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FLOW REQUIREMENTS FOR RECREATION AND WILDLIFE IN NEW ZEALAND RIVERS — A REVIEW

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ABSTRACT

As increasing pressure for development is put on New Zealand's rivers, there is increasing concern that non-developmental uses, particularly recreation, provision of fish and wildlife habitat and enhancement of scenic beauty, be catered for. The factors controlling these uses, which are commonly referred to as "instream uses", are reviewed, and their relationship with discharge discussed. Application of the incremental method of flow analysis is described; although vigorous adherence to the method is at present limited by lack of full information on the flow needs of each instream use, it provides the best framework for assessing instream flow requirements. The other commonly used method, the Montana method, has severe limitations, and should be restricted to reconnaissance-level planning.

INTRODUCTION

The rivers of New Zealand have been progressively developed by man for a number of economically important uses, particularly irrigation, water supply, hydro-electricity generation and waste disposal. As pressure upon the water resource has built up, and as the population's wealth and leisure time have increased, concern has grown that continuing development of rivers may eliminate several other uses, whose economic value is difficult to define, but whose contribution to the quality of life is nonetheless great. These uses, which have come to be known as "instream uses" (Orsborn and Allman, 1976; Fraser, 1978), include recreation (angling, canoeing and rafting, swimming, and the like), provision of habitat for wildlife and fish (which may be important for recreational hunting or fishing, or may be regarded simply as of intrinsic value), and enhancement of scenic beauty.

The requirements of the developmental uses of rivers and the type of information needed to assess their practicability are now well established, and recent reports such as those on the Kaihu River (Northland Catchment Commission, 1979), the Motu River (Riddell, 1980), and the Ashley River (North Canterbury Catchment Board, 1982) represent a wide range of approaches to data collection and analysis which are conditioned by specific project requirements. They range from the emphasis on flood hydrology in the Motu to the emphasis on low flows and groundwater recharge in the Ashley. However, the type of information necessary to assess the suitability of a given river for instream uses, and the likely impact of development, is not so well established, and discussions of possible impacts on instream uses have generally been narrative and qualitative in style. Such presentations have tended to receive less weight than quantitative treatments of the hydrological, engineering and economic aspects of a project proposal. Nevertheless, assessments of proposals for water resource development are paying increasing attention to probable impacts on the river environment and its "instream uses". For example, the summary chapter of a report on the Ashley River (North Canterbury Catchment Board, 1982) devotes 19 pages to a discussion of fish, wildlife, and recreational uses, and only 8 to irrigation and power generation. The "wild and scenic river" provisions of the 1981 amendment to the 1967 Water and Soil Conservation Act have in particular prompted examination of the instream uses to which rivers such as the Motu, Ahuriri and Rakaia are put, their relationship with the physical characteristics of the rivers, and the implications of water resource development.

Overseas, there have been increasing efforts to quantify project impacts on instream uses, particularly on the freshwater fishery (Smith, 1979; Stalnaker and Arnette, 1976). Other instream uses have also received consideration, and Cortell and Associates (1977), for example, prepared a manual for evaluation of river suitability for a variety of human instream uses in the USA. In New Zealand, Jowett (1980) considered swimming, wading, canoeing, jetboating, and fish and wildlife habitat in his evaluation of the impact of power development on the upper Clutha River, and Mosley (1982b) proposed a method to establish the discharge required to permit passage of recreational craft and migrating sport fish along braided rivers.

The need for an objective, quantitative method of assessing the flow requirements of instream uses and allocating flows is now widely recognised, and was the subject of seminars sponsored by the New Zealand Committee for Water Pollution Research (McColl, 1982) and the Auckland Regional Authority (1983). The purpose of this paper is to review the types of instream use which could be considered when evaluating a proposal for development of a given river's water resource, and to consider the information needed to assess the value of a river for each instream use. Those aspects of the river environment will be emphasised which may change with hydrological regime. Water quality considerations will not be referred to because they have been extensively discussed (Alabaster and Lloyd, 1980; Environmental Protection Agency, 1976; Church et al, 1979; Smith, 1982; Water Quality Criteria Working Party, 1981), and are the subject of legislation which establishes minimum standards for certain uses (Water and Soil Conservation Act, 1967, section 26).

