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RIVER LOW FLOWS: CONFLICTS OF WATER USE

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RIVER LOW FLOWS: CONFLICTS OF WATER USE

Proceedings of a seminar held by the New Zealand Limnological Society for the New Zealand Committee for Water Pollution Research at Lincoln College, Canterbury in May 1982.

Edited by:
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Head Office
Wellington

WELLINGTON 1982

River Low Flows: Conflicts of Water Use

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Competing demands for river water resources have created the need for a rational and environmentally sound approach to water allocation. In this publication a regional water board officer outlines the problems and requirements of water allocation planning, a design engineer describes methods for setting river flows having regard to in-stream uses, a fisheries scientist describes the techniques for evaluating the habitat requirements of New Zealand native and introduced freshwater fish, and a biologist describes the effects on river ecosystems of regulated low flows:

Case studies on the Tekapo, Clutha and Hawea Rivers are included.

Keywords: Water allocation; water management; rivers; low flows; in-stream uses; fish habitat; river biology; aquatic invertebrates; minimum flows; fishery management.

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CONTENTS

FOREWORD

The New Zealand Committee for Water Pollution Research sponsored this seminar to stimulate an exchange of information between a water manager, a power planner, a biologist and a fisheries scientist, before the New Zealand Limnological Society and members of the public.

The conflict is between increasing impoundment or abstraction of rivers and consequential decreasing instream uses. If rivers must be harnessed, then it should be done with sensitivity to the needs of fisheries, recreation and river ecosystems. The proceedings of this seminar give hope that a rational solution exists to at least part of this conflict.

The seminar was introduced by Dr D J Painter (NZ Agricultural Engineering Institute) and chaired by Mr C Anderson (Southland representative of the acclimatisation societies on the Freshwater Fisheries Advisory Council).

The Committee is most grateful to the National Water and Soil Conservation Organisation for publishing these proceedings.

INTRODUCTION

New Zealand's natural resources of lakes and fast-flowing rivers have been systematically harnessed for hydro-electric development and irrigation. In 1980 there were 72 existing hydro-electric power schemes in New Zealand, 16 schemes under construction and 12 more proposed in the near future. In addition there were 16 small hydro schemes for which preliminary investigation reports have been completed (Teirney 1980). There are presently eight major irrigation schemes under construction with many more under consideration (NZ Official Yearbook 1981). Some of these schemes are extremely controversial with strong opposition from recreational users. For example, the Lower Rakaia and Central Plains scheme would irrigate 200 000 ha but may seriously affect fish and fisheries in the Rakaia River (Glova 1981). Studies of such impacts are urgent in many rivers and the transfer of appropriate information to water managers is vital.

In this seminar an administrator in a catchment board outlines the legal and social complexities of water allocation and draws clear attention to the need for rational methods of assessing recreational and fishery needs. ".... it is better to be long on data collection, * interpretation and presentation and short on emotion." The three following speakers take up this challenge and describe methods for assessing instream needs of fish and some effects of flow regulation and residual flows on stream biology. The talks are published here as useful statements on the present level of knowledge and they are commended to those interested or involved in river management.

ABSTRACTS

THE ADMINISTRATOR'S VIEWPOINT

O A Stringer

This paper reviews the conflicts affecting decision-making at the regional water board level. The Water and Soil Conservation Act 1967 itself carries with it the seeds of dissent with water boards and their staff often disagreeing on interpretation. Decisions on the issue of water rights are seldom clear cut; a large factor in renewal of a water right is the political force exerted by the holders.

A sound data base is a prerequisite for decision-making despite the political nature of many decisions. Water boards often lack capability in the biological, social science and planning disciplines.

Water resource planning ideally sets out to rationalise water allocation, but unfortunately early water rights were let before resources were well understood. Regional water boards have limited power and responsibilities and this limits planning because to be effective the full resources of a region need to be considered. The plan should maximise social welfare. In practice 'economic welfare' is substituted for social welfare and this is one of the most fertile fields for conflict, especially because some water users cannot present their case in economic terms. In this field too, experts often disagree.

Recreation must be included in resource planning but this requires information, special methods and a change in attitudes to resource use. Cases for recreation require much more data than is commonly available at present and possibly less emotion.

Management objectives need to be clearly stated in a manner understandable to the public; this can be difficult when complex issues are involved. National policy should be set in general terms; regional policies should be more specific.

Water quality standards must be achievable, measurable and enforceable. Terms like "a conspicuous extent" or "substantially free" are open to dispute and should be avoided. Control measures must be functional, adequate and flexible. The most appropriate place to define such details is in a water management statement.

THE INCREMENTAL APPROACH TO INSTREAM FLOW NEEDS: NEW ZEALAND CASE STUDIES

I G Jowett

This paper describes the incremental approach to setting instream flow values at acceptable levels for fisheries or other uses. The method was developed in the United States and has been applied in New Zealand

to the Tekapo and Clutha Rivers. It is an objective method for quantitatively estimating instream habitat. The method is based on the assumption that the suitability of a species habitat can be described by selected physical variables (depth, distance, profile, substrate, velocity, cover). Any proposed changes in stream flow can be converted into predictions of changes in potential habitat suitability.

The first step is a stream survey of representative reaches and transects. In a large river this would take a jet boat team several weeks. The data which is collected is analysed to predict depth and velocity for unmeasured flows. The suitability of predicted habitat is evaluated using curves which describe fish preferences. Summation of point measurements gives a weighted usable area for the fish species of interest and, with appropriate curves, predictions for the different life stages of the species are possible.

The method has limitations where hydraulic prediction is difficult (e.g. shallow braids or turbulent rivers) and, more importantly, where a number of other factors such as changes to catchment condition, water quality, temperature, channel morphology and flow regime must be considered.

In the Tekapo River the method predicted that generally the river was at flows below optimum for a trout fishery and any further reduction in flow would decrease its usefulness as a fishing river. In the Upper Clutha, by contrast, the method predicted that flow reductions would increase the suitability of the river as trout habitat. It is suggested that optimum flow for food production would be 75 m^3 sec^{-1} (existing mean 260 m^3 sec^{-1}) and that for spawning, rearing and resting, 30 m^3 sec^{-1}. It also enabled predictions of the relative suitabilities for rainbow and brown trout.

A powerful feature of the method is the ability to make predictions for flows lower than those that occur commonly under natural conditions and to provide objective information on potential habitat at these flow conditions. This information is valuable when considering the impact of change in water resource use.

FISHERY IMPACT EVALUATION - APPLICATION OF THE INCREMENTAL METHOD

G J Glova

With the increasing demands on the nation's flowing water resources, improved methods for assessing the potential effects of developments on fish and fisheries are needed. One method used widely in the United States in determining instream flow requirements is that of "incremental analysis". While there are a number of versions of this method, the most sophisticated one is the IFG method, developed by the Instream Flow Group, Fort Collins, Colorado. The application and limitations of this method as a tool in fisheries impact assessment are discussed.

The incremental method uses a computer model to predict the physical conditions (e.g. water depths, velocities) in a selected reach at a range of discharges, using data collected at a single discharge. The predicted values are then weighted using fish habitat suitability criteria, and total available habitat for each species by life stage is then computed at the desired discharges. The methods and problems of obtaining data on habitat suitability for New Zealand fish species are described. The effects of interspecific and intraspecific competition on predictions are discussed.

For rivers (e.g. braided channels) to which the programmes of hydraulic models are not applicable, an alternative approach is to obtain measurements of hydraulic conditions at a range of discharges in selected reaches, and compute the weighted usable areas available for fish. The usable area for each species by life stage is then plotted against the measured discharges, to allow prediction of areas available for fish at other discharges within the approximate range measured.

The "incremental method", or some version of it, is regarded as a useful tool in assessing the changes in available habitats for fish with alterations in river discharge. In conjunction, for example, with studies that provide quantification of the fish and fishery resources present and description of life history patterns, the incremental method offers invaluable complementation in the overall assessments of impacts on fisheries.

THE EFFECTS OF LOW FLOW REGULATION ON RIVER WATER QUALITY AND BIOLOGY: A CASE STUDY

B J Biggs

The general effects of low flow regulation on aspects of the biology and water quality of rivers are summarised. Particular attention is given to changes in water depth, wetted perimeter and water velocity as factors affecting biota. In general, flow regulation appears to be detrimental to riverine biota.

Preliminary results are presented from a study on the Hawea River, an impoundment-regulated flow in Otago. Discharge in the river varies from 5.6 m^3 sec^{-1} in summer to 230 m^3 sec^{-1} in winter. Water quality is generally high although large diurnal fluctuations in temperature and pH occur during low flow periods. Prolific growths of periphyton stimulated by low flow conditions are thought to cause the pH fluctuations.

Benthic invertebrate density increases from around 7000 m^{-2} 100 m below the control gates to around 17 000 m^{-2} 15 km downstream. Species richness also increases downstream. The net spinning caddis-fly larvae *Aoteapsyche tepoka* is dominant at the upper stations and chironomid larvae are dominant at the lower station. The Hawea River displays many of the characteristics typical of impoundment-regulated flows in North America and Britain.

PRESENTED PAPERS

THE ADMINISTRATOR'S VIEWPOINT

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LEGISLATION

The Water and Soil Conservation Act 1967 carries with it the seeds of dissent. Terms such as "adequate account", "best uses", "more beneficial uses" are open to a wide range of interpretations. The aspirations of the individual will dictate how such terms are interpreted and hence how that person believes the legislation should be applied. Acts of Parliament should be precise and explicit and should minimise administrative interpretation. However, after 13 years of experience with the Water and Soil Conservation Act, regional water boards and their staff are not unanimous on how the Act should be applied, or indeed on how it should be amended to improve it.

It is not necessary to progress beyond reading the legislation to be in conflict.

WATER RIGHTS

Every water right granted represents an attrition of the resource to another user. Every development project leads to a restriction of choice.

The merits of any given application or objection to that application are seldom clear cut. On the contrary, all things are relative, decision-making becomes a balancing act, and the effect on the resource a matter of degree. Decisions on water rights, made in the early years, based on limited knowledge and perhaps made in isolation, can result in conflict. As an example, on the farming scene possession of a water right in a water-short area allows the holder to increase production. This in turn affects the desirability and marketability and hence the value of the property. In addition, the farmer might well have considerable capital invested in irrigation equipment. Five or 10 years after granting the right, alienation of the water or restriction of its use would have a damaging effect, and in a case where indebtedness is high, could be a deciding factor in survival of the enterprise. A water right can become an asset that, indirectly, can be bought and sold or used as security. The example given, when multiplied by 50 or 100 farmers, represents a potent political force on the local scene. While early rights were granted for relatively short terms (five years) to permit a more detailed study of the resource, there is no denying that a holder of a right expects renewal on expiry, and usually gets it.

DATA COLLECTION

To avoid these problems and to minimise dissension requires a solid background of data and experience in interpreting those data.

It is unrealistic to believe that all decision-making will be on purely technical grounds. It is inevitable that political considerations will exert an influence. However, this does not lessen the need for a sound data base. I would suggest that this need extends over a broad field and into areas where water boards do not always possess the necessary expertise or resources. For instance, water boards are competent in quantifying the water resource, can make an average economic appraisal, but generally lack capability in the biological, social science and planning disciplines.

PLANNING AND MANAGEMENT

Water resource planning is an attempt to rationalise water allocation. Where demand is high and the resource scarce, thorough investigation and forward planning should precede allocation of the resource. However, the reverse has often been the case. From the day the Water and Soil Conservation Act became operative, water boards were faced with making decisions on applications for water rights. It would be quite unrealistic to suggest that those early decisions should have been deferred until all was known about the water resources of the area.

Boards have limited power and responsibilities and water resource planning tends to be limited in scope.

To be fully effective a water resource plan should be integrated into an overall plan for the resources of the region. Water resource planning requires a systematic and objective identification of other resources that might be affected. If this is not done then unnecessary restraints may be placed on the development of a region. Planning for resource use should be oriented towards maximising the welfare of society. Social welfare is not capable of measurement as it reflects a very wide range of opinions and aspirations. In practice, "economic welfare" which can be measured, is substituted for "social welfare". There is no more fertile field than this in which to grow a crop of conflict. Some users find it nigh on impossible to present their case in economic terms, while others can readily produce impressive documented evidence of economic benefit.

From there it is just a short step to production of expert evidence to discredit the expert evidence of the opposition. Spare a thought for the unhappy water board faced with experts who emphatically disagree. An attempt should be made to evaluate likely future use, but unless tangible evidence exists to support a belief in that use, there will be conflict in preventing competitors using the resource in the meantime. There is reason to challenge the validity of "reserving" part of a scarce resource for a speculative future use.

RECREATION

The Water and Soil Conservation Act is quite clear on the point that recreational uses must be included in water resource planning. How is this to be done? To introduce recreation as an equal partner requires planning information, planning methods and to a large degree a change in social attitudes to resource use. Where is this to come from if not from the user? Factual information is required on the needs of recreation. Any group wishing to prepare a case for recreation should have in mind that it is better to be long on data collection, interpretation and presentation and short on emotion.

