate no improvement in areas previously expected to recover naturally, then an extension of the revegetation work would be required but this decision should not be necessary for at least a decade.

Over the remaining areas reliance is placed on natural recovery of the vegetation following removal of domestic animals and the intensified control of wild animals.

(f) Fire Control - This includes preventive measures and fire fighting services. The Mt Fyffe State Forest already has statutary protection against unauthorised burning and similar protection would be afforded the upper Kowhai catchment upon it being declared a Soil Conservation Reserve.

At present the fire authorities for the area, the Kaikoura County Council and the N.Z. Forest Service, are very limited in capacity to deal with fire outbreaks in the upper catchments and some reorganisation and co-ordination are necessary to improve upon the present position. The Kaikoura County Council equipment would be non functional away from County roads; the Forest Service mobile and heavy equipment is stationed at Balmoral and Hanmer some three hours travelling time away; while the two Honorary Forest Rangers are equipped with knapsack sprayers only.

As the Marlborough Catchment Board has a depot, plant, personnel and will be equipped with heavy machinery, four wheel drive vehicles and radios close at hand, it would appear logical for the Board to have some authority and responsibility with respect to fire fighting.

PRIORITIES AND PROGRAMME OF WORKS

First priority has been given to the gravel detention work for the Mt Fyffe streams and to the Kowhai River improvements. Of equal priority are the upper catchment works on the south side of Mt Fyffe to ensure the earliest possible control over catchments discharging into the Mt Fyffe floodway. Although construction of the floodway would proceed at an early stage between the fans, the connecting of the streams to the floodway would be carried out only after control of the gravel flow has been obtained.

Drainage and stream improvements on the plains area would be done as early as possible in order to provide a reasonably large initial benefit to those paying the highest rates.

The erosion control works, which are vital to the future of the scheme, would shift in emphasis to the Kowhai catchment upon the completion of works in the catchments of the Mt Fyffe streams, although it is proposed to effect retirement of domestic stock from the Kowhai during the first four years of the scheme.