My work has concentrated on those rivers (the Motu, Ahuriri and Rakaia Rivers) which have been the subject of applications for National Water Conservation Orders under the Water and Soil Conservation Act (1967, amended 1981), and on gravel-bedded rivers in the South Island (Waiho, Ashley, Ohau, Hurunui). This review may therefore show some bias, but the principles discussed herein are, I believe, applicable to any watercourse, whether it be the Clutha River or a small stream in Auckland.

DEFINITION

There is still argument over the definition of the term "instream use", as is demonstrated by a recent exchange between Milhous (1983) and Anderson (1983). In this review, I have followed common usage, and have used the term to include recreation (boating, swimming, angling, tramping up riverbeds, etc), provision of habitat for wildlife and fish, and enhancement of scenic beauty. Navigation and waste disposal are both, strictly speaking, also instream uses, as is hydroelectricity generation in some circumstances. However, navigation other than for recreation is of negligible importance in New Zealand, and since it is also related to river flow in the same way as recreational boating, will not be considered further. Waste disposal is an important "instream use" of river channels throughout New Zealand, but limitations on use for waste disposal are caused less by channel characteristics or flow levels (since waste can be discharged into and flow along a completely dry channel, so long as its capacity is large enough) than by the impact of the waste discharge itself upon water quality, and thereby on other uses of water. The limitations on a proposed waste discharge may therefore be defined in terms of the water quality requirements of other water users, and will accordingly not be discussed further.

FACTORS CONTROLLING INSTREAM USES

The term "instream use" implies a user. *Homo sapiens* is not the only species to rely on rivers for livelihood and recreation. Other terrestrial animals, birds, fish and other aquatic species, and insects may be wholly or partly dependent upon rivers for at least part of their existence, and indeed the requirements of some species of fish for such activities as spawning and feeding are better defined than those of man for activities like angling or rafting. Much of the work on instream flow needs has to date concentrated upon the requirements of other species, particularly fish, (Stalnaker and Arnette, 1976), because they provide a basis for a human instream use—angling, in the case of fish. More recently, as society has accepted that the continued presence of other species is of intrinsic value, instream flow needs have been reviewed from a less restrictedly human perspective; for example, Robertson et al (1983) have examined the requirements of birds that use the Ahuriri River. However, the character of a river is in principle amenable to description in terms of a limited number of factors, irrespective of which species uses the river, and for what purpose (Mosley, 1982a). For any one use, only some of those factors may be relevant, but rather than discuss in detail the dependency between each instream use and the factors that control it, the aim of this paper is to introduce the reader to general principles and enhance his awareness of the range of factors that must be considered.

In a synthesis of previous work on characterisation of the river environment, Mosley (1982a) listed about eighty factors which may be used to describe the character and appearance of a river (Table 1). Factors in groups C and D are of prime importance to fish, whereas factors in groups B and C are primarily dominant for large mammals. Many human activities may similarly be dependent upon only a small suite of factors. For instance, jetboating is primarily controlled by factors in group C, although many of the factors in the other groups have some significance, through their influence on the aesthetic character of the riverscape.

TABLE 1—Summary of the Factors that Determine the Character of a River, condensed from Mosley (1982a).