MANAGEMENT

The objectives need to be clearly stated and subject to review. The management strategies should be presented in a manner readily understandable to the public. Herein lies a difficulty. The criteria upon which a resource is to be shared may be understandable to the hydrologist or the engineer, but completely incomprehensible to the layman. Some aspects of management leading to conflict are:-

Placing restrictions on demand.
How demand is restricted.
Who should have first call on the resource?
Should there be priorities between groups of users?
Should there be priorities within groups of users?
Do regional priorities outweigh local priorities?
Will national priorities prevail over regional or local priorities?

It would be expecting too much to suggest that a national policy on water resource use would be a panacea. National policy should be in general terms to let us country folks know what are New Zealand's priorities and where the nation is heading. Regional policies can be more specific because one would expect them to be in tune with the local aspirations. To the individual a water right can be very specific. In a well ordered society his specific requirements and limitations would fit neatly into the regional plan which, in turn, would be an integral part of the grand strategy of the nation. Dream on.

WATER QUALITY

Waste disposal is a legitimate use of natural water. The terms "pollution" and "toxicity" are relative.

The standards set for water quality must be achievable, measurable and enforceable. One cannot measure "a conspicuous extent" or "substantially free". Such terms are matters of opinion and therefore open to dispute. We should avoid them. Control measures must be functional, adequate and flexible and should be coordinated with other aspects of resource management to ensure that technical, economic and social factors are considered.

Standards set for water quality should spell out the objectives. If any substance added to the natural water is considered to be undesirable in certain concentrations, then the threshold value should be stated.

Further, the manner in which samples will be taken, the method of testing and interpretation of results should be stated. This gives the location of the ball park, the game expected to be in progress and the rules applicable.

It is not necessary to embody all the detail in legislation. It could be clearly defined in a water management statement.

THE INCREMENTAL APPROACH TO INSTREAM FLOW NEEDS

NEW ZEALAND CASE STUDIES

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INTRODUCTION

This paper describes a method which may assist in resolving some water allocation conflicts in a more rational manner than has been the case in the past and with less dependance on the adversary system. The results are given of two case studies using the method in New Zealand.

BACKGROUND

The method is called the Incremental Method (Anon 1980) and was developed in the United States. It has been applied to two rivers in New Zealand and complements other New Zealand work aimed at classifying rivers in terms of their hydraulic characteristics and defining fish habitat preferences.

The incremental method is objective and as such is more defensible in water right hearings than subjective opinion. It enables the quantitative estimation of instream habitat and the setting of flow levels which will maintain instream habitat at acceptable levels. This can be valuable information for a water allocation plan. The actual decision on water allocation would be made through arbitration or negotiation using this information.

The incremental method is based on specific field measurements and permits the quantification of changes in available habitat as a function of flow. The methodology is based on the assumption that the suitability of a species habitat can be described by measuring selected physical properties of the stream and that changes in habitat can be quantified by these variables. Thus, the effects of any incremental change in streamflow can be displayed in terms of changes in potential habitat suitability so that in a given stream it is possible to predict the amount of available habitat at unmeasured flows.

The alteration of flow is not the only constraint affecting a fishery. Other factors may be important and catchment conditions, water quality, water temperature, channel morphology and flow regime must all be considered. Methods for determination of water quality, temperature change and channel morphology are available or are under development. Changes in flow regime can be evaluated by computer modelling techniques - simulation - but the necessary quantitative links between flow regime and biology/ecology have yet to be established.

METHOD

The first step in assessing the impact of altering streamflow on habitat potential is a stream survey. Because it would be impossible to survey the entire river, representative reaches are selected. These should contain areas typical of those found in the river such as a braided channel, or a single thread channel. All should be sufficiently long to contain a range of flow types such as riffles, bars, rapids, pools or runs.

The locations of the representative reaches and transects should be selected jointly by the biologist and hydrologist. This ensures that both the necessary hydraulic and biologic conditions are surveyed. Once the reach is defined, transects across the reach are spaced at fixed intervals so that their selection is unbiased. The water surface profile and depths, velocities and distances along each transect are measured for hydraulic calculations. Substrate, depth, velocity and cover at each point on each transect are used to assess habitat suitability.

The whole survey can take some time. At least 600-1000 point measurements on perhaps 20 or more transects are necessary to obtain a good sample of available habitat. In a wadeable river this will take 3-5 days. In a larger river, a party working from a jet boat may take three weeks.

The analysis of these field data involves two steps:

(i) predicting depth and velocity distributions for unmeasured flows;

(ii) evaluation of the suitability of the predicted habitat.

Each point measurement is taken as representing a cell which has particular values of depth, velocity, substrate and cover. For each cell habitat suitability is evaluated using probability-of-use curves. For example, brown trout adults in North America are reported to have preferences for flow, depth, substrate and temperature as shown in Fig. 1 (Bovee 1978a). Thus a cell with velocity of 0.5 m sec^{-1}, depth 0.5 m and with boulder substrate would be given probability-of-use factors of 0.55, 0.65 and 0.8 respectively using these curves. These factors, when multiplied by the surface area of the cell, determine the combined preference value of the cell. This is called the weighted usable area and is calculated for each cell, in each transect, in each reach to obtain the total weighted usable area at the measured flow.

By repeating the process for predicted hydraulic conditions at other flows, a relationship between weighted usable area and flow is obtained. The weighted usable area can be determined for each life stage of a fish species at any chosen flow condition. It is this information that can be used with value in impact assessment.

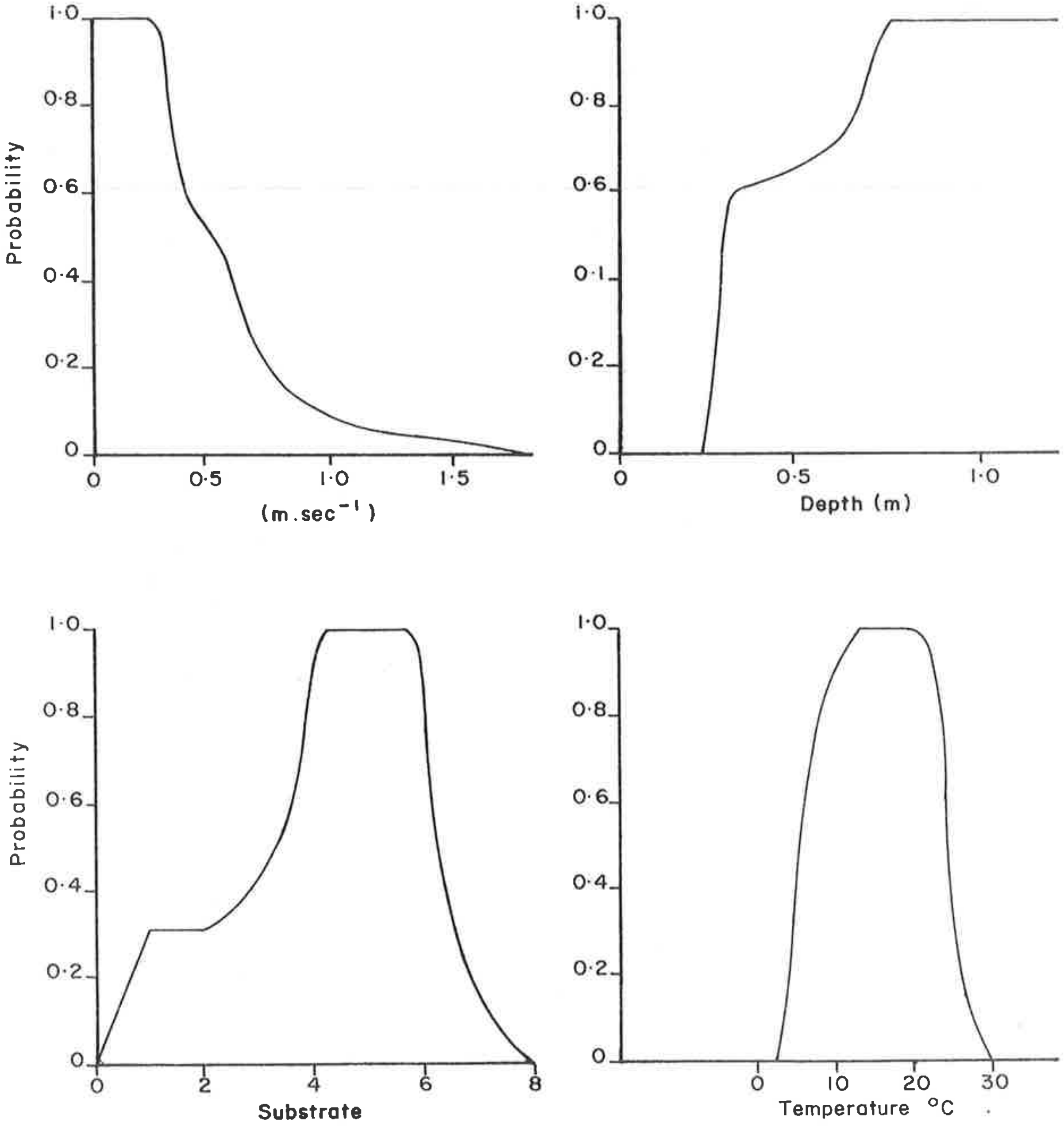

Fig. 1 Probability-of-use curves for adult brown trout (after Bovee 1978a). The probability factors are read from the curves and used to calculate the proportion of the stream bed usable by brown trout. The substrate factor is based on coded scale of texture from fine to coarse.

LIMITATIONS OF METHOD

1. The method does not apply to lakes or estuaries - it is only for flowing water.

2. Under certain conditions, such as shallow braids or very turbulent waters, hydraulic predictions cannot be made and the predictive component of the method should not be used. In this case river surveys at two or three different flows can be used for a limited amount of prediction. This technique has not yet been used in New Zealand.

3. Ideally habitat preference curves should be developed (or the US ones confirmed) for New Zealand salmonids.

4. The method cannot be used to predict the effect on fishery production. Procedures for estimating the effect on fishery production from instream habitat are currently under study in the US (Ms L D Teirney, Fisheries Research Division, Ministry of Agriculture and Fisheries, Wellington pers. comm.) and in the meantime the variation of weighted usable area should be regarded as a general indicator of the variation of habitat with flow. The prediction of fish production requires a complete understanding of this variation along with changes in water quality, temperature, channel morphology and flow regime and their effects on the fishery.

CASE STUDIES

1. Tekapo River

The Tekapo River was once a typical glacial, milky coloured river with a mean discharge of 80 m^3 sec^{-1}. In 1978 water was diverted from the river and discharged directly into Lake Pukaki. This left a residual river fed from non-glacial sources with an estimated mean flow of 10 m^3 sec^{-1}, one eighth of its previous mean flow. This change has largely been beneficial to the trout population - the water is clearer and the gravels, velocities and depths are more suitable for spawning.

The brief was to survey the river and estimate the effect of a further 3 m^3 sec^{-1} flow reduction. Because of the short time available a predictive method was adopted to estimate the area of suitable habitat available at a variety of flows.

Four typical 300 m reaches were surveyed by wading. A total of about 700 depths, velocities and substrate compositions were measured in four days. Two reaches were braided and two were single thread channels. The braided channels differed - one had split into multiple channels of similar size whereas the other had one main channel with subsidiary braids.

From measurements at flows of 14 to 16 m^3 sec^{-1}, depths and velocities were predicted for flows from 6 to 16 m^3 sec^{-1}. The weighted usable areas suitable for spawning, food production, rearing and resting (Osborn and Allman 1976) were estimated from the predicted distributions of depth and velocity.