ECONOMICS OF THE SCHEME

A cost-benefit analysis indicates that, from the

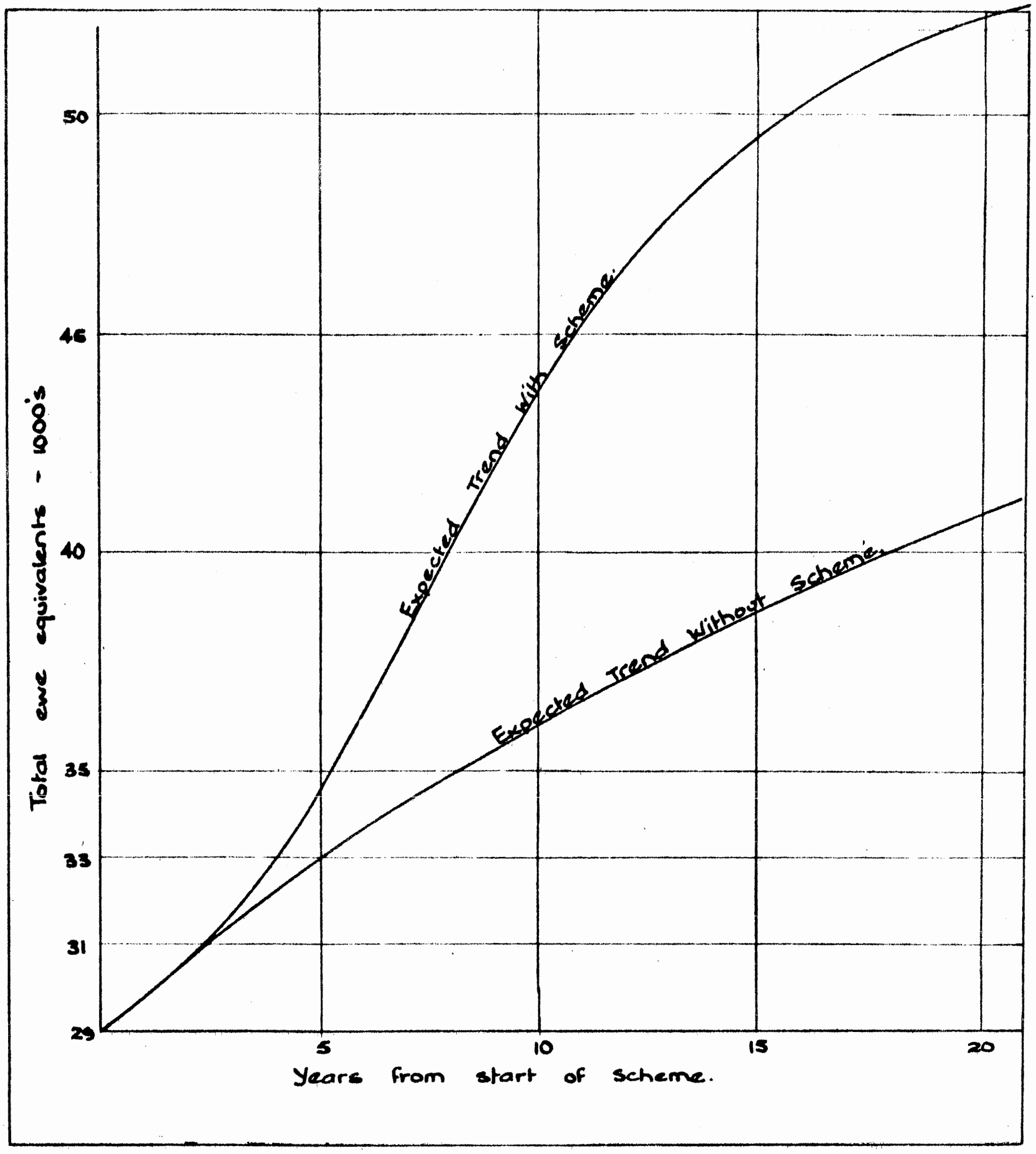

Figure 7

Expected production trends with and without scheme

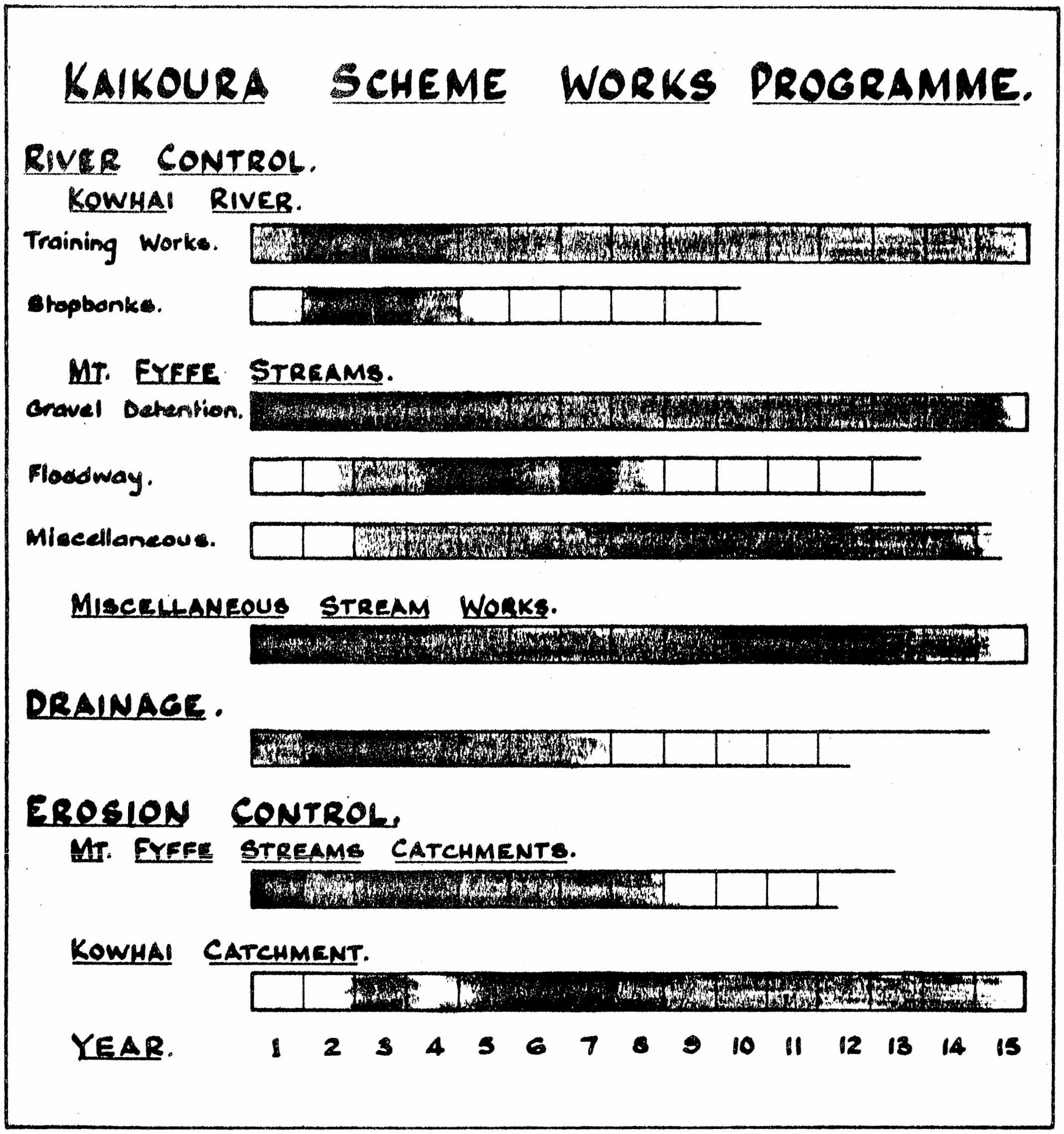

Figure 8

Kaikoura Scheme works programme

national view point, the proposed scheme would be a sound investment. Flood losses, which have been extremely heavy in the past, will be virtually eliminated while considerable production increases should result, both from agriculture and forestry. The potential for forestry in the area is high and by planting considerable areas of its river protection reserves in forests the Board will be tapping this potential while at the same time the land in question will be utilised in a manner that will fulfill its flood protective function.

The analysis showed that, for a discount of 5.5%, the present worth of nett returns is $903,911 while the ratio of present worth of returns to present worth of costs is 1.39. The internal rate of return is determined to be 10.2%.

CONCLUSION

Earlier attempts to deal with the unusual problems of the Kaikoura plains were mainly piecemeal river control works without any attention being paid to the upper catchments. These works managed to maintain the precarious balance of the rivers on their fans, while providing only limited relief from flooding. In contrast the present engineering proposals have been designed to give a positive and long lasting solution to the flooding and drainage problems facing this area. The erosion control proposals will be long-term in their effect and should be considered as a form of insurance against conditions which, if left uncontrolled, will ultimately lead to a failure of river control work. This in turn would necessitate a further major scheme in future years.

The value of the scheme to the district covers many fields, including increased production, reduced flood losses, security, increased land values, greater confidence and secure communications. Because Kaikoura is now a vital staging point in the national road and rail system, delays caused by flood damage to either road or rail would have an adverse effect throughout the whole country.

The total cost of the scheme of $1,174,000 appears formidable but the average annual expenditure of $78,300 is not such an imposing figure and when considered in relation to the benefits, both tangible and intangible, which the district would gain the scheme expenditure is well justified.

ACKNOWLEDGEMENT

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THE ECONOMIC PRINCIPLES OF MULTIPURPOSE RESOURCE USE

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SUMMARY

The paper briefly outlines resource characteristics and the relationships between products which use the same resources. This is followed by a discussion of the aims of project planning - the criteria to be considered - the maximization of technical, aesthetic, ecological or economic criteria. Some discussion is also devoted to a brief clarification of the difference between technical spillovers and secondary benefits. The paper is completed by a short discussion of the social welfare criterion and the responsibilities of planners.

RESOURCE CHARACTERISTICS

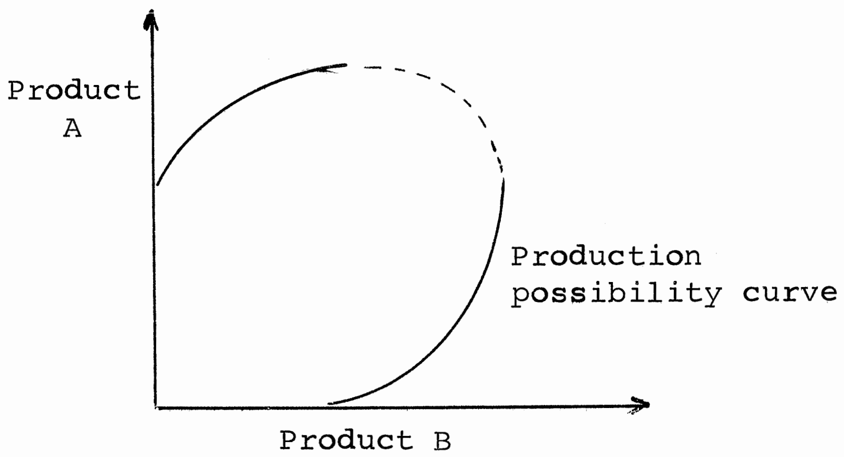
Any attempt to elaborate the principles of multi-purpose resource use must commence with a brief discussion of the differences in resource characteristics as these greatly influence the production opportunities.