- A LANDSCAPE SETTING—LANDSCAPE BEYOND THE FLOODPLAIN
    - Valley type and dimensions
    - Lithology
    - Vegetation and land use
    - Presence, number and character of terrace levels
    - Degree of constriction of channel by valley sides
- B FLOODPLAIN SETTING
    - Presence, extent and dimensions of floodplain
    - Floodplain surficial material and soil type
    - Vegetation and land use
- C CHANNEL CHARACTER
    - Channel pattern and presence of islands and bar forms
    - Channel dimensions—width, sinuosity and meander wavelength, slope, and degree of braiding
    - Obstructions in channel—type and degree
    - Bank height and degree of erosion
    - Bed material (including rock outcrops)
    - Bank material (including rock outcrops)
- D WATER CHARACTER
    - Colour, turbidity, odour, taste
    - Flow velocity and depth
    - Temperature
    - Water chemistry (including pollutants)
    - Presence of floating solids, solids on bed, floating liquids
    - Bacteriological water quality
    - Fauna present (fish, invertebrates, etc)
    - Flora present (weeds, algae, diatoms, etc)
- E SCENIC QUALITY AND RECREATIONAL POTENTIAL
    - Diversity of scene
    - Confinement of view and presence of far vistas
    - Utility crossings
    - Litter
    - Presence of beaches, islands and campsites
    - Accessibility of banks
    - Ease of access to water
    - Points of interest
    - Grade of river on International River Classification Scale, and number of rapids
    - Floatability and obstructions to navigation for different craft
    - Flow fluctuation and permanence of flow
    - Abundance of fauna

FISH

The instream use which has dominated attention both in New Zealand and overseas is angling and the freshwater fishery, and, by extension, the provision of habitat necessary for maintenance of the various life stages and activities of the fish species in a river system.

Of the forty-odd species present in New Zealand's estuary, river and lake systems (McDowall, 1978), many—the lamprey, the eels, five whitebait species, seven introduced salmonids, the so-called "coarse" fish (perch, tench, and rudd), and the estuarine kahawai, mullets and flounders—are of direct use for recreation or food. Of the others, many, like the torrentfish and the bullies, are endemic, and as part of New Zealand's heritage have intrinsic value. More practically, they are also part of the food chain, both for larger fish and for fish-eating birds.

There is now much literature available on the factors that control habitat suitability for fish, and methods are available to study the impact of water resource development upon habitat quality and quantity. The most sophisticated method has been developed by the Co-operative Instream Flow Group (CIFG) of the US Fish and Wildlife Service, and is generally referred to as the "incremental method" (Co-operative Instream

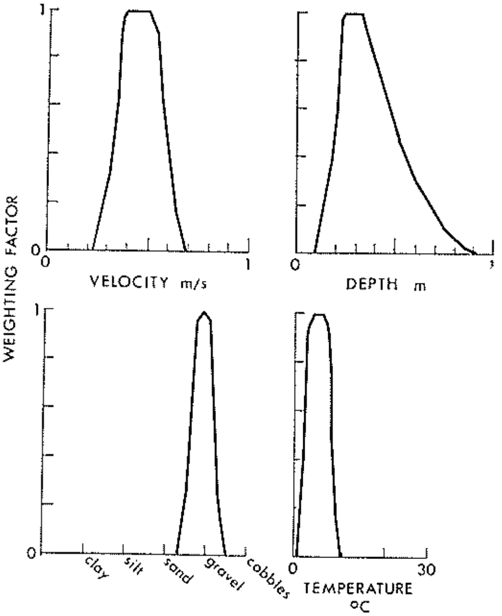

FIG. 1—Examples of "probability of use" or "habitat suitability" curves, redrawn from Bovee (1978) for spawning sockeye salmon.

Flow Group, 1982; Tierney, 1982). In principle, the method assumes that fish habitat is controlled by a number of physical characteristics of a stream channel, particularly water depth and velocity, substrate (that is, bed sediment), water temperature, and water quality. An incremental change in discharge may cause a change in one or more of these controlling factors; a change in available habitat quantity or quality will result. Each life stage and species of fish is considered to have a preference for certain ranges of these characteristics, which results in there being a "probability of use" of a given volume of water with a given combination of characteristics. This may be estimated by simply counting the number of fish present in locations whose physical characteristics are measured. Statistical or hydraulic modelling techniques may be used to predict the effect of changes in discharge upon the pertinent physical characteristics, and thence upon suitability of the habitat for species and life stages of interest. The end result is an index of net habitat suitability called weighted usable area.