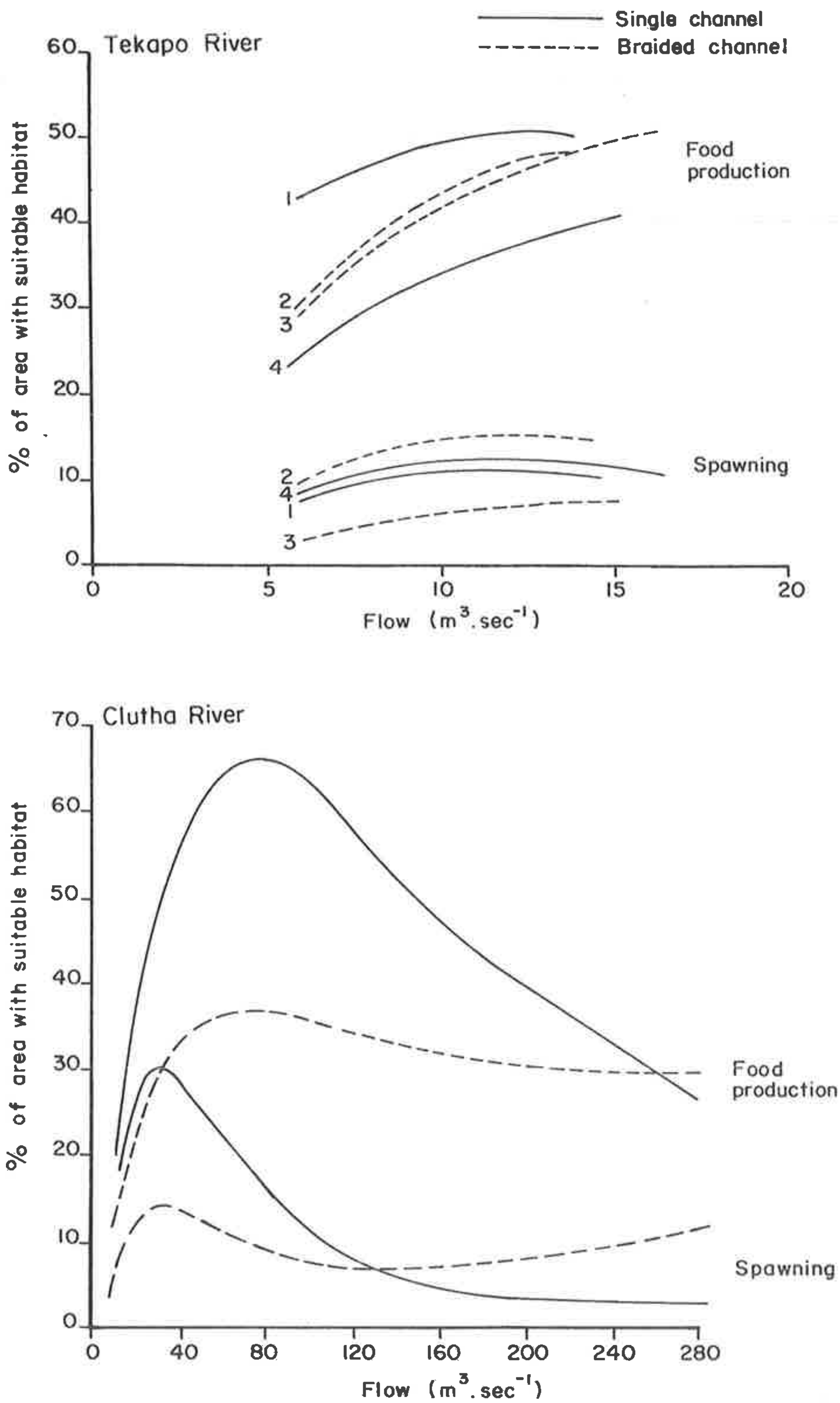

Fig. 2 Percentage of area with suitable habitat in sections of the Tekapo and Clutha Rivers.

The results suggested that about 40% of the area is presently suitable for food production and any reduction in flow will reduce the potential capacity of the river to produce food (Fig. 2). The optimum flow for food production is apparently somewhat higher than the flows measured here. About 10% of the area is estimated to be suitable for spawning at present and it appears that an optimum flow for spawning is about 13-14 m^3 sec^{-1} (Fig. 2).

The conclusion of the study was that the river was generally at flows below optimum for a trout fishery and any further reductions would decrease its usefulness as a fishing river.

2. Clutha River

Hydro-electric development of the upper reaches of the Clutha is planned and all proposals will leave some of the present riverbed dry. The task was to survey the existing 260 m^3 sec^{-1} river and to estimate a reasonable size for a residual river.

The fieldwork was carried out over a period of three weeks. About 1500 measurements were taken from a jet boat and the total area surveyed was about 90 000 m^2. Two reaches were surveyed - one with a side braid containing about 10% of the flow and the other in a single confined channel.

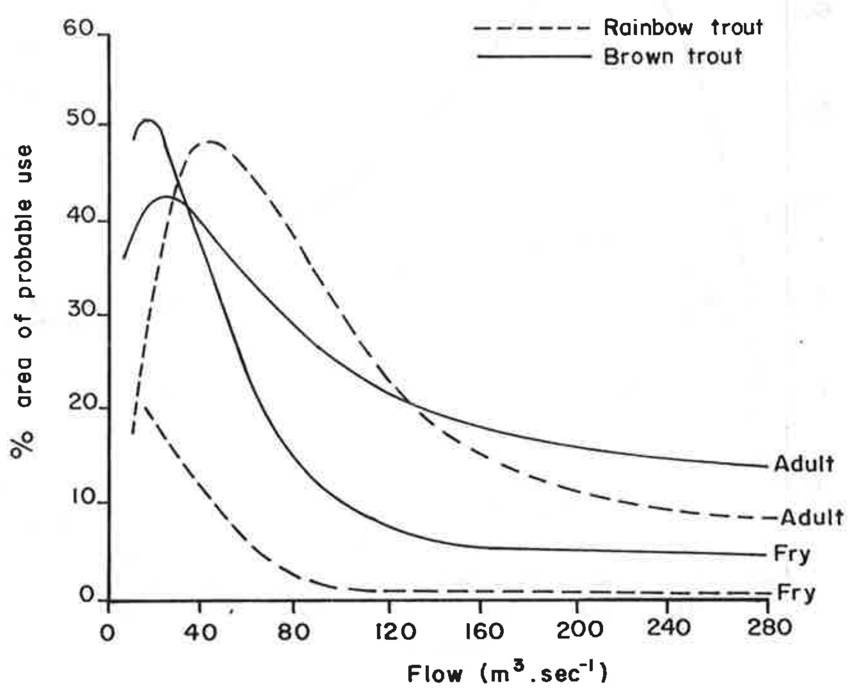

Fig. 3 Comparison of the suitability of a section of the Clutha River above the Lindis confluence for rainbow trout and brown trout under a range of flow conditions.

The analysis was similar to that in the Tekapo, with the addition of computer simulation to predict the changes in flow regime.

The results were more startling. It appeared that a reduction in flow would enhance the food production of the river and increase its suitability for trout. It is interesting to note that the side braid had considerable value compared to the much larger main channel (Fig. 2).

Overall this analysis revealed that an optimum flow for food production would be about 75 $m^3 sec^{-1}$ while flows of about 30 $m^3 sec^{-1}$ would give optimum areas for spawning, rearing and resting.

It seemed possible that reduced flows would favour brown trout rather than the more popular, more easily caught rainbow trout, or that the river might turn into a nursery rather than habitat for large adult fish. This was investigated using probability-of-use curves (Bovee 1978a) which showed the habitat preferences of adult, juvenile and fry of both brown and rainbow trout. Not surprisingly, this showed that rainbows would prefer slightly higher flows about 40 $m^3 sec^{-1}$ compared to 20 $m^3 sec^{-1}$ for the browns (Fig. 3) - but it also showed that the unmodified river was slightly better for brown trout than rainbow trout and that a reduction in flow would benefit the rainbow trout population more than that of the brown trout. As expected the smaller flows would benefit the juveniles and fry of both species.

The conclusion from this study was that flows of about 30 $m^3 sec^{-1}$ would continue to support a reasonable fishery. There are, however, some questions about algal growth and temperature, both of which could cause problems during long periods without high flows. Extrapolation from 260 $m^3 sec^{-1}$ to 10 $m^3 sec^{-1}$ is rather severe and there must be some limit to the accuracy of the method. Similarly, such a large reduction may alter the river morphology. Overall, the results of this study in estimating desired levels of flow were supported by the independent findings of other agencies and the results seem to have received general acceptance.

CONCLUSIONS

The power of the incremental method is the ability to predict instream habitat for flows lower than those that occur with any reasonable frequency under natural conditions. Both case studies gave objective answers to the question of what would happen to the potential habitat if flows were reduced.

FISHERY IMPACT EVALUATION - APPLICATION OF THE INCREMENTAL METHOD

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INTRODUCTION

With increasing demands to develop the nation's flowing waters, there is a need for methods that will enable us to predict the effects of proposed developments on riverine fish and fisheries. In the United States one method widely used to determine minimum flow requirements for fish and other aquatic life forms is that of "incremental analysis". Though there are a number of versions of this method, the most sophisticated and hydraulically sensitive is that developed by the Instream Flow Group (IFG), Fort Collins, Colorado (Bovee 1978b), commonly referred to as the IFG incremental method. Jowett (supra) has briefly described the components and operation of this method and has given a brief overview of its application in two case studies in New Zealand. Stated in its simplest form, the method permits quantitative determination of changes in potential habitat with alteration in stream flow. It is based on the premise that the suitability of habitat for a particular species can be described by measuring selected instream variables such as water depth, velocity, substrate composition and cover. By quantifying the changes in these variables with incremental changes in stream flow, the changes in potential habitat can be predicted at unmeasured flows.

The aim of my presentation will be to give a biologist's viewpoint of the IFG method as a tool in fishery impact evaluation, with some emphasis on both the collection and synthesis of biological data required in the model. For a description of how the biological and hydrological data are assimilated in the model the reader should refer to the previous paper (Jowett supra).

FISH HABITAT AND DATA COLLECTION

To use the IFG method the habitat requirements by life stage of each of the species concerned must be known. To obtain meaningful predictions of impacts the IFG team recommend that users of the model should develop their own habitat (probability-of-use) curves for the species in their area. The life stages of fish typically are those of the adult, spawning, incubation, alevin or larva, rearing, and migration of both juvenile and adult stages. The stages chosen for impact assessment will differ with species and the nature of the development project. To describe the habitat requirements of the various stages of importance by species is a considerable task. In New Zealand there are 27 species of native freshwater fishes, many of which are anadromous* (McDowall 1978). So far the habitat requirements for none of these species has been fully described. So far none of the habitat requirements of these species has been fully described. For some,

* migrate between salt and freshwater

description will be extremely difficult or nearly impossible because of the nature of the rivers or streams in which they live. For the salmonids, we have been using overseas data compiled by the Instream Flow Group, Fort Collins (Bovee 1978a), with some modification as necessary to suit specific rivers (e.g. Jowett and Wing 1980). The need to describe the habitat requirements for at least the more common species in New Zealand is urgent. As a start towards achieving this goal Fisheries Research Division, Ministry of Agriculture and Fisheries, is collecting habitat use data for both the native and introduced salmonid fishes in some of the braided rivers of the South Island. Our present emphasis is on braided rivers because they are the ones for which major developments are being planned.

The collection of fish habitat use data present various problems. Firstly, many individuals cannot be seen, either because of prevailing turbid waters or because of the cryptic nature of the fish themselves. As a result, the exact location of individual fish cannot be determined but only approximated by the use of special sampling methods. Secondly, stream habitats are diverse and no single sampling method that is applicable to flowing waters (e.g. electric fishing, seine netting, drift diving, trapping, drift gill netting, prima cording) can be applied to all habitat types. Electric fishing, for example, is restricted mainly for safety reasons to areas of wadable depths and moderate velocities. On the other hand, seining works best in relatively deep, slack water areas with snag-free, smooth bottoms. However, one disadvantage with the latter is that it provides a bulk sample of fish with no opportunity to obtain information on the individual locations occupied by the fish prior to capture.

Other problems with data collection are those associated with random sampling procedures. Ideally, sampling should be done along randomly selected transects at sufficient frequency to cover all the possible habitats used by the fish. However, truly random procedures can be very unproductive in terms of catch per unit effort in low density populations and often impossible to carry out because of water depth and/or velocity limitations. To overcome these problems we have had to resort to systematic sampling procedures as shown in Fig. 1.

Briefly, the method involves subsampling habitat areas by electric fishing small segments (usually 3 or 6 m^2) along chosen transects across the channel. The number and location of transects depends on both the size and physical variation of the habitat to be sampled. Riffles, for example, are areas of complex flow and usually require more intensive sampling than do runs. A minimum of three electric fishing passes are made in each of the segments and the catch from each is placed in separate buckets. The fish are anaesthetised, measured, species identified and then released downstream. Water depth and velocity at 0.6 of the depth from the surface are measured in the lower, middle and upper area of each segment; substrate composition and cover objects are usually estimated by eye. Working in an upstream direction, the procedure is then repeated in the remaining segments in the order shown in Fig. 1.