Resources may be grouped into three major classes. Primarily they can be separated into stock or flow resources. Stock resources, such as coal or minerals, exist in limited quantities and can either be used or left intact. Flow resources are available in a steady stream over time. However, some, such as rivers, can be stored then used at some later period. The third major category exhibits some of the characteristics of both stock and flow resources. This group is referred to as biological resources and includes soil fertility. This resource fund may be totally destroyed, maintained at the initial level or, alternatively, increased.

The alternative uses of a watershed's land and water must therefore be considered in relation to their productivity as stock, biological or flow resources. Logically, criteria used to determine optimum use concepts for stock resources may be inappropriate if applied to the other classes.

PRODUCT RELATIONSHIPS

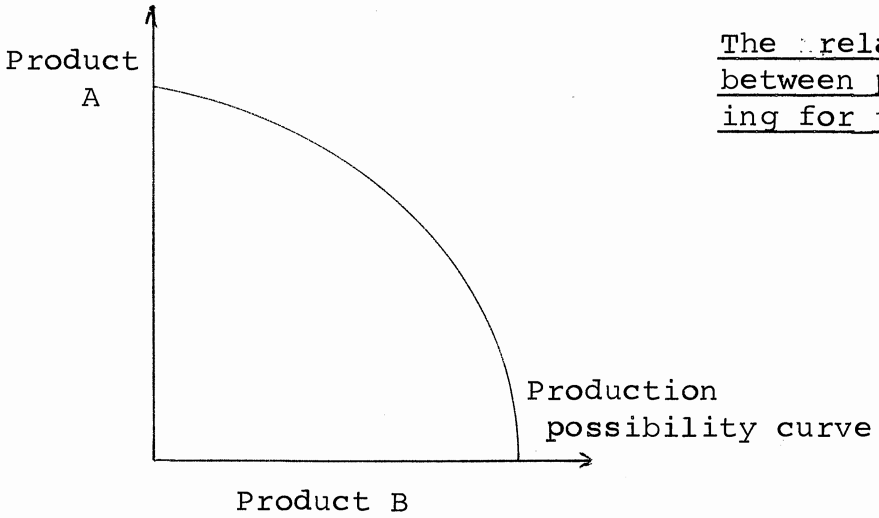
(a) Competitive - A further complication arises from resource use. Having accepted that resources have different characteristics, it must also be realised that the relationships between the alternative products are not always the same. Resource use does not involve a simple choice to produce only one of a number of products. That is only one possibility. In a watershed context choice can be made between the production of livestock or trees or cash crops or even the retention of the land in its natural state - these are all competitive uses for land and most people involved in agricultural production are making decisions of this type continually. The relationship between two competitive products is shown below. More complex situations involving many competitive enterprises cannot be represented geometrically.



<u>The Relationship between products which are technical complements when using the same resource</u>

$$\frac{\Delta A}{\Delta B} > 0$$

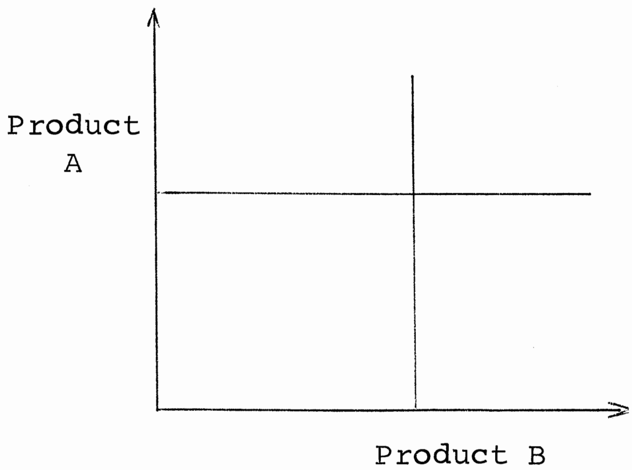
(b) Complementary - By contrast, a combination of products can be obtained which increases the total production. The presence of some trees will increase livestock and crop production in a windy climate and the addition of cattle will increase the output of mutton and wool under rough feed conditions. In these situations products complement each other with improvement in the levels of output of both. The relationship is quite common and is the basis of combined mixed cropping and livestock enterprises.



The relationship between products competing for the same resource

$$\frac{\Delta A}{\Delta B} < 0$$

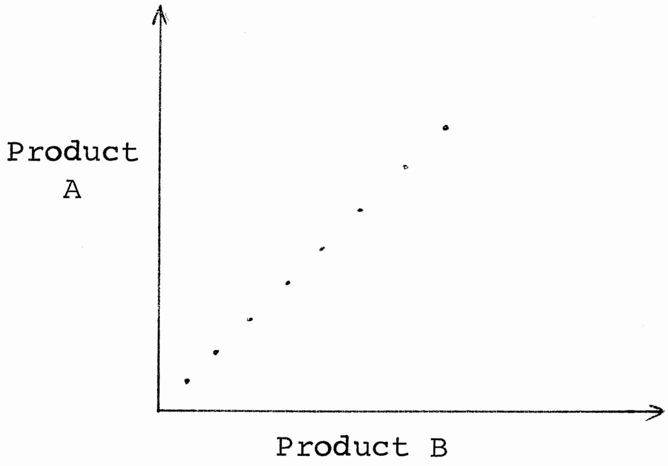
(c) Supplementary - Finally, products may utilise the same basic resources but without affecting each other in any way. Either product may be produced at any level, with or without the other. These products are commonly referred to as supplements. Recreation and forestry or agriculture often fall into this category.



The relationship between supplementary products

$$\frac{\Delta A}{\Delta B} = 0$$

Where the production of one product creates a second product at the same time but in a fixed proportion to the first product, they are known as joint products. Butter-fat and skim milk, mutton and wool, tree trunks and branches are well known examples. This relationship is shown diagrammatically below.



The production relationship between joint products

$$\frac{\Delta A}{\Delta B} = 1$$

In a water resource setting clear examples of these production relationships exist. Water may be consumed in any of a number of ways - irrigation, domestic, industrial or hydro-electric power generation to name a few. Each of these uses is competitive. Alternatively, a body of stored water may produce fish and in this sense the relationship may be complementary. Further, the presence of water may encourage the development of a number of recreational activities all of which are supplementary.

The relationship between the two resources, water and land, should not, however, be overlooked. Where stored water covers land which would normally be used for agricultural production, the products of this water are competitive for land use. Further, combined uses of both land and water can be considered in a similar manner. They may act as substitutes for each other, or as complements, in which case certain ways of using land may improve the available water resource. (For a complete exposition of resource and product relationships refer to Heady (1).)

Several production possibilities can now be envisaged within any watershed. Traditional pastoral products, forestry, aesthetic aspects, electricity, irrigation, water and land based recreation are but a few. The selection of any one may have a negative effect or increase the output of other products. The 'efficient' use of these resources must therefore imply the determination of an optimum volume of production whether as a single product or in combination with others.