Probability-of-use or habitat-suitability curves have been prepared for a number of North American fish species (Bovee, 1978), some of which have been introduced to New Zealand rivers (Figure 1). The curves for the introduced salmonids are being verified, and similar curves are being prepared for endemic species (Glova, 1982; Shirvell and Dungey, 1983). The incremental method, which is widely used for fishery management purposes in the United States, is now increasingly used in New Zealand to evaluate the effect of changing discharge upon rivers in New Zealand (Jowett, 1980, 1982; Mosley, 1982c, 1983a; Glova and Duncan, 1983; Figure 2).

Recently, attention has been directed to the less-readily quantified controls upon fish habitat quality, particularly upon cover—overhanging banks and vegetation, submerged logs and other objects, turbidity, water surface opacity (caused by "white water") and so on. Common observation indicates that some fiish prefer cover for some activities—for example, resting adult brown and rainbow trout are frequently found tucked underneath overhanging banks or submerged debris—although not for other activities such as spawning and feeding. Quantification of fish preference for cover is hindered by the difficulty of observing fish and of measuring cover, but the Co-operative Instream Flow Group has attempted to include cover type and density as a component in its incremental method of instream flow assessment (Table 2).

The incremental method in effect defines potential habitat in terms of variables which are themselves related to discharge, but additional information is necessary to estimate the actual fish population using that potential habitat. The CIFG method is being developed to include simulation of a fish population over a period of years, using information on survival rates at each life stage. Deverall and Jowett (1983) modelled the returning adult quinnat salmon population of the Hakatarmea River, using discharge and sediment transport data for the river and estimates of in-river survival rates of the young from elsewhere. However, work by G. J. Glova (pers. comm., 1982) on the Ashley, Hurunui and Rakaia

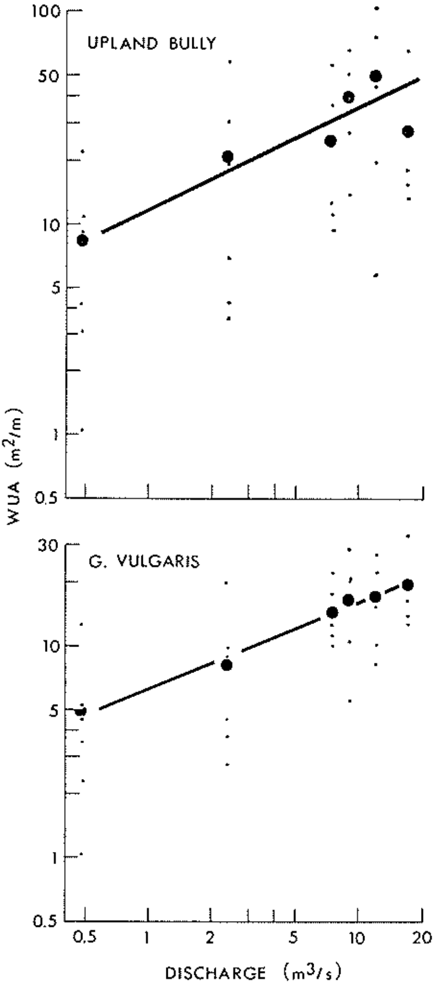

FIG. 2—Change in weighted usable area (WUA) for upland bully *(Gobiomorphus breviceps)* and *Galaxias vulgaris* with discharge in the Ahuriri River. Dots are for individual transects across the river, and solid circles are averages for six reaches, in each of which several transects were located. Habitat suitability data were provided by G. J. Glova; only velocity and depth were considered, as the other variables which control WUA are unchanged over the flow range examined.