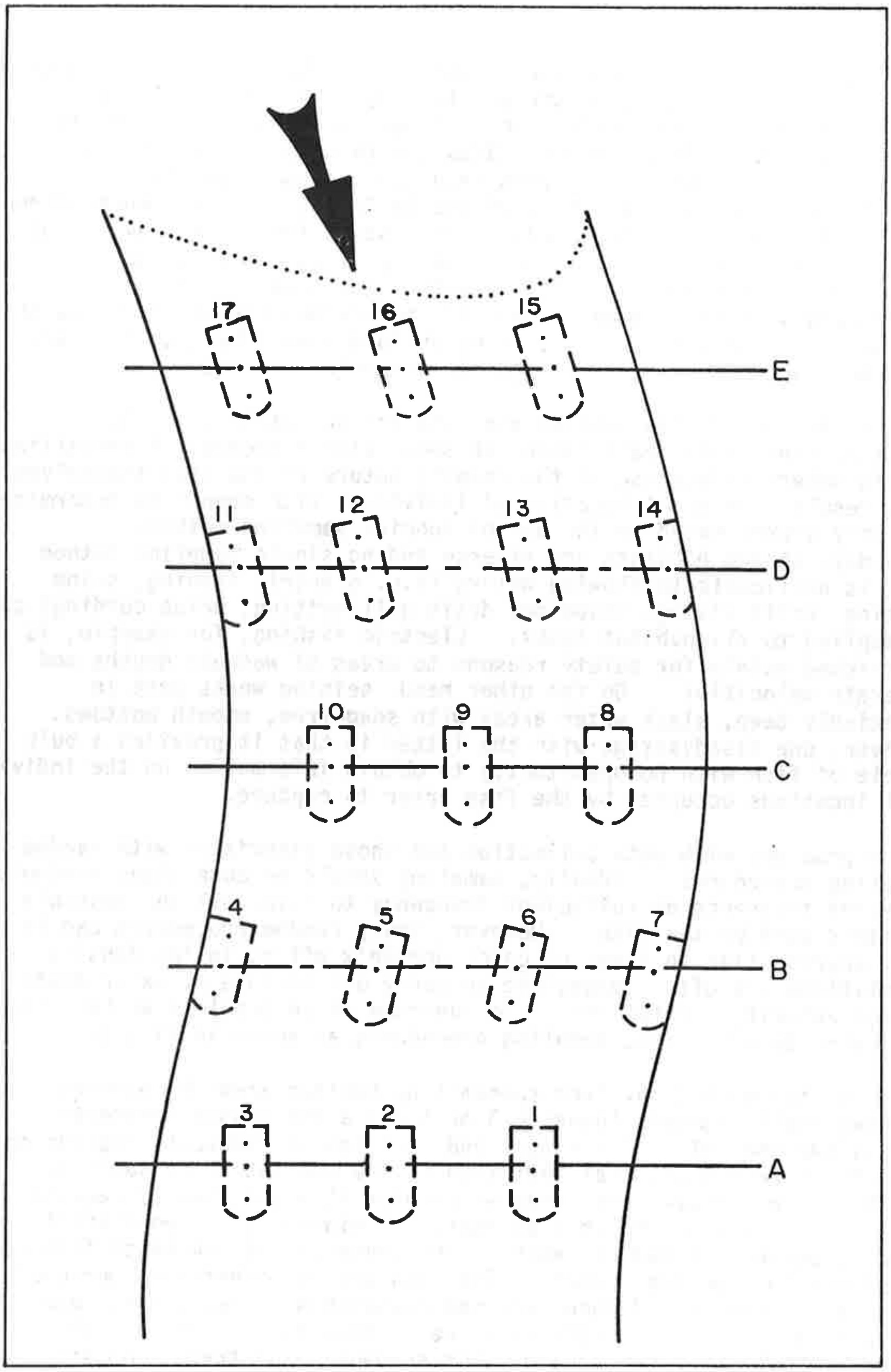

Fig. 1 Diagram showing the transect sampling method, a procedure suitable for subsampling populations of bottom-dwelling fish species. Subsampling segments are dotted, the dots within indicate approximate locations of measurements of current velocity and water depth. Sampling sequence is indicated in the order numbered.

Both season and river flows must be considered when collecting habitat use data. The incorporation in the IFG model of habitat use data derived from fish populations in which the available instream resources (e.g. food supply, cover, resting sites, spawning areas) are either grossly over-exploited (as can occur during excessively low flows) or under-utilised (as in immediate post-flood periods) is likely to result in misleading interpretations of impacts. Preferably, data should be collected during periods of flow when the supply of, and the demand for, available instream resources are judged to be at or near equilibrium. This is usually a period of moderately low, stable flow; it can occur in different seasons depending on the river and/or the climate of the catchment.

FISH HABITAT DATA SYNTHESIS

Before it can be used in the model, fish habitat use data must first be converted to probability-of-use functions. We use a method similar to that described by Bovee (1978b). Application of the method is briefly described here, using water velocity data collected on bluegilled bully *(Gobiomorphus hubbsi)* populations in a few of the braided rivers in Canterbury (Table 1).

TABLE 1: The derivation of water velocity preference of the bluegilled bully *(Gobiomorphus hubbsi)* using data collected in the Rakaia, Hurunui and Ashley Rivers

Velocity $m\ s^{-1}$	Fish Frequency A	Sampling Frequency B	Adjusted Fish Frequency $100\,\frac{(A)}{(B)}$	3-Point Moving Average	Probability Level
0.1	0	39	0		
0.2	10	80	13	12	0.13
0.3	34	150	23	21	0.22
0.4	53	204	26	26	0.28
0.5	64	213	30	34	0.36
0.6	95	213	45	37	0.39
0.7	76	217	35	51	0.54
0.8	128	174	74	59	0.63
0.9	91	131	69	80	0.85
1.0	94	96	98	94	1.00
1.1	70	61	115	88	0.94
1.2	25	48	52	78	0.83
1.3	14	21	67	58	0.62
1.4	6	11	55	55	0.59
1.5	3	7	43	33	0.35
1.6	0	4	0		
TOTALS	772	1669			

Both the numbers of fish and sampling frequency are tallied per increment of water velocity. Plotting the frequency distributions (Fig. 2) is optional, although useful in comparing fish catch against sampling effort. In the illustrated example sampling (upper graph) is seriously biased - both the slow and fast velocity areas have been inadequately sampled relative to that of the intermediate velocities. Such sampling bias is an inherent problem with the transect sampling method, mainly because river channels are typically U-shaped in cross-section and the intermediate conditions are, therefore, more frequently encountered than others. Such gaps in data, should they occur, are best filled by additional but selective sampling. Overall, sampling should be distributed fairly evenly over the range of conditions present in a river.

Sampling bias, if not too serious, can be adjusted by dividing the fish tally in each increment by the sampling frequency (see Table 1). Moving averages are then applied to smooth out irregularities between the points and to enhance unimodality. These results are then scaled so that the highest value is unity (Table 1) and then plotted as the probability-of-use by the species for the range of conditions sampled (Fig. 2, bottom).

SENSITIVITY OF FISH HABITAT CURVES

Intra- and interspecific competition for resources can significantly alter a species pattern of habitat use. Under conditions of intense intraspecific (within a species) competition, individuals of a population will tend to utilise the full range of their potential habitats. However, with intense interspecific (between species) competition, individuals of a species will tend to narrow their range and use the habitats to which they are best adapted and thus have some competitive advantage over the other species. For these reasons it is important that habitat use data are collected from fish populations in which space is not seriously limiting.

In relation to competition two questions can be asked: first, what effect does competition within and between species have on probability-of-use curves? Second, how sensitive is the IFG model to shifts in the probability-of-use curves? As yet, neither of these questions has been addressed in the literature. Of the two, the first is the more difficult to answer and requires empirical or experimental studies (preferably the latter) of fish populations at both low and high densities. The second question can be satisfactorily answered by carrying out a simple but tedious matrix of calculations using probability-of-use curves of various shapes with various optima.

As an example, let us consider some water velocity data available for torrentfish *(Cheimarrichthys fosteri)* and bluegilled bully *(Gobiomorphus hubbsi)* populations, and from these speculate on the probable effects of competition on their use of space. These two species are appropriate for illustration as they have very similar habitat preferences. Probability-of-use curves for these species under different competitive situations are shown in Fig. 3; the effects of these curves on weighted usable area computations are shown in Table 2.

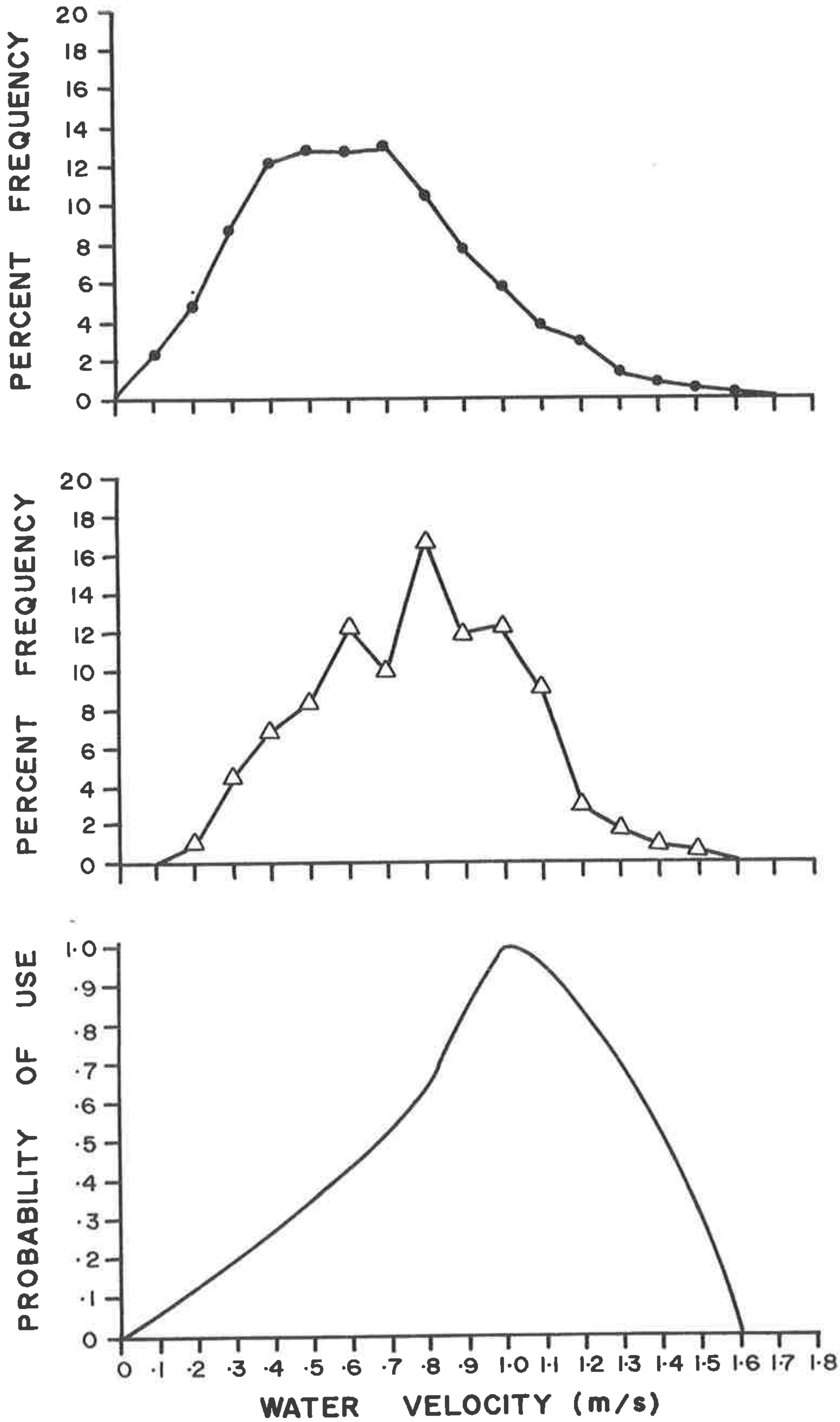

Fig. 2 Sampling frequency (top), catch frequency (middle) and probability-of-use (bottom) at a range of water velocities for the bluegilled bully *(Gobiomorphus hubbsi)* in the Ashley, Hurunui and Rakaia Rivers combined.

TABLE 2: Available habitat ($m^2\ km^{-1}$) at a range of depths and velocities in the Hurunui River at Balmoral during low flow, summer 1981 (Dr M P Mosley, Water and Soil Division, Ministry of Works and Development, pers. comm.). Weighted usable area values have been calculated for each of the columns using the probability-of-use curves in Figure 3. (Intra = intraspecific competition: inter = interspecific competition).