THE CRITERIA FOR PROJECT SELECTION

Much has been written recently of the need for the multiple use of resources as though this implies that the optimum and most efficient use of the resource will be generally attained by this means. This is not necessarily the case. This assumption almost begs the question. It is not possible to determine the optimum or the efficient point unless a choice is made between the alternative products. And to choose between these products calls for the determination of satisfactory selection criteria.

A wide range of criteria have been used by various organisations or individuals; some of these are discussed below. Broadly these criteria, or bases of choice, fall into several categories.

A. The maximisation of a particular technical product.

B. The maximisation of aesthetic returns.

C. The preservation of some optimal ecological state.

D. The maximisation of the economic returns to society, the individual or both.

E. The maximisation of social welfare.

The confusion surrounding the appropriate criterion to use is in part resolved by the intellectual discipline under consideration. The determination of an optimum from an ecological viewpoint will often lead to a very different use of natural resources than the economists' view of optimum use. Each optimum use concept has merit, but neither is equivalent nor may be appropriate to define the optimum use with reference to social welfare. These criteria need to be considered more closely.

A. The Technical Criterion - Consider the first criterion, the technical product produced at a maximum level. This is characteristically an engineering concept. A decision may be made to store the greatest possible quantity of irrigation water for use during the summer. At first sight this ideal may seem satisfactory, but unless reference is made to drought frequency this initial criterion will be useless. Further it is quite obvious that the criterion avoids reference to cost; it involves an assumption that all water stored will be used profitably. A more useful criterion must incorporate both technical and economic aims as a bare minimum.

The generation of hydro-electric power creates similar difficulties. The decision to obtain the maximum possible number of kilowatts of power from a watershed may sound quite valid. In fact, this criterion must incorporate an assumption that in order to maximise society's welfare the maximum level of technical production must be obtained. Because the cost per kilowatt generated is rarely constant, this criterion is in fact quite unsatisfactory. Logically, it may be cheaper to produce the same number of kilowatts from a smaller dam in the watershed plus an oil fired or coal fired power station. If the second case is correct the first criterion is not appropriate.

As an alternative, it may be possible to generate the same number of kilowatts using two or three small dams instead of one large dam. In these circumstances reference must be made to economic criteria to choose between the alternatives as they are technically identical.

B. The Aesthetic Criterion - The second criterion suggested is the maximisation of aesthetic returns. This has great merit, however, the concept logically leads to problems of definition. Aesthetic appeal depends on the value judgement of each individual. Ranking of alternatives must be attempted subjectively with values awarded in general terms such as good, better or best. Since ranking methods used by individuals to assess the aesthetic appeal of projects are not equivalent, it is difficult to aggregate these opinions into a ranking system for society as a whole. While broad social aesthetic preferences are evident, it is difficult to be objective when ranking the aesthetic appeal of similar projects. When these projects are still in the planning stage the problems are acute.

Consider for instance the picturesque, quiet little Central Otago town of Cromwell or the alternative of another enormous hydro-electric lake which would flood it. You may not favour the lake. Alternatively, consider the calm, clear blue lake set in beautiful Central Otago hills and mountains instead of the half forgotten ex goldrush town of Cromwell. You may now favour the lake. Beauty is in the eye of the beholder or whoever describes the scene.

The paper does not pretend to solve this problem, but seeks to remind planners of their responsibility to inform society of the likely changes in its environment before irrevocable decisions are made. Society has the right to choose its own environment by accepted democratic procedures rather than having the opinions of one or two planners with their own value judgements forced upon it.

C. The Ecological Criterion - The determination of an optimum ecological state also leads to similar difficulties. While many ecolgocial aspects can be quantified, the determination of the ecological optimum may involve value judgements. For this reason there are many who believe that a wilderness environment most closely resembles the optimum ecological state. This is the ecological balance which exists in the complete absence of man - the antithesis of the technological environment. Again, however, the criterion rests on value judgements, involving aesthetic appeal and the desirable area of wilderness, as it cannot be automatically construed that society will become better off if the entire countryside is set aside as a wilderness.

D. The Economic Criterion - The last two criteria, the maximisation of economic returns to society and the maximisation of social welfare, are of principal concern in this paper. An extensive literature exists in these two fields. Several principles emerge. Firstly, maximum social wlefare is not synonymous with the maximum economic wealth of society - the two criteria are distinctly different. Secondly, if the total wealth of society is increased this does not necessarily mean that society as a whole is better off, especially if the gain in wealth is limited to only a few people. The distribution of wealth is obviously very important.

The economic evaluation of any project calls for the determination of the precise costs and benefits associated with that particular project. Projects are subsequently ranked by an appropriate economic criterion - the net revenue, benefit cost ratio or internal rate of return. Each of the economic criteria has specific limitations which have been widely publicised. It is up to the planner to familiarise himself with the limitations of these analytical techniques and not to assume blindly that the more sophisticated techniques will lead to correct project selection if their limitations are ignored.

Occasionally project selection has been based on rather simple concepts. Some planners have suggested that a project is satisfactory and should therefore go ahead merely because it is profitable ($B - C > 0$). Even more mysteriously others have suggested that because the gross revenue of a project is higher than its alternative it is the most desirable. Both these approaches are invalid and would very readily lead to wrong conclusions. Gross revenue calculations ignore costs and for this reason are generally useless. Net revenue calculations are also misleading unless the projects are mutually exclusive (McKean(2).) The net revenue (Benefits - Costs) of a programme may be slightly higher than an alternative investment, but if the alternative is much cheaper and if capital is in short supply the cheaper project would be the better investment.

The real concern of any economic evaluation procedure is to establish the marginal productivity to society of the capital to be invested in the suggested project and to compare this with the full range of alternative investments open to society. Thus to determine the most desirable project or selection of projects, all benefits and all costs relating to each project must be calculated. It is unforgivable to suggest that a project does not have to be evaluated economically merely because it is not competitive for land or water with other resource users. All projects requiring investment are competitive for capital and this is in very limited supply both to society and to individuals.

It is ridiculous to suggest that land or water resources within a watershed must be fully used in order to avoid waste. This concept has been referred to by Turvey (3) as the 'Stalinist Maximand'. In many cases such attempts to completely use these resources merely result in a more serious waste to society - the waste of capital. Even the generation of electricity must be evaluated properly if capital costs are to be minimised. Assuming consumer demand projections can be determined accurately and a criterion of 'least cost' power generation is used, the evaluation procedure must take into account - the length of life of the structure, the time taken to build it, the loss of profits of other producers flooded out and the annual operating costs. Because these costs are spread over time in all cases, an appropriate discount rate, with an adjustment for uncertainty, should be used to equate these costs for each alternative project. The use of the least cost criterion as a suitable evaluation technique for some water resource projects has been discussed by Steiner (4).