TABLE 2—The preference† of brown and adult rainbow trout for a variety of cover types (from Tierney, 1982, table 1).

Cover Code	Cover Description	Preference Factor Brown trout	Preference Factor Rainbow trout
0	No physical cover.	0.05	0.05
1	0-25% of cell affected by object cover*.	0.1	0.2
4	75-100% of cell affected by object cover.	0.5	0.8
5	0-25% of cell affected by overhanging vegetation.	0.2	0.1
9	0-25% of cell affected by undercut bank.	0.25	0.1
13	0-25% of cell has object cover combined with overhanging vegetation.	0.25	0.25
20	75-100% of cell has object cover combined with undercut bank.	1.0	1.0
21	0-25% of cell has combination of undercut bank with overhanging vegetation.	0.25	0.1
25	0-25% of cell has a combination of object cover, undercut bank and overhanging vegetation.	0.25	0.25
28	75-100% of cell has a combination of object cover, undercut bank and overhanging vegetation.	1.0	1.0

* Object cover—boulders, submerged logs, patches of white water, etc.

† Data gathered by Cooperative Instream Flow Group, applicable to fish in Wyoming streams, are not necessarily appropriate for the same species in New Zealand rivers because of differences in river characteristics and available habitat.

Rivers shows that the index of habitat suitability, "weighted usable area", was poorly related to actual populations of a number of endemic and introduced fish species. This is presumably due to other factors listed by Smith (1979), particularly channel morphology (the relative numbers of riffles, pools, runs, backwaters and the frequency of channel change), flow regime, food supply, competition and instream cover. This implies that the habitat preference data needed for application of the incremental method may be reliable only for the river or river type in which they are collected (Glova and Duncan, 1983; Tierney, 1982), and that preference data collected in what may be only sub-optimal habitat must be used with caution.

WILDLIFE

Usage of rivers by terrestrial animals is primarily for drinking water, for lines of travel, and as favoured areas for grazing. The factors controlling use are, therefore, rather simple; presence or absence of water in the channel and of suitable vegetation along the banks and flood plain in the case of drinking and grazing, and negotiability in the case of travel.

River beds become more negotiable, both in a lengthwise direction and across the channel, as flow drops. Jowett (1980) considered across-channel negotiability in the Clutha River from the point of view of controlling stock movement from one side to the other, by assessing the number of crossing places in two study reaches at a range of discharges. He did not, however, specify the depth, velocity and sediment combinations necessary to permit negotiation of a channel by stock, and until such information is available discussion of this particular instream use will be inconclusive.

An important use of rivers is as an environment for shooting game birds—ducks and geese—and, by extension, the provision of habitat needed by the various life stages and activities of the species present. Most of the bird species that may be observed along rivers (almost eighty at the Ashley River estuary, for example (North Canterbury Catchment Board, 1982)), do not hold any direct interest for the sportsman, but are of intrinsic value and are protected by legislation. Some species, such as the blue duck (*Hymenolaimus malacorhynchos*), may be permanent residents of a particular river, depending upon it at all life stages and for all activities, whereas others may use a river only for nesting and for rearing of young, before migrating elsewhere. However, the survival of a species which spends part of its time elsewhere—for example, the wrybill (*Anarhynchus frontalis*), the majority of which nest in South Island braided rivers but overwinter in northern North Island harbours—is nevertheless dependent upon the continued availability of suitable habitat in or along a river.