	Velocity ($m\ s^{-1}$)																	
Depth (m)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	
0.1	559	1096	1924	532														
0.2		168	615	839	559	783	559	951										
0.3				559	671	727	391	1174	615	1845	559	391						
0.4				224	951	336	503	671	1901	1845	727	1845	1174		559			
0.5						447			951	951	1789	3467	1566	671	168			
0.6										224	559	671	1523	727	391		224	
0.7					224		224	336	112		336	224		280	224			
0.8							224				336		615	336	1454	280	727	
0.9								336				224	336	559	839	447	336	
1.0									224			224			336	112	224	
1.1										447								
TOTALS	559	1264	2539	2154	2405	2293	1901	3468	3803	5312	4306	7046	5214	2573	3971	839	1511	51158

	Weighted Usable Area ($m^2\ km^{-1}$)																	Totals	% Change
Low intra. (torrentfish)					24	46	76	235	494	1222	1593	3805	3910	2572	3692	587	227	18483	0
High intra. (torrentfish)			152	442	557	803	822	2114	2966	5047	4306	7045	5213	2521	3692	570	227	36497	+ 97
Low inter. (torrentfish)				63	96	161	228	604	989	1912	2153	4721	4692	2572	2779	478	453	21901	+ 18
High inter. (torrentfish)								173	532	1222	1507	3523	3806	2523	3773	629	302	17991	- 2.7
High inter. (bluegilled bully)		38	181	259	409	573	666	1803	3042	4993	4306	7046	4641	1590	1469	185	120	31320	+ 69.5

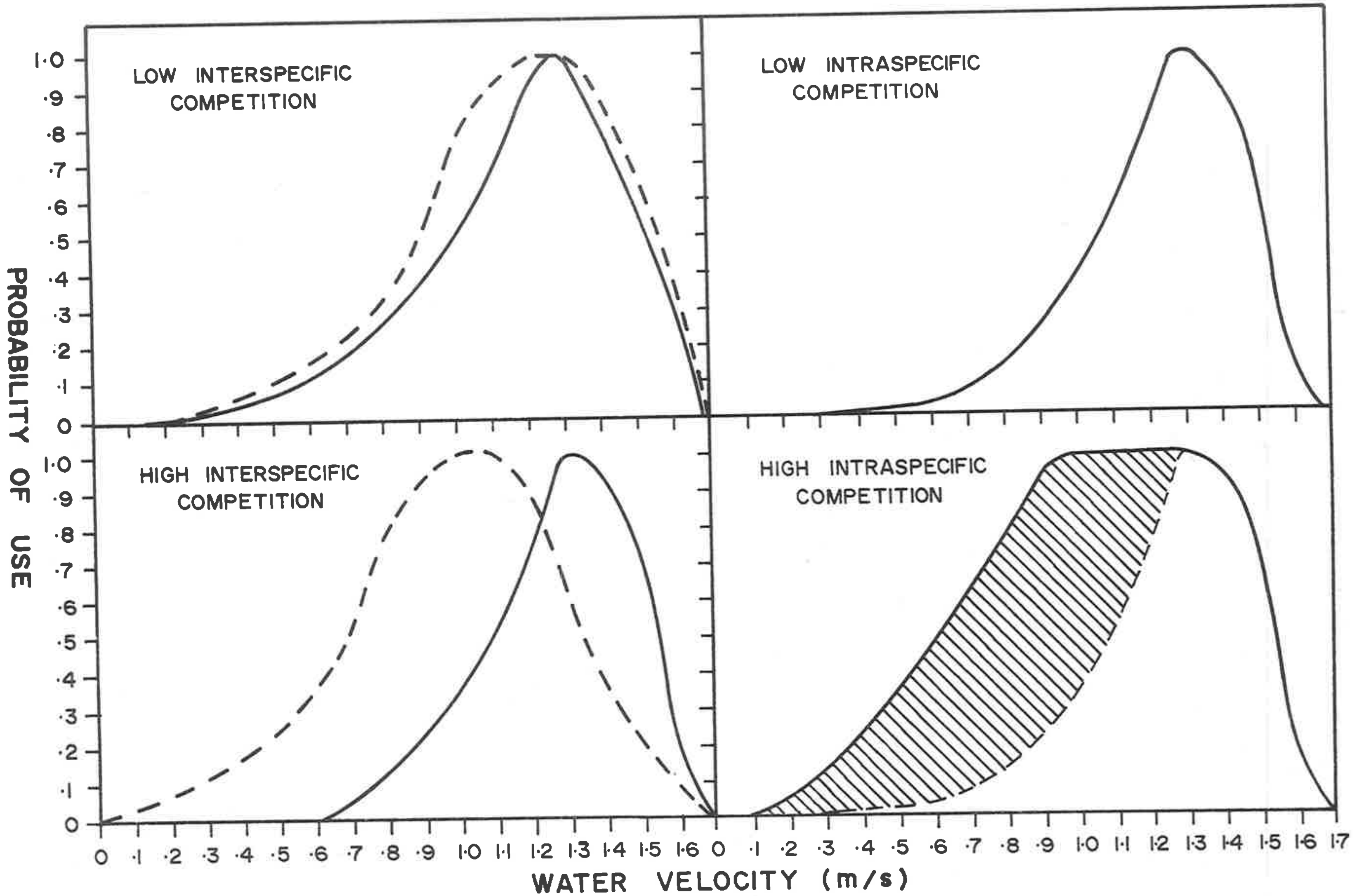

Fig. 3 Probability-of-use curves for torrentfish *(Cheimarrichthys fosteri)* (solid line) and bluegilled bully *(Gobiomorphus hubbsi)* (dotted line), in relation to competition. The curves for low competition are based on data collected during low flows in the Ashley (upper left) and Hurunui (upper right) Rivers in summer, 1981. The high competition examples are hypothetical; the hatched area represents the difference in habitat use by torrentfish from that at low competition.

Under conditions of low interspecific competition torrentfish and bluegilled bully have very similar velocity requirements (Fig. 3, upper left). Similarly, under low intraspecific competition they are highly selective and utilise a relatively narrow range of velocities as shown for torrentfish in the Hurunui River (Fig. 3, upper right). We have no data for exceedingly dense populations of these two species under ample flows, but speculate that each would increase its use of slower velocities in cases of high intraspecific competition (Fig. 3, bottom right) and conversely contract its velocity range in cases of high interspecific competition (Fig. 3, bottom left). It is surmised that the pattern of habitat use for a species is largely influenced by resource supply and demand.

Accepting that patterns of habitat use vary in response to resources, what effect does this have on computations of potential habitat (weighted usable area)? To test this, the curves in Fig. 3 were applied to a matrix of available habitat data collected in the Hurunui River by Dr M P Mosley, Water and Soil Division, Ministry of Works and Development (pers. comm.) (Table 2). Each of the area values in the matrix is multiplied by its corresponding probability-of-use value from the curves to give weighted usable area. These are then summed for the entire matrix to give total weighted usable area which is a quantitive measure of habitat suitability. As might be expected, the greatest difference in the amounts of potential habitat exist between the low and high intraspecific competition examples - total weighted usable area of the latter is approximately double that of the former. Major differences also occur between the areas calculated from the two curves in the high interspecific situation (Fig. 3, bottom left). The curves for torrentfish in the example of low inter- and intraspecific competition gave an area difference of 18% in spite of the seemingly minor differences between them.

In the actual IFG model, depth and velocity are only two of the factors used to compute weighted usable area; substrate and cover are other examples. Additional variables may lessen the sensitivity of the model to changes in the curves. Nonetheless, the significant changes which occurred in the above example should caution us in using a set of species-specific curves on a nationwide basis. Clearly, further study is required to evaluate the effects of altered flows on fish habitat preferences and on the interaction both within and between species. It is likely that any significant alteration to the natural flow regime will cause some shift in proportional abundance in the "species mix". Whether this is of significance or not will depend on resource values and management goals.

SOME ADVANTAGES AND DISADVANTAGES OF THE IFG METHOD

The outstanding feature of the model is that it can predict with reasonable accuracy the physical conditions (e.g. water depths, velocities) in a selected reach at a range of discharges using data collected at a single discharge. The predicted values are then weighted using fish habitat suitability criteria, and total suitable habitat for each species by life stage is then computed at the desired discharges. This is particularly useful as it provides insight to the changes in suitable habitats for fish with alterations in discharge. Such information is objective and quantifiable and can provide the basis for negotiation between the developers and resource management agencies.

Weighted usable area is a meaningful index of flowing water habitat. It is an estimate of potential optimum habitat that will exist in a river at a given discharge. It does not predict directly the change in numbers or biomass of fish populations that will result from the alterations in discharge. Some of the more common applications of weighted usable area data are illustrated in Fig. 4. Briefly, it can be used to illustrate seasonal differences or similarities in potential habitat between species in a river (e.g. Fig. 4, top), changes in pattern of weighted usable area with discharge between rivers (e.g. Fig. 4, middle) or changes in fish standing stock with changes in weighted usable area (Fig. 4, bottom).

Once the groundwork of developing habitat suitability functions for the various fish species is completed the IFG model can be applied with a minimum of fieldwork. Essentially, all that is required are measurements of certain hydraulic parameters along selected transects at a particular discharge. Thus, results can be produced relatively rapidly.

The major limitation of the model is that it cannot be applied to braided rivers. The behaviour of flowing water in such rivers is complex and, in most cases, impossible to model hydraulically. However, it seems that experienced hydrologists can make intelligent use of such a model in simple braided rivers, e.g. Clutha, Tekapo (see previous paper).

Another limitation of the model is that it was designed to handle hydraulic parameters (e.g. water depth, velocity, elevation) and not others. Cover of various forms is a complex attribute of fish habitats. To determine changes in the availability of cover with alterations in discharge is a most difficult task. At best, cover and other characters of habitats (e.g. presence of silts, algae, stability of gravels etc.) can only be applied as subjectively rated weighting factors in data analysis.

In any impact assessment it is important first to attempt to determine what factor(s) is limiting fish populations. In some rivers fish populations may be limited by the available habitats at flood flows rather than at low flows. In such cases predictions of impacts of reduced flows by the IFG method or some related version are likely to be rendered meaningless.

ALTERNATIVE METHOD

An alternative approach to the IFG method is to obtain measurements of hydraulic conditions at a range of discharges in selected reaches and then compute the weighted usable areas available for fish. The usable area for each species by life stage is then plotted against the measured discharges to allow prediction of areas available for fish at other discharges. This is a simple, straightforward method that can be used on both braided and single channel rivers and one which water resource managers and planning tribunals are more likely to accept. It does not require complex computer analysis; the computations can be done with most desk calculators.

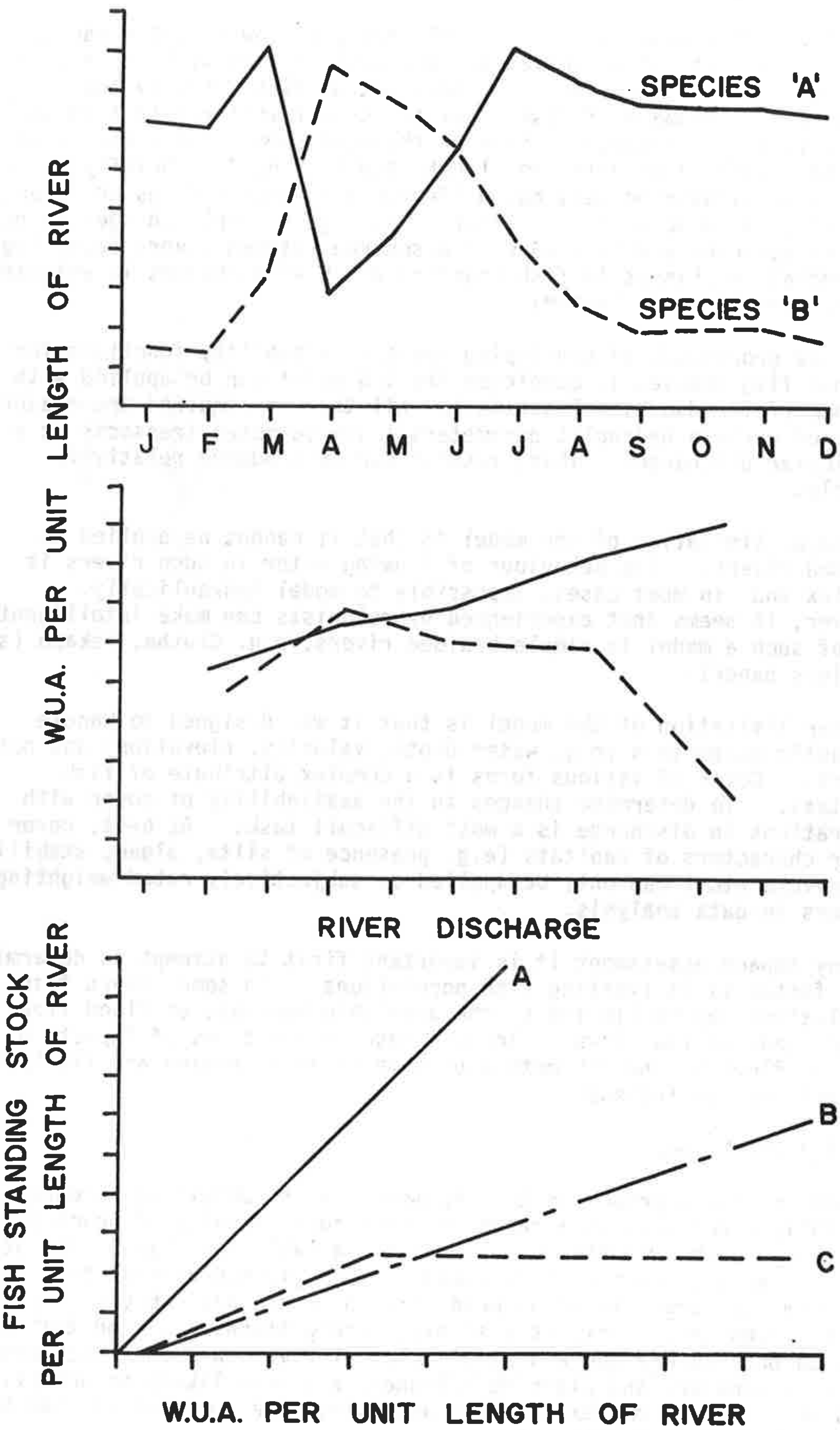

Fig. 4 Hypothetical examples of some of the more common usages of weighted usable area data.