Technical Spillovers and Secondary Benefits -

In order to estimate the venefits or costs of a particular project it is necessary to include 'periferal' costs and benefits accruing to others as a direct result of the project. McKean (2) discusses this aspect at length. The conclusion reached is that the only benefits or costs of this type which should be included are those of other producers whose technical (not financial) production possibilities are altered as a result of the project. The inclusion of secondary benefits, as distinct from these technical spillovers, commonly leads to double counting and is unrealistic unless labour unemployment is a problem within the economy. If all resources are fully employed within an economy, secondary benefits are non-existent. For instance, the development at West Arm, Manapouri creates secondary benefits through employment for barbers or grocers, but as a result people throughout the rest of New Zealand grow longer hair and a few grocers' shops close down - the effect is cancelled and the secondary benefit is non-existent.

Secondary benefits are only of importance in a regional context or within an economy in which resources - especially labour - are not fully employed.

Returning to technical spillovers, it now becomes apparent that the most acute evaluation problems for planners arise from competitive projects - those which reduce or nullify the opportunities of others. This is especially so where the loss is of an aesthetic or ecological nature and it is in these circumstances that the planner has a responsibility to ensure that the final decision is made by a fully informed society in democratic manner. Where the spillovers are complementary or supplementary in nature the project may be justified by economic criteria alone. If it is financially worthwhile to proceed with a project, complementary or supplementary spillovers of an aesthetic or ecological nature add further to its value, but it becomes unnecessary to attempt to place cardinal values on these spillovers.

E. The Social Welfare Criterion - The final criterion is that the welfare of society should be maximised. Many factors combined to affect social welfare - these include income levels, employment opportunities, health and our satisfaction with the environment in which we live.

Where watersheds are concerned, national income levels and the environment are directly affected and there are some side effects on other aspects of social welfare. This criterion really includes all the criteria mentioned earlier in this paper and weighs them according to society's own needs. The contribution to social welfare is therefore the final measure of the worth of a project, whether multi or single purpose. Truely valuable projects improve national wealth as well as the environment and contribute significantly to the other aspects of social welfare. This is the epitome of multipurpose resource use. The general principle is reflected by Leopold (5) who wrote 'Man will not be satisfied by a financially lucrative economy in an environmental desert'.

Optimal multipurpose resource use implies the selection of projects which maximise the welfare of society through the improvement of one or more factors affecting social welfare. Watershed planning cannot be considered in isolation from other parts of the economy, in perspective it is no more important than efficient transport systems, health services or education each of which affects social welfare. Good planning reflects society's own aims, bad planning reflects the dictates of individuals.

Finally, it must be reiterated that a technical plan for the use of natural resources on a large scale no matter how brilliantly conceived and executed may be a flop from society's point of view if its contribution to social welfare is small. In its broadest perspective the term optimal multipurpose resource use implies that a project will satisfy each criterion discussed, with resultant maximum returns to society's happiness or satisfaction.

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HUMAN BEHAVIOUR IN RESOURCE USE AND MANAGEMENT

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INTRODUCTION

The Water and Soil Conservation Act 1967 is described in the long title as:

"An act to promote a national policy in respect of natural water, and to make better provision for the conservation, allocation, use and quality of natural water, and for promoting soil conservation and preventing damage by flood and erosion, and for promoting and controlling multiple uses of natural water and the drainage of land, and for ensuring adequate account is taken of the needs of primary and secondary industry, water supplies of local authorities, fisheries, wildlife habitats, and all recreational uses of natural water." N.Z. Statutes, Vol. 2, 1967, pp 1015-1016.

The passing of the Act is another reminder of the many ways in which a resource may be used, be it water, air or soil, flood plain, national forest or high country lake. In turn, this symposium shows that we have considerable knowledge of the operation of physical processes in resource use and that, from this viewpoint, we can specify what would be a reasonably wise combination of uses for a particular resource. Moreover we have been informed that there are now keener economic tools than those in the "Green Book" (U.S. Inter-Agency Committee on Water Resources, 1958) for uncovering the relative merits of alternative projects (Maas et al, 1968).

By application of current knowledge and techniques we can indicate what is economically and physically desirable but, paradoxically we are not yet able to fully explain why resources are used as they are, let along how we are to achieve wiser allocations in the future. To understand this widening gap between knowledge and practice in resource management we must know how actual choices in resource use are made, and how we might appraise new uses. It is from this point of view, the process of decision-making, that I approach the problem given me by your Secretary - "The benefits from an understanding of human behaviour in programme planning and implementation".

Firstly, I will present a method of analysis for describing resource decisions: secondly, I will illustrate its possible application by reference to human behaviour in the occupance of flood plain environments: and finally I will reconsider the broad field of resource management. My discussion follows American research, notably by geographers associated with the University of Chicago and drawing inspiration from White (1945, 1961, 1964). The significance of this work for water resource systems is increasingly recognised in North America (Hufschmidt and Fiering, 1967; Jackson, 1965). The New Zealand literature, however, shows little awareness, apart from a passing reference in the journal Soil and Water (Caddie, 1967). One application in a New Zealand setting has been made by a research student (Ericksen, 1967) and I will draw on his unpublished results.

CHOICE IN RESOURCE USE

Decisions on the use of resources may be regarded as involving managers and establishments (White, 1961). A manager may be defined as an individual, including a corporation and government agency, who acts as a unit in the management of an establishment. An establishment may be defined as a single residence or organisation that has a distinct usage of an area. Thus a city dweller is the manager of a city residence which is the establishment; the bureaucracy of the N.Z. Electricity Department is the manager of a government dam; a runholder is the manager of a high country station.

The uses of resources are defined by human assessments whether the resource be a physical class, for example soil or water, or an areal combination for example mountain country, coast, or flood plain. Any given use can be achieved by several kinds of adjustment: a manager may use forest land for the production of timber or for various combinations of uses and he can adjust his technology, for instance by varying logging methods, time of harvest, management techniques.

Theoretical and Practical Ranges of Choice - For any given physical environment there is a theoretical range of choice in the use of that resource. This theoretical range includes all the ways that the particular environment has been used anywhere in the world at any time and includes new ways of use which may be invented. In a single drainage basin, for example, there is an immense number of possible combinations for water use and control.

However, no manager has all the possibilities open to him. Within the theoretical range lies the practical range of choice which is frequently very much smaller. Some of the theoretical choices are rejected because they seem to the manager to be unwise. Others are closed to him, whether they seem unwise or wise, and these blocked choices appear to arise from social guides in the manager's culture. In some cases he may not recognise certain ideas or situations as being choices for him. He is unaware of them; he does not perceive them as open to him even though he is well-educated and lives in an advanced society. In other cases there may be social restraints which narrow the range, from political regulations prohibiting the farming of rabbits through to more subtle but no less rigid restraints of religious beliefs and personal values.