There is increasing interest in rivers as habitats for bird populations; for example, the Minister of Internal Affairs in January 1983 applied for a Water Conservation Order for the Ahuriri River on the grounds of its outstanding value as habitat for several wetland birds. While much is known in general terms of the usage of rivers by birds, only recently has detailed work been started to find the precise microhabitats and their characteristics which are favoured by different species of New Zealand birds for various activities—nesting, feeding, "loafing" and so on (O'Donnell and Moore, 1983; Robertson et al, 1983). The range of factors that must be considered is large, and several may be affected by variations in discharge. Most obvious is the areal extent of different types of subhabitat—small side-braids and riffle areas which provide good feeding grounds, exposed gravel bars composed of clean, loose gravel which are swept clear of vegetation, but are not regularly inundated during the nesting season, and so on. Surveys in the Ahuriri, Rakaia and Waitaki Rivers have focussed on the frequency with which each microhabitat is used by each species for each activity. In the future, such data may make it feasible to predict the potential impact of water resource development upon bird life, as a consequence of changes in the areas of each microhabitat in response to changing discharge. In principle, it is possible to construct habitat suitability curves for birds in the same way as for fish, to show their dependence upon water depth, velocity, substrate, area and number of islands and side braids, and other flow-related variables. This approach would permit quantitative estimates of discharge-related changes in aquatic microhabitats (used primarily for feeding), and could be applied with modification to the non-aquatic habitats used for nesting, "loafing", etc. However, it is not clear that such an increase in detail would be an improvement over consideration simply of area of each microhabitat, especially since a bird population on a given river is likely to be

TABLE 3—Human Instream Uses.

Contact Uses	Non-contact Uses	Associated (Water Enhanced) Uses
Paddling/wading	Angling (bank and boat)	Sightseeing/aesthetic value
Angling (wading)	Boating (non-powered)/ rowing/flat water canoeing	Nature study/bird watching
Swimming	Sailing	Picnicing
Tubing/drift diving*	Flat water powerboating	Hunting/shooting
Water-skiing		Tramping (non-riverbed routes)
White water rafting/ canoeing		
Tramping (via riverbed routes)	Jetboating	Horse and trail bike riding
	Camping (for water supply, washing/bathing)	

* Drift diving—floating with the current with snorkel and face mask.

limited by only one or two factors. For example, the availability of prime nesting habitat (safe from inundation by floods and predation by terrestrial animals) may be the predominant factor in the case of the black stilt in the Ahuriri River. The prime need, then, in environmental impact analysis is to identify these limiting factors and to assess their response to artificial changes in flow regime, for example noting any possible changes in the occurrence and nature of freshes which could modify the frequency of inundation of nesting areas and the frequency of disturbance by bed-material movement over feeding grounds.

MAN

In addition to the instream uses discussed in the preceding sections, which relate to provision of habitat for other species in whose survival man has an interest, there are a large number of ways in which man personally uses rivers (Table 3). So-called "instream" uses are not, in fact, necessarily carried out in the stream, and uses may be divided broadly into contact and non-contact uses, with some that are intermediate (e.g., sailing is a non-contact use which may under some conditions become a contact use, usually inadvertently). Rivers may also represent an important component of a recreational activity in that the presence of running water seems to enhance the environment for most people for many outdoor activities ("associated uses"—Table 3). Many of the human instream uses listed in Table 3 are controlled by the same variables, particularly water surface width, depth, velocity and substrate, and are conveniently discussed together. There do not appear to be any data appropriate for preparation of "habitat suitability" or probability-of-use curves for human instream uses, but their requirements can in general terms be stated. For instance, the turning circle of a power boat towing a water-skier or the