This procedure has received some use in the United States. It was first applied in New Zealand by Dr M P Mosley (Water and Soil Division, Ministry of Works and Development, pers. comm.) in a hydrological study on the Ohau River. It is the method being used on the Lower Rakaia in an effort to determine the changes in available habitats for fish by the proposed irrigation schemes. The main drawback with this method is that often it is not possible to obtain measurements of hydraulic conditions at the proposed minimum flow prior to actual development of the scheme. In the Rakaia we are hoping to overcome this with a temporary shutdown of the Coleridge and Highbank Power Stations at periods of low, stable flow.

CONCLUSIONS

The IFG method, or some version of it, is regarded as a useful tool in assessing changes in available habitats for fish likely to result from alterations in river discharge. However, hydraulic modelling should not be perceived as the "long awaited for tool" that is going to solve all of our fisheries problems related to water abstraction and minimum flows. To base assessment of impact of any major hydro-electric or irrigation scheme solely on the results obtained from hydraulic modelling is potentially dangerous. Studies are also needed to gain an understanding of a river system biologically. Use of the method should be regarded as a part of the suite of biological studies required to assess impacts. When used in conjunction with studies that provide quantification of the fish and fishery resources present and description of fish life history patterns, hydraulic modelling can provide invaluable complementation in the overall assessment of impacts.

THE EFFECTS OF LOW FLOW REGULATION ON RIVER WATER QUALITY AND BIOLOGY

A CASE STUDY

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INTRODUCTION

Low flow regulation can have a number of effects on river and stream ecosystems. A summary based on northern hemisphere studies is presented in Fig. 1. In New Zealand, low flow regulation is practised in a number of rivers and there are proposals to regulate others. For example, to develop the power generating potential of the Upper Clutha River it is proposed to dam the river at Luggate and Queensberry, divert water along canals to a power station at the head of Lake Dunstan and leave a residual flow in the present river channel. It is important to be able to predict the ecological effects of such developments.

Biggs (1982) suggested these developments would cause a reduction in wetted perimeter and depth, a general change from a run to a pool-riffle-run river structure, a reduction in flow variability, increased summer water temperature, higher light intensities at the substrate surface, stabilisation or armouring of the substrate, prolific growth of benthic algae (which could cause fairly wide diurnal fluctuations in dissolved oxygen and pH), an increase in density of benthic invertebrates and a decrease in invertebrate diversity.

At the time of the above assessment there were no data available on the biology and water quality of impoundment regulated residual flows in New Zealand. This paper describes a study of the Hawea River that was carried out during a summer residual flow period to test the validity of the Clutha River predictions.

SITE DESCRIPTION

The Hawea River, North Otago, is fed by Lake Hawea (Fig. 2). The lake occupies a glacial valley at an altitude of 350 m, is bounded by tussock vegetated highlands and mountain ranges and is considered to be oligotrophic.

The level of Lake Hawea has been regulated to aid downstream power generation since 1959. Water from snowmelt and runoff is stored in the lake in spring and summer and is discharged to supplement the Clutha River in winter (Fig. 3). The discharge from the lake ranges from a residual flow of 5.6 m^3 sec^{-1} in summer to over 200 m^3 sec^{-1} in winter. The mean discharge is 62 m^3 sec^{-1} (Ministry of Works and Development 1978). Low flows of < 10 m^3 sec^{-1} now occur in the river

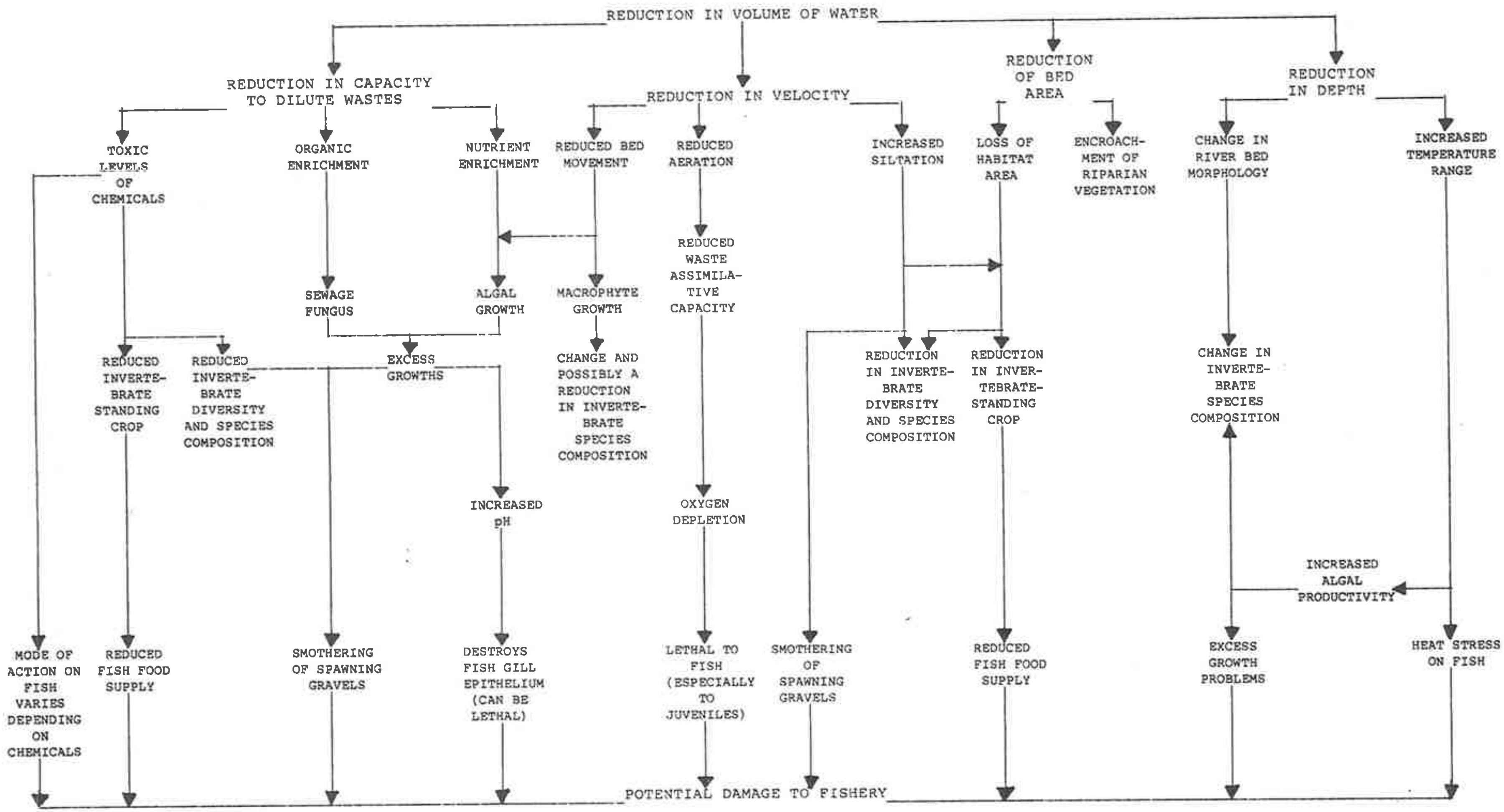

Fig. 1 Summary of the effects of low flow regulation on river ecology and fisheries.

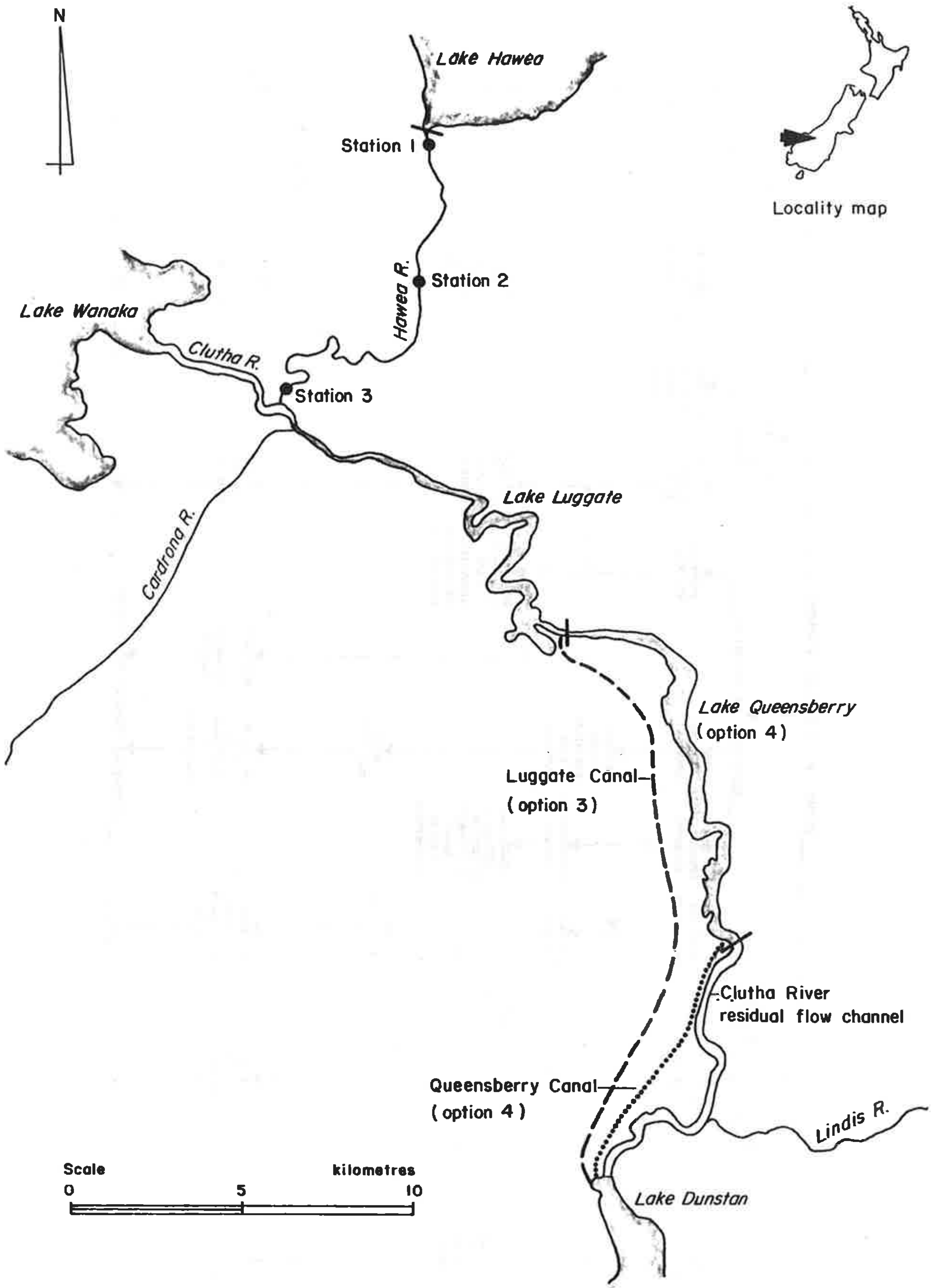

Fig. 2 Location of the Hawea River study sites and Upper Clutha River power development options.

for up to 50% of the time, whereas previously flows as low as these occurred only about 1% of the time (Fig. 3). Higher flows also occur more often and rapid changes from low to high discharges occur (see Appendix 1). Lake water temperatures near the control gates range from about 8°C in winter to about 18°C in summer.

From the outlet of Lake Hawea to the Camphill Road bridge (a distance of 4.8 km), the river is narrow (ca. 18 m) and deep (2-3 m) under average flow conditions. There is little turbulence in this section and the river banks are steep and high.

From the Camphill bridge to the confluence of the Clutha River (9.0 km), the river meanders considerably, generally maintains a single thread channel and is steeper and more turbulent than the upper section. The banks are lower, the bed wider (ca. 25 m) and the river generally shallower (ca. 2 m) in this section.

METHODS

Three stations were selected for the study (Fig. 2). Station 1 was 200 m below the Lake Hawea control gates; Station 2 was immediately upstream of the Camphill bridge and Station 3 was 200 m upstream of the Clutha River confluence.

Hydrological data, collected from the Camphill bridge gauging station by Water and Soil Division, Ministry of Works and Development, were obtained from TIDEDA (Thompson and Wrigley 1974). Supporting observations were made of the river morphology under three discharges from the control gates (88, 15 and 5.6 m^3 sec^{-1}), the sediment type, encroachment of riparian vegetation on the river channel and periphyton accumulation.