Elements in Decision Making - It is within the practical range of choice in resource use that the manager must select. Whatever the choice, our interest lies in the considerations that enter into the selection of a particular course of action. Two questions are critical: firstly, how does a manager deal with this aspect of decision making; and secondly, how does his appraisal compare with that made by others.

In some cases a manager may make the most elementary choice: "What's good enough for Dad is good enough for me". In other words the assessment will not necessarily be conscious nor explicit: it may range from highly intuitive to sophisticated computation. The steps may not appear rational nor linked yet the analysis identifies the way a manager decides. His appraisal is likely to differ from that of another manager, as for example the farmer's estimate of soil fertility may differ from that of the soil scientist.

In this approach to resource use, the interaction between population, environment and technology occurs within a framework of three parts: first is the theoretical range of choice for any resource manager and this is set by the culture and institutions which permit or prohibit a particular choice; and third is the actual selection within these limits and this depends upon the way in which a manager analyses the different elements in the decision.

CHOICE OF ADJUSTMENT TO FLOODS.

The approach may be illustrated from studies of urban occupance of flood plains (White, 1964). The assumption is that the flood hazard is the chief variable in the resource base, the physical phenomenon of the flood being capable of measurement and predictable manipulation.

Our common approach to the flood problem is to ask questions such as the following: what land and buildings are subject to flood damage; what is the nature of the flood event; what protection works are provided; what is public policy on flood control? Years of study of the questions and answers have not greatly advanced our understanding of the complex decisions that lead to occupance of flood plains and they have not given us guides to predict the consequences of changes in public policies affecting flood plains. The decision-making framework starts with different questions; how do managers on flood plains estimate the flood hazard; what adjustments do they see as possible and which would they adopt; how are gains and losses of various adjustments calculated; what account of technological change is taken in projecting future demands and adjustments?

<u>Traditional and Other Choices</u> - The traditional choice

for occupants of flood plains is to bear the loss from occasional floods or to urge the construction of protective engineering works, notably stopbanks. However, there are other adjustments which should be considered and which individual managers have in fact chosen in one place or another.

The range of alternative adjustments are included in the decision-making framework which can be set out in tabular form (Table 1). On the left-hand side are listed well known adjustments that are possible on many flood plains. There are six elements that may enter into decisions on flood plain use.

Table 1 - Table of Elements in Decisions as to Adjustments to Floods

Adjustment	Perception by Manager of:					
	Theoretical Choice	Flood Hazard	Technology	Economic Efficiency	Spatial Linkage	Practical Choice
Loss Bearing	1	1	1	1	1	1
Flood Control	1	1	1	1	1	1
Emergency Actions	1	1	1	0	0	0
Structural Change	1	1	0	0	0	0
Insurance	1	1	0	0	0	0
Public Relief	0	0	0	0	0	0
Changing Land Use	0	0	0	0	0	0

1 - Perceived   0 - Not Perceived

(Source: White, 1964 (9).)

1. The perception which managers have of the theoretical range of choice open to them in making adjustments to floods. Is the manager aware, for example, of structural alterations to his building as a way of possible savings in flood damage?

2. The perception which managers have of the flood hazard. How does this view differ from the probability of flooding as known to the hydrologist?

3. The technology perceived by the manager. Does he have command of the techniques, for example, of altering his dwelling to reduce flood losses?

4. His perception of economic efficiency. How does he assess costs and benefits in choosing an adjustment?

5. His perception of spatial linkage. Is he aware of the effect of his action in the flood plain on resource use in other areas?

6. The role of social guides. How do social constraints, for example the absence of a responsible, local, catchment board, affect his awareness of adjustments?

A major aspect in the decision process is perception by the resource manager, be he city dweller, government administrator or legislator. His view, his awareness set conditions of choice as surely as the natural factors impose certain restraints.

In the example in Table 1 the manager is aware of the choices of loss bearing, flood control, emergency actions, structural change and insurance. He does not think public relief or change in land use is open to him. He sees the flood hazard as sufficient for him to consider some action in addition to loss bearing. However, he does not have the technology of adjusting his building to reduce flood losses nor of writing insurance. He believes the cost of emergency actions to be too great to adopt this adjustment. Thus he is left with bearing the loss or relying upon flood protection works neither of which he regards as objectionable to others in the town in terms of the effects on land use. His perception of any of the factors could be altered by social action changing his information or other conditions within which choice is made. Thus the practical choice arises from the manager's perception of these elements. He arrives at this position over a period of time and not in one formal and fateful decision.

The model is descriptive rather than normative. It states three conditions necessary for the adoption of an adjustment; firstly, that the adjustment is perceived as a possible choice; secondly, that no obstacle to it is seen on the grounds of hazard, available technology, economic results, and wider spatial impact; and thirdly, that social institutions do not block its adoption.

Two companion volumes in the American literature provide an application of the model. Kates (1962) concentrated on the perception of flood hazard and range of choice while White (1964) examined the circumstances in which public and private managers choose among several possible adjustments to floods. Both found experience to be a powerful factor in the perception by resource managers, "the prison of experience" to use Kates' telling phrase. White found strong association between those who perceive and adopt structural measures and their length of tenure on the flood plain, and between the perception and adoption of emergency measures and their location within reach of the latest major flood.

A NEW ZEALAND EXAMPLE

The method of analysis has recently been used in a New Zealand context by a research student in the Department of Geography at the University of Canterbury (Ericksen, 1967). The study area was the town of Opotiki, most of which lies on the flood plain of the Waioeka and Otara rivers in the Bay of Plenty. The project was concerned with the general interaction between the flood hazard and human behaviour and, specifically, with the way individuals perceived the flood hazard and their attitudes towards measures for reducing flood damage.

Following Kates (1962), a series of lengthy interviews and questionnaires were conducted among samples of managers of residential and commercial establishments. The data yielded a number of statistical tables as well as interpretative material. I will use a few of the results to indicate something of the scope and findings of this pioneer work in the management of resources in New Zealand.

<u>Perception of Flood Hazard</u> - Systematic records of flood flows in the Opotiki rivers began only in 1957. The original flood control scheme of the Poverty Bay Catchment Board in 1962 was based on empirical procedures for evaluating the flood hazard because of the short record of flood flows. The scheme specified stopbanks to provide protection from a 100-year flood. Two years after these estimates, in 1964, a flood with an estimated frequency of 250 years occurred and this was thought to be sufficiently large to adopt as the new design flood. Within three years, in 1967, a flow almost equal to the enlarged design flood occurred (Jones, 1967). If prediction of magnitude and frequency of floods is complex for the technical experts and subject to considerable uncertainty, how do common managers evaluate the flood hazard?

The flood hazard information of each manager is compounded of knowledge and experience. In Table 2 the Opotiki respondents are classified according to their present information and their expectation of future flooding. All managers knew they were on a flood plain: 80 percent had at least one experience of flood water on their property and one half had experienced two or more floods.