Table 4—Summary of Flow Requirements for Human Instream Use

Activity	Water surface width (W), depth (D), velocity (V) requirements			Preferred Sediment Requirements	Preferred Other Requirements
	Minimum	Maximum	Preferred		
Paddling/wading	W - D - V -	W - D 1.2 V 1.8	W - D 0.4-0.6 V <0.5	Sand and gravel preferred. Algal or silt coating undesirable. No debris, broken glass, etc.	Bacteriological and toxicant water quality standards to be met. Water temperature 15-25 °c preferred. DxV product less than 1.0. Bottom visible. Easy access and sloping beach desirable.
Angling/wading	As above	As above	As above	As above	As above, and/or fish habitat requirements.
Swimming	W 5.0 D 0.8 V -	W - D - V 1.0	W >10.0 D 1.5 V <0.3	As for paddling/wading.	As for paddling/wading. Length of channel usable >50 m. For diving from bank, D≧2.0 m.
Tubing/drift diving	W 5.0 D 0.3 V -	W - D - V -	W 20.0 D 0.8-1.5 V 1.0-2.0	As for paddling/wading. For "white water" form of sport, as for rafting/canoeing.	No hazards-overhanging/submerged trees, etc. Bacteriological and toxicant water quality standards met. Bottom visible. Water temperature 10-25 °c Access at top and bottom of reach to be travelled. Class II or III on International Scale. (I or II for drift diving). Obstacles can be portaged. Slots between rocks >1.0 m.
White water rafting/canoeing	W 7.5 D 0.2 V -	W - D - V 4.5	W >20.0 D 0.8-1.5 V 1.0-3.0	Presence of large boulders and bedrock outcrops to provide interest. Sediment on riffles of gravel size and not angular to minimise wear and tear.	As for tubing/drift diving except, Class II to IV on International Scale. Slots between rocks >2 m.
Tramping* (riverbed routes)	W - D - V -	W - D 1.2 V 1.8	W - D - V -	Gravel bed desirable for easy travel. Algal or silt coating undesirable. Stable boulders, rock outcrops and small waterfalls desirable for interesting travel.	DxV product less than 1.0 on skewed gravel shoals for easy crossing, or footbridges available. River does not impinge on bluffs, to minimise need for river crossings. Floodplain or terrace surfaces present for easy travel. Water temperature >10 °c. Bottom visible.

Angling (bank)	W - D - V -	W - D overbank V -	W, D, V as for fish habitat preferences	As for fish habitat preferences. No snags on stream bed.	As for fish habitat preferences, and: Easy access to and along bank. Stable (non-caving) bank. Vegetation-free for 5m back.
Angling (boat)	W 7.5 D 0.3 V -	W - D - V 3.0	as for fish habitat preferences, and W >7.5 D 0.6-1.5 V <1.5	As for angling (bank)	As for fish habitat preferences, and/or As for boating (non-powered).
Boating (non-powered)/rowing/flat water canoeing	W 7.5 (20.0 for rowing) D 0.5 V -	W - D - V 1.5	W >20.0 D 0.6-1.5 V <0.5	Sand bed preferable. No snags on stream bed.	No snags in stream. Easy access to river. No hazards-weirs, etc.
Sailing	W 30.0 D 0.8 V -	W - D - V 0.5	W >60.0 D ~1.5 V ~0.0	As for boating (non-powered).	As for boating (non-powered).
Flat water power-boating (low power)	W 7.5 D 0.6 V -	W - D - V 3.0	W >30.0 D ~1.5 V <1.5	As for boating (non-powered).	As for boating (non-powered).
Flat water power-boating (high power)/waterskiing	W 30.0 D 1.5 V -	W - D - V 4.5	W >90 D ~3.0 V <1.5	As for boating (non-powered).	As for boating (non-powered).
Jetboating	W 5.0 D 0.1 V -	W - D - V 4.5	W >5.0 D >0.6 V <4.5	As for white water rafting.	Easy access to river. Minimum depth over riffles >0.2 m. No hazards-weirs, submerged piles, overhanging trees, etc. Bottom visible.
Camping (for water supply and washing/bathing)	W 0.5 D 0.1 V -	W - D - V -	W - D - V -	As for paddling/wading.	As for paddling/wading.

* Width, depth and velocity criteria for tramping in river gorges must be relaxed, when swimming across pools is expedient. The extreme form of this activity is pack floating, for which sport hydraulic criteria can hardly be set.