Five benthic invertebrate samples were obtained at each station during a low flow period (5.6 m^3 sec^{-1}) in February 1981 using a Surber sampler (0.062 m^2 quadrat fitted with a 310μ m mesh net). Samples were preserved in 40% iso-propyl alcohol and sorted under 6.5 times magnification.

Temperature, percentage dissolved oxygen saturation and pH were recorded with meters at each station at flows of 5.6, 15 and 88 m^3 sec^{-1}. The measurements were made at mid-afternoon for all flows and also at half-hour intervals from before dawn until 11 pm at the 5.6 m^3 sec^{-1} flow at Station 3.

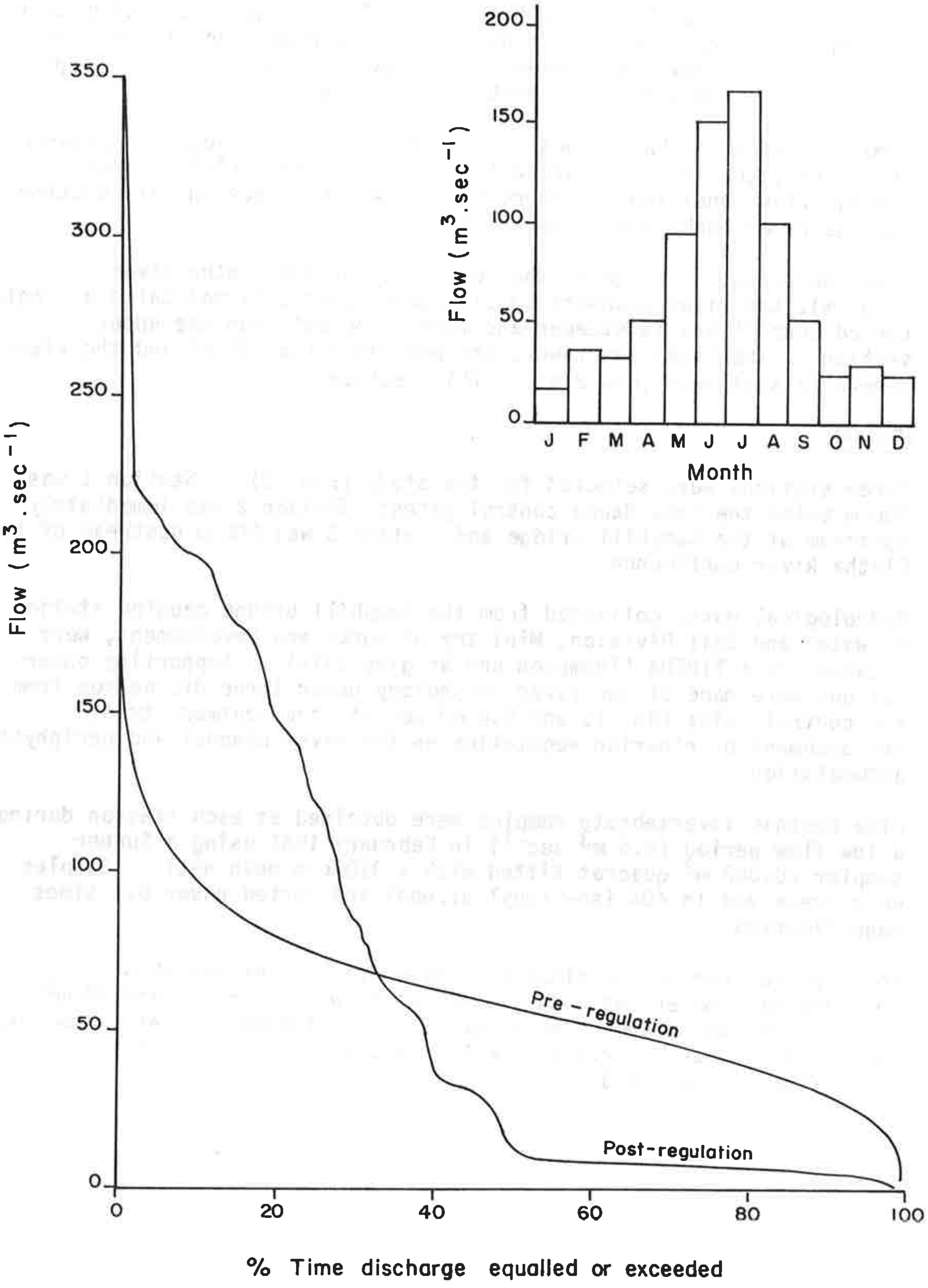

Fig. 3 Hawea River flow duration curves for pre-regulation (1931-1957) and post-regulation (1960-1977) periods and mean monthly flows for a typical 10 year post-regulation period (1966-1975).

RESULTS AND DISCUSSION

(i) Hydrology

Curves of maximum depth, mean cross-section velocity and wetted perimeter against discharge at the Camphill Road bridge (Fig. 4) show that depth and velocity are strongly affected by changes in flow but there is a relatively small effect on wetted perimeter. At summer residual flows (5.6 m^3 sec^{-1}) river depth is 55% less, velocity is about 80% less and wetted perimeter is about 20% less than before regulation (mean February discharge was 73 m^3 sec^{-1}).

The reduction in wetted perimeter would cause a proportional loss of productive habitat area for algae and invertebrates in the river.

(ii) River Morphology

At a discharge of 88 m^3 sec^{-1} the river consisted mainly of a swift flowing run with intermittent short turbulent reaches. At a discharge of 15 m^3 sec^{-1}, most of the upper section remained as a medium flowing run and some weakly developed riffles and pools appeared in the lower section. At a discharge of 5.6 m^3 sec^{-1} the upper section maintained its run character but the lower section developed a strong pool-riffle-run structure with the depth of pools being 1.5 to 3 m, the riffles 0.2-0.3 m and the runs 0.75-1.2 m.

(iii) Bed Sediment

The bed sediment is mostly armoured by large stones and boulders with short sections (< 20 m) of mobile gravels below sites of bank erosion. By contrast, in the unregulated Upper Clutha River, banks of gravels occur and fines accumulate between the large stones and boulders.

Flow control at the Lake Hawea outlet may prevent lakeshore gravels from entering the river especially in summer, and low flows appear insufficient to move the fine gravels derived from bank erosion. Water velocities of 0.61-1.22 m^3 sec^{-1} are necessary to move sediment 25-100 mm in size (US Army Corps 1973), these being considerably faster than those occurring in the river under residual flows (e.g. Fig. 4).

(iv) Riparian Vegetation

During the November-February low flow period considerable willow growth occurred in dry sections of riverbed.

When flow increased in early March many of the willow bushes were uprooted or submerged. Trees that had become well established in sheltered areas could survive periodic inundation, although some were uprooted during high winter flows. Leaves and organic debris that accumulated under the trees were washed into the river under these conditions and may have become a source of food material for the benthic invertebrates.

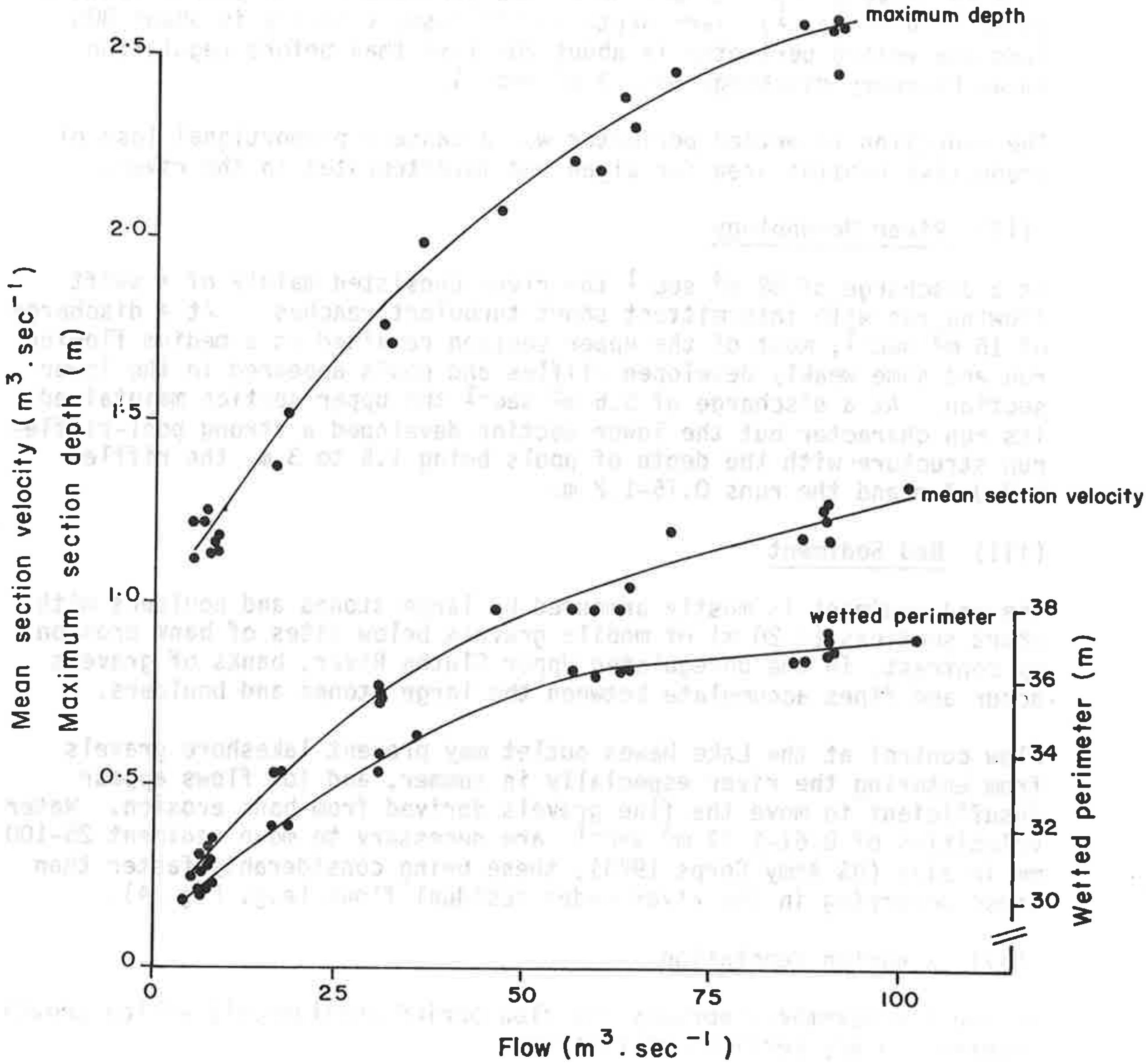

Fig. 4 The relationship between flow (< 100 m^3 sec^{-1}) and three hydrological variables in the Hawea River.

(v) Periphyton

Large accumulations of periphyton occur throughout the river, especially in the shallow river section during summer. Extensive colonisation by periphyton begins in spring following reduction in discharge and is probably enhanced by stable flow, higher light intensities at the substrate surface and warming of the water. Periphyton mats did not appear in the adjacent section of the Clutha River except in shallow-riffle areas. Periphyton growing in the deep and swift sections of the Clutha River were mainly encrusting forms.

(vi) Benthic Invertebrates

Benthic invertebrate data obtained at the three stations in the Hawea River are presented in Table 1.

TABLE 1: Numbers of invertebrates and invertebrate taxa, and invertebrate diversity index at three sampling stations in the Hawea River

Station	No. of Organisms m^{-2}	No. of Taxa*	Shannon-Weaver Diversity Index
1. (Upper river)	7 300	14	1.46
2. (Middle river)	9 970	25	2.04
3. (Lower river)	17 100	22	1.81

The density of invertebrates at Station 1, near the outlet from Lake Hawea, was comparatively low and was dominated by net-spinning larvae of the caddis-fly *Aoteapsyche tepoka*. The mayflies *Deleatidium* sp. and *Zephlebia* sp. were the next most abundant organisms, although at much lower densities. The low numbers of most taxa at the station (13 taxa comprising a total of 1260 organisms m^{-2} or 17% of the numbers) and thus low diversity index, suggests a harsh physical environment. At this station there is an armoured bed sediment and rapid changes in discharge caused by sudden release of water from the control gates.

Station 2 had a medium density of invertebrates with *Aoteapsyche tepoka* being dominant and comprising 60% of the community. The largest number of taxa were collected at this station, but with the five most abundant organisms making up 95% of the community.

Station 3 had large accumulations of periphyton and a high mean density of invertebrates. Chironomid larvae made up 68% of the organisms and *Aoteapsyche tepoka* were subdominant. Periphyton is an unsuitable habitat for rock surface dwelling organisms such as some mayflies and stoneflies, but favours others such as chironomids. A high number of

* Invertebrates identified to the lowest practicable taxonomic level.

chironomids and low diversity index is a condition analogous to a river receiving mild organic pollution (Hynes 1960). By comparison, the Clutha River, an unregulated limnocrene environment, had a lower invertebrate density but higher diversity than the Hawea River as indicated in Table 2.