It is logical to assume that the greater the knowledge and experience of flooding held by a manager, the greater will his expectation of a future flood be. In Opotiki, however, the expectation of future flooding does not correspond closely to either knowledge or past experience of flooding. Less than one fifth perceived floods as a hazard. Of those who had experienced two or more floods, more did not expect a future flood than perceived the hazard. Yet eight floods had entered the town between 1957 and 1964, within the time span of most of the respondents.

Table 2 - Perception of Flood Hazard by Opotiki Respondents

Present Hazard Information	Expectation of Future Hazard (% of respondents) No	Uncertain	Yes	Total
Knowledge but no flood experience	9.2	7.8	2.1	19.1
Knowledge and one flood experience	14.9	11.3	5.7	31.9
Knowledge and two or more flood experiences	18.4	19.2	11.3	48.9
Total	42.5	38.3	19.1	99.9
(No. of respondents)	(60)	(54)	(27)	(141)

Source: Adapted from Ericksen, 1967(57).

This optimistic attitude may be a result of the flood protection activities of the Poverty Bay Catchment Board. Table 3 compares several characteristics of the Opotiki flood situation with those of six American towns studied by Kates (1962). Opotiki has the greatest frequency of flooding of all the towns with the exception of Darlington. It also has 100 percent flood knowledge and the third highest percentage of managerial experience of flooding. Nevertheless its expectation of future floods ranks very low, only above Watkins Glen, a town which has had only one flood experience in the last 30 years. Since Opotiki is the only town in the list with large scale river control and flood abatement works, its low rank in the perception of the flood hazard may be attributed to the stopbanking scheme of which every respondent showed awareness.

Table 3 - Information of Flood Hazard and Flood Protection for Opotiki and United States Examples

Study Site	Flood Knowledge		Flood Experience		Expectation of Future Flood		Knowledge of Protection Works	
	%	Rank	%	Rank	%	Rank	%	Rank
Darlington	100	1	92	2	100	1	92	2
Aurora	100	1	93	1	87	2	13	7
El Cerrito-Richmond	91	3	73	4	45	3	82	3
La Follette	93	2	49	5	43	4	60	5
Desert Hot Springs	31	4	12	7	25	5	56	6
Opotiki	100	1	81	3	19	6	100	1
Watkins Glen	100	1	40	6	10	7	80	4

Source: Adapted from Kates, 1962 (82) and Ericksen, 1967 (62).

Perception and Adoption of Adjustments - The range in choice of adjustment to flooding in Opotiki includes the following: bearing the loss, emergency actions, structural changes, insurance, flood control and abatement and changing the land use. As the model suggests, perception of an adjustment does not mean it will be adopted (Table 1).

Table 4 displays the expectation of bearing future flood losses in relation to the managers' experience of flooding. It shows that few expect future losses even though two-thirds of them had borne losses in the 1964 flood. Although many householders recognised the risk of flooding elsewhere in the town, they failed to perceive a risk to their own property, believing they were beyond the reach of any flood. In effect they denied their location on a flood plain.

Table 4 - Expectation of Bearing Flood Losses by Opotiki Respondents

	Expectation of Bearing Flood Loss				
	No	Uncertain	Yes	No Response	Total
Number of Respondents	59	58	17	7	141
Percentage	41.8	41.1	12.0	5.0	99.9

Source: Adapted from Ericksen, 1967 (68)

Bearing the loss does not reduce flood damage directly but expectation of future losses does encourage the search for alternative adjustments. In Opotiki, the people had reduced the flood hazard to a certainty and were optimistic. This misguided confidence encourages flood plain settlement, reduces the range of adjustments, and increases the potential of flood damage. If this situation is widespread in New Zealand, as assumed, it is not surprising that the costs of flood damage continue to grow despite immense sums spent on massive engineering protection works.

Another type of adjustment to flooding consists of emergency actions of various kinds. Table 5 shows the individual managers' perception and adoption of them. At least one emergency action of a kind requiring no preparation was widely perceived although less widely adopted. Actions of a kind requiring prior preparation were neither widely perceived nor adopted.

Structural alterations to buildings were more widely perceived and adopted than many Opotiki managers, including officials, believed. Managers of commercial buildings were greater adopters of this adjustment; one third of the respondents had elevated their buildings wholely or partly to reduce flood losses. Residential managers were less likely to perceive or adopt any of this group of adjustments.

Table 5 - Perception and Adoption of Individual Emergency Actions by Opotiki Respondents

Individual Emergency Actions	Respondents Number	%
1. Requiring no prior preparation (e.g. elevate goods)		
Total perceiving at least one action	125	88.6
Total adopting at least one action in past	89	63.1
2. Requiring prior preparation - stored materials for flood fighting		
Total perceiving	21	14.8
Total adopting in past	8	5.6

Source: Adapted from Ericksen, 1967 (71)

Insurance, flood control and abatement, and changing land use were also analysed as adjustments to flooding. Almost all the findings confirm the *a priori* assumption that man in this decision-making context acts in a manner of bounded rationality once we no longer assume that common knowledge of past floods means expectation of future floods and losses. When managers perceive the hazard they try to do something about it. However, they may, in their minds, remove the threat of flood and therefore of the need for action. In this they may be unconsciously assisted by public measures aimed at their protection. For example, the widespread community choice of massive engineering solutions may, if adopted, decrease the awareness of a hazard which, in physical terms, still exists. In turn, the range of adjustments perceived and adopted may be narrowed, thereby increasing the damage when flooding next occurs.

PUBLIC GUIDES TO CHOICE

The analysis exposes the danger of oversimplifying choices through a narrow policy of dealing with flood losses by providing protection, initially under engineering agencies and to an increasing extent under the banner of watershed management. The behavioural approach to flood plain occupance should not be misconstrued as an attack on the construction of stopbanks. It does, however, argue for a policy of extending the range of choice of adjustments; it does show how a programme of works may rebound.

The Opotiki example is useful in that it does give some evidence that is not inconsistent with American results. However, this is only the first New Zealand study. We need more research on a comparative basis but in different flood plain situations before the implications for New Zealand are clear.

More generally, however, the method of analysis may be extended to a wide range of natural hazards as in North America (Burton and Kates, 1964). In addition to river floods, it has been used in analyses involving coastal storms, snowfalls and drought (Burton, Kates and Snead, 1969: Rooney, 1967: Saarinen, 1966). In different directions, the framework has led to better understanding of wilderness use, multiple recreational demands, industrial water supply and the whole field of attitudes in resource management decision-making (Lucas, 1964: O'Riordan, 1969: Wong, 1969: White, in prep). These studies make an important contribution to our understanding of environmental perception and behaviour, a field which has practical as well as theoretical implications (Lowenthal, 1967: Kates and Wohlwill, 1966).