TABLE 2: Mean density (numbers $.m^{-2}$) and mean diversity of invertebrates sampled from the Clutha and Hawea Rivers

	Clutha River[1]	Hawea River[2]
Mean density	2 300	11 400
Mean diversity (H)	2.3	1.6
Number of samples	33	15

1 - Sampled February 1980 (B J Biggs and T Malthus unpublished data).
2 - This is an ensemble of data in the preceding table.

These data suggest that regulation is stimulating the numbers of invertebrates in the Hawea River.

(vii) Water Quality

Monthly water quality data for Station 2, from July 1979 to September 1980 (Ministry of Works and Development unpublished data), indicate that the Hawea River waters are generally of a high quality. However, during periods of low flow pH was noted to be high and approached levels that over extended periods could be detrimental to fish (> pH 9.0, Alabaster and Lloyd 1980).

During a 15 hour period of residual flow in the lower section of the Hawea River water temperature varied from 12°C in the early morning to 19°C in the mid-afternoon while at the lake outlet, temperature remained at 16°C throughout the day. Oxygen saturation ranged from 78% before sunrise to 116% in the mid-afternoon and pH ranged from 7.5 to 9 over the same period.

To determine the effect of reductions in discharge on water temperature and pH, mid-afternoon recordings were taken at the three sampling stations at discharges of 88, 15 and 5.6 $m^3 \ sec^{-1}$ (Fig. 5). Under residual flow conditions pH increased from 7.7 at the outlet to 9.0, at 13.8 km downstream (Station 3). At a flow of 88 $m^3 \ sec^{-1}$, pH only increased to 8.1 down the river. Over the same section temperature increased from 16°C to 19°C during residual flow conditions.

At the three discharges considered pH was inversely related to flow, showing that the capacity of the river to dilute hydroxyl ions released during photosynthesis varied. A strong relationship was also evident between pH and the ratio between distance from the control gates and discharge (Fig. 6). Using this as a nomograph, a quantitative prediction can be made of the upper midsummer pH levels in the Clutha River for some of the power development options and a given residual flow (Table 3). Assumptions are that:

(a) similar algal growth will occur in the regulated section of the Clutha River to that in the Hawea River, and

(b) the mean wetted perimeter-discharge ratio will be similar in the two rivers.

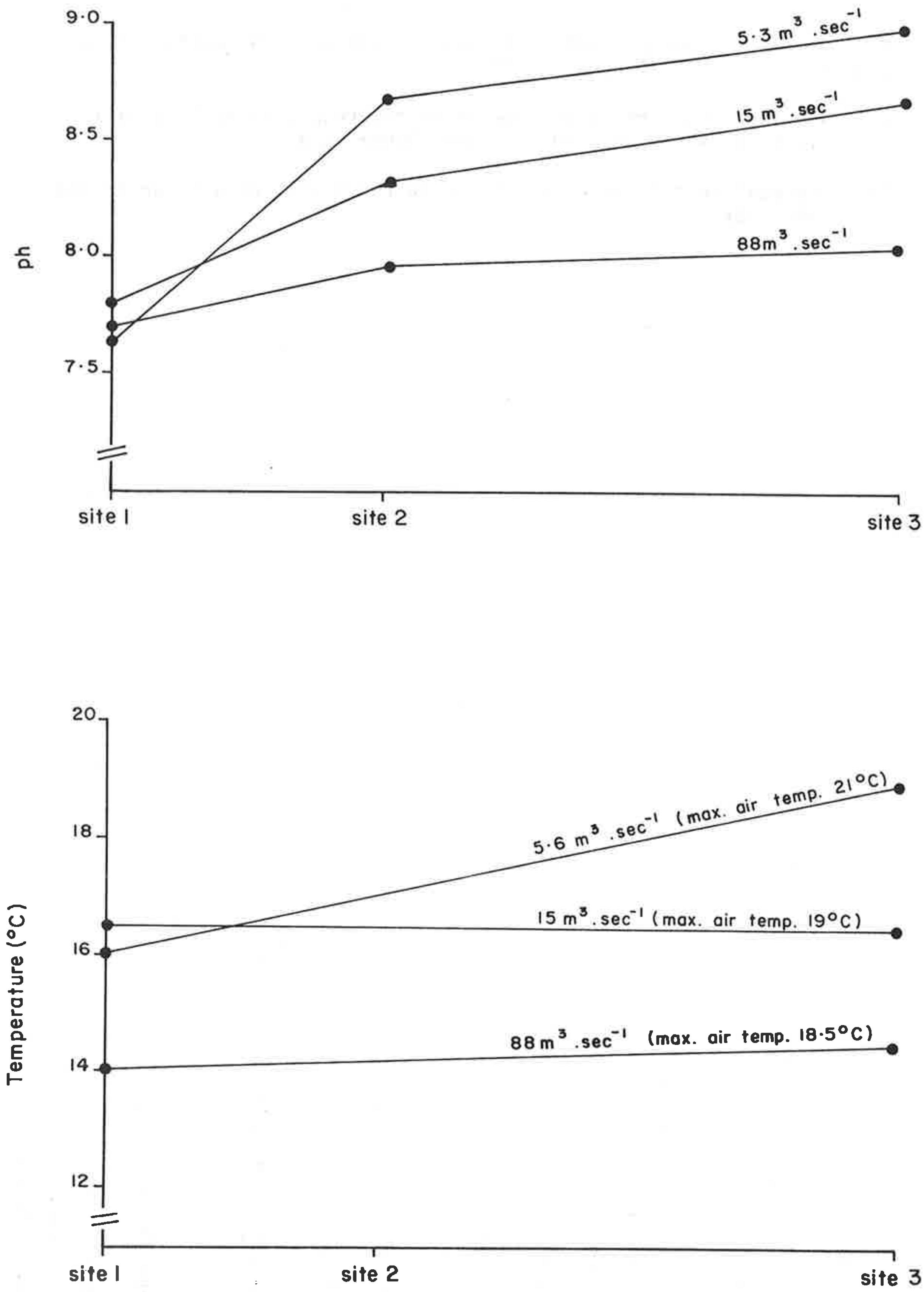

Fig. 5 Mid-afternoon changes in pH and temperature along the Hawea River at three flows.

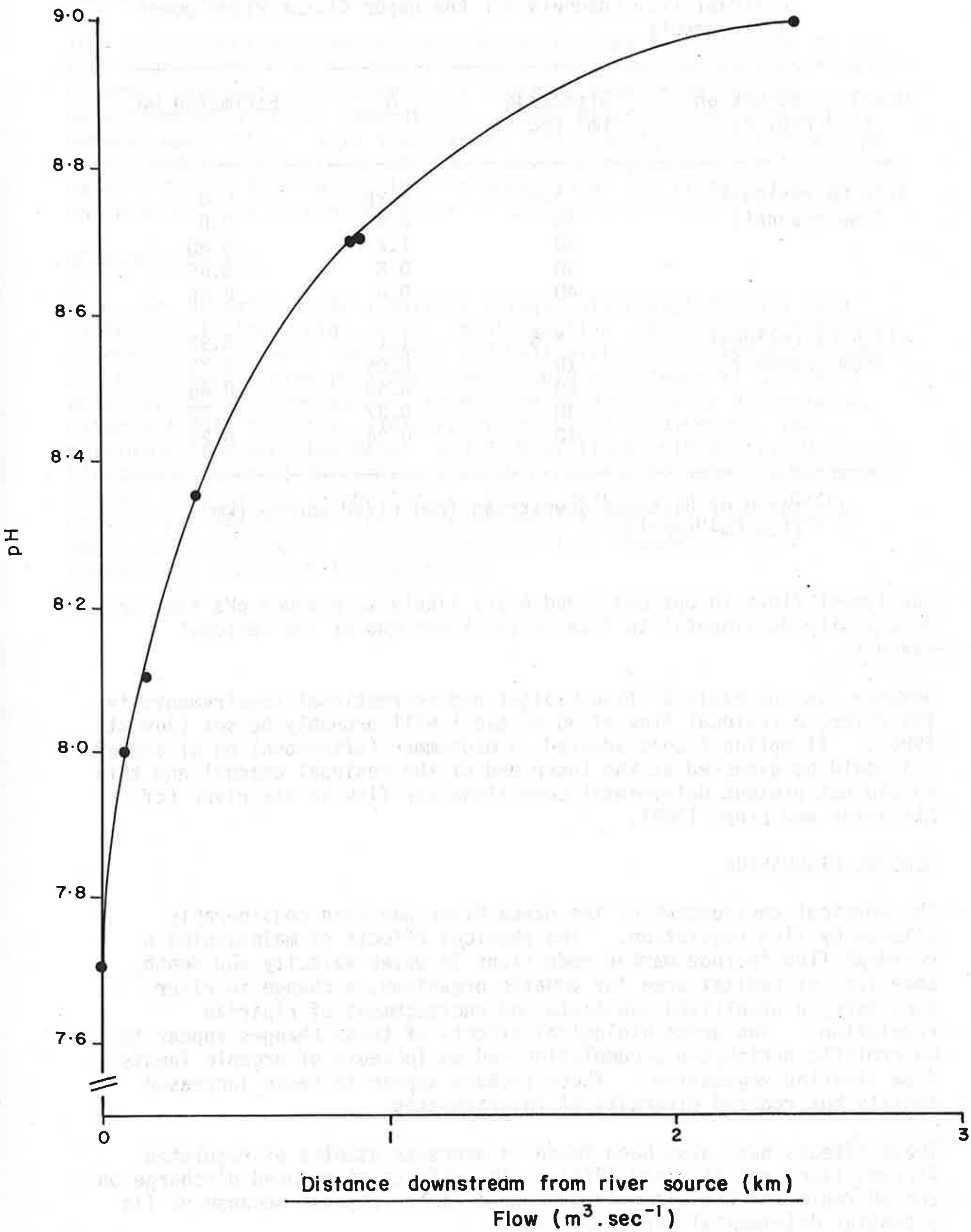

Fig. 6 Relationship between mid-afternoon pH and the ratio of distance of sample site downstream from the Lake Hawea control gates: flow.

TABLE 3: Estimates of pH at a range of discharges in two proposed residual flow channels for the Upper Clutha River power developments

Development Option (See Fig. 2)	Discharge (m^3 sec^{-1})	q	Estimated pH
3(24 km residual flow channel)	5.6	4.28	9.0
	10	2.4	9.0
	20	1.2	8.80
	30	0.8	8.65
	40	0.6	8.56
4(9.6 km residual flow channel)	5.6	1.7	8.92
	10	0.96	8.73
	20	0.48	8.46
	30	0.32	8.35
	40	0.24	8.24

q - ratio of distance downstream from river source (km): flow (m^3 sec^{-1}).

The lowest flows in options 3 and 4 are likely to produce pHs that are potentially detrimental to fish at the lower end of the residual channel.

However, on the basis of fish habitat and recreational requirements in the river, a residual flow of 30 m^3 sec^{-1} will probably be set (Jowett 1980). If option 4 were adopted, a midsummer (afternoon) pH of around 8.4 would be expected at the lower end of the residual channel and this should not present detrimental conditions for fish in the river (cf. Alabaster and Lloyd 1980).

GENERAL DISCUSSION

The physical environment of the Hawea River has been considerably altered by flow regulation. The physical effects of maintaining a residual flow include marked reductions in water velocity and depth, some loss of habitat area for aquatic organisms, a change in river structure, a stabilised substrate and encroachment of riparian vegetation. The gross biological effects of these changes appear to be prolific periphyton accumulation and an increase of organic inputs from riparian vegetation. These factors appear to cause increased density but reduced diversity of invertebrates.

These effects have also been found in overseas studies of regulated streams (Ward and Stanford 1979). The effects of reduced discharge on the pH regime of the river is of considerable interest because of its potential detrimental effect on fish.

The results of the Hawea River study indicate that no amendments are required to the earlier predictions (Biggs 1982) on the likely downstream effects of impounding and diverting most of the flow from a section of the Upper Clutha River.

This study describes changes in a stream ecosystem in response to low flow regulation. Most notable in this change is the stabilisation of riverbed sediment, encroachment of riparian vegetation and the establishment of algal communities. Many other changes seem consequent upon this. This study shows that some of the changes can be quantified and possibly predicted. Water managers may, in the future, be able to set flow levels in consideration of the river ecosystem as a whole as well as in consideration of the needs of fisheries.

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APPENDIX 1: Short-term fluctuations in discharge from the Lake Hawea control gates

Date	Time	Discharge $m^3\ sec^{-1}$
10 July 1980	0945	53
11 July 1980	0945	5.6
13 July 1980	0930	33
	1130	53
	1300	75
	1330	106
16 July 1980	1015	53
	1045	11
17 July 1980	0945	33
	1145	53
	1315	75
	1345	106
20 July 1980	1200	124

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