Multi-purpose projects in resource development are usually found in the public sector but we cannot assume that decision making is any more perfect than in the private sphere. Recent work in allocation techniques for water resource developments has drawn attention to the role of the decision maker and his attitudes to, and perception of, the problems that confront him (O'Riordan and More, 1969). In the model discussed in this paper, man is bounded by his innate difficulties of computing and by time and place of which he is a product. Within these bounds, however, man may be observed as acting rationally in the management of resources in order to achieve a more satisfactory life for himself and his fellows. What is economically optimum by a computer may not necessarily be so visualised by the human user. The persistent danger is that we may forget this in our excitement with computer, cost-benefit analysis: that we might assume man to be omniscient, rational and economic: and that as a result we may design programmes and policies to allocate resources in a way that represents no more than an idealised approximation of the actions of very few if any men on the face of this earth. The risk of this happening in New Zealand has been increased by the economic emphasis of the recent National Development Conference.

The analysis of present and future resource use is subject to great uncertainties as innovations, affluence, leisure and mobility create new demands and exert new pressures. The shifts may be rapid and drastic. As scientists, we are increasingly aware of our ignorance of sensitivities in ecosystems. In contrast there is growing public faith in massive engineering measures as panaceas and they are often supported in the political arena because of their employment of labour and apparent economic gain. These massive projects may stimulate rather than reduce the very shortages or difficulties they aim to forestall by diverting attention from the full range of choice in adjustments. We need to do more than widen the range of choice in resource use. We also need to widen the spatial range of analysis because of man's rapidly-growing capacity to disturb the ecological balance. To attain a new state of equilibrium among the elements of the landscape, we must seek regional integration of management measures - from watershed to delta, and from wilderness to city plain.

Under the banner of watershed management we must avoid narrowing the range of choice for human adjustment in resource use. I find apposite a reflective quatrain composed by that scholar-economist, Kenneth Boulding, during the recent star-studded symposium on the "Further Environments of North America" (Darling and Milton, 1966, 717).

"The eightfold way of typing soil
Is mostly pretty useless toil.
For land is typed by man's intent,
And classified by paying rent."

Any thoughtful effort to predict the outcome of human decisions to advance or retreat in our lands must take account of those factors which promise to affect the choices that lie ahead. Most of our programmes as to what is right for future environments appear to be based on untested opinions about people's preferences, value systems and human behaviour. As pressure on multiple resource use mounts and assessment of economic efficiency is refined, the need to understand management decisions and their consequences assumes a crucial role. It would seem unwise to continue to tamper with the environment without concurrently striving to determine the real and lasting effects of our actions.

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WHAT DOES WATERSHED MANAGEMENT MEAN IN NEW ZEALAND

Concluding remarks:

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This has been a wide-ranging and very varied symposium and it is difficult to summarise in a few words.

This is the first time that a symposium has been held in New Zealand under the title of Watershed Management and I have been surprised at the extent to which people have accepted the term without much question. Only one questioner asked, "Why are we using the word watershed, isn't catchment the correct term?" Strictly, catchment is correct but the Oxford dictionary does include the popular usage of watershed as a catchment or river basin. Watershed management is a phrase that is with us and one which has a greater international understanding than catchment management. Criticism of the phrase is misguided if it is directed at the word watershed. The important word is management.

Now this management cannot be the exclusive right of the soil conservator or the engineer or the farm advisory officer. To be effective watershed management must be interdisciplinary. I think it is significant that this symposium has drawn together one of the most comprehensive audiences that has ever come together in New Zealand to discuss water. We have soil conservators sitting beside engineers. We have hydrologists and geographers, plant ecologists and wildlife managers, meteorologists and soil scientists, land administrators and foresters, farmers and farm advisory officers. We even have a number of representatives from the vast unwashed student body who do not normally seem to have much affinity for water.

Well, what does watershed management mean in New Zealand?

Mr Packer and Dr Laycock have a very good outline of what watershed management means in the United States but it is pretty obvious that although we may have borrowed the terminology from the Americans, there are some major differences in the practice of watershed management between the two countries. In the first place, I suggest that watershed management in New Zealand must include a very much higher river management component than it does overseas. I think Mr Watt gave the best definition of the term. It implies the integrated development of all the natural resources of the catchment for a particular purpose. Unlike traditional soil conservation, the primary object of watershed management is the management for water. Although soil management is involved, this is usually in a secondary role. Watershed management has an integrating feature which has been missing in the past.

It is also of interest to note that soil conservation is not now taught as a subject at Lincoln College. It has been replaced by watershed management and students who want to become soil conservators do the basic subjects of agricultural hydrology and watershed management. These are being taught in the Engineering Department and not in the Soil Science Department. One advantage of this is that this Department is teaching both soil conservators and engineers. These people sit in the same classes, drink beer and play rugby together and this is likely to make them much better mates in the future than you have been in the past.

I believe that this is important for without looking at specific papers I suggest that Mr Wright and Mr Koutsos' was the most significant paper. This was the best explanation of what watershed management means in New Zealand. A soil conservator and an engineer who combined beautifully to present the watershed management type problems which are distinctly New Zealand problems.

However, the symposium hasn't only been about watershed management, but it has tried to relate this to the much broader field of water resources development. In doing so, it becomes apparent that there is some confusion about the meaning of the terms watershed management, hydrology and water resources development.

I have already mentioned watershed management. Water resources development means what it says. It is the development of the water resources of a basin or a region or nation in such a way that we make the optimum use of them. Now when we say optimum we immediately become involved in economics. This is important, for water resources development goes a long way beyond watershed management and hydrology and becomes involved in economic, social, legal and political considerations.

Hydrology is merely the basic tool of the watershed manager and the water resource developer. While we don't all need to be experts in hydrology, we do need to know something about it. This science is simply the common language between disciplines.

Thus watershed managers must use their understanding of hydrology to manage the water resource at its source. If this symposium has done nothing else, I hope that it has given us a clearer understanding of what watershed management is, and of its place in the much broader field of water resources development.

LINCOLN PAPERS IN WATER RESOURCES

No. 1: Water Resources Symposium, 40th ANZAAS Congress: Part 1.

No. 2: Water Resources Symposium, 40th ANZAAS Congress: Part 2. (Out of print)

No. 3: Hydrologic Characteristics of Catchments - Walter C. Boughton

Lag Time for Natural Catchments - A. J. Askew (Out of print)

No. 4: Financing Catchment Schemes in New Zealand

No. 5: The Measurement of Soil Loss from Fractional Acre Plots - J. A. Hayward

No. 6: Contour Plans by Computer - Water C. Boughton

No. 7: The Use of Fractional Acre Plots to Predict Soil Loss from a Mountain Catchment - J. A. Hayward

No. 8: Watershed Management: Part 1.

No. 9: Watershed Management: Part 2.