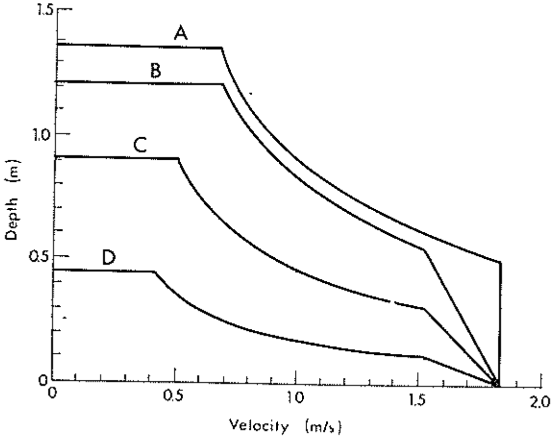

FIG. 3—Depth and velocity limits for safe wading (redrawn from Cortell and Associates, 1977, figure 10). A. Tall, heavy adults. B. Average adults to teenagers. C. Sub-teen children. D. Pre-school children.

draught of a planing jetboat provide good estimates of the minimum water surface width and depth required for those activities, respectively.

Table 4 lists the minimum, maximum and preferred depths, velocities and widths for the contact and non-contact uses listed in Table 3. These are based on criteria proposed by Cortell and Associates (1977), modified by the writer on the basis of his own experience of New Zealand conditions and after consultation with appropriately experienced colleagues. Preferred conditions for substrate and other factors have also been tabulated. Just as there are habitat suitability criteria for each life stage of fish, criteria for human instream uses are also dependent upon age-group, and on the physical characteristics of the individual. This is particularly the case for contact uses, where size and strength are needed to resist the force of flowing water. Although there is a well-known rule of thumb that the depth-velocity product (measured in metres) should not exceed 1.0 for safe wading, this varies with age and body weight; Figure 3 presents more detailed depth-velocity limits for different age and size groups.

Many of the criteria listed in Table 4 can be only approximate, because of the adaptability and diversity of individuals. This applies particularly to the white water sports of rafting, canoeing and jetboating; differences in skill and nerve are great, so that a grade III river on the International Scale ("medium difficulty. Waves are numerous, high and irregular. Passages are clear but narrow and require expertise in manoeuvering") would be terrifying for some people and merely 'interesting" (a common canoeist's term) for others.

In addition to the factors included in Table 4, the suitability of a given watercourse for most, if not all, of the contact and non-contact uses is partly controlled by its aesthetic character, which is itself controlled by a variety of factors (Table 1). Aesthetic character is not clearly related to conditions of flow, water depth or velocity, etc; it may be high in a watercourse that is only a trickle (over boulders in a mountain stream) or a torrent (through the Kawarau River Gorge at Nevis Bluff). Chubb and Baumann (1977) proposed a method for quantifying the factors that describe river character and combined them into an index of river recreation suitability, but their method has been only partially tested. There have been numerous other attempts to quantify scenic beauty, and some effort to relate the preferences of members of the public to measurable attributes of the landscape. The most promising appears to be the "scenic beauty estimation" procedure introduced by Daniel and Boster (1976), which has as yet been applied only to forest landscapes and road corridors. To date, assessment of the aesthetic character and suitability of New Zealand rivers has been at a level of subjective judgement only (Wild and Scenic Rivers Steering Committee, 1982; Eggar and Eggar, 1981), or has used ordinal scale estimation of only a few factors (Eggar et al, 1979), procedures which receive little support in the literature on landscape evaluation (e.g., Dearden, 1980). The writer is presently extending the work of Daniel and Boster to New Zealand riverscapes, in order to improve our understanding of public preference of different river environments.

Although there may be some optimal condition for each human instream use, reference to which would allow an estimate of the potential suitability of a given reach of river for this use, actual usage is heavily dependent upon factors other than those listed in Table 4. Just as fish may be found in large numbers in sub-optimal habitat because that is all that is available, humans use for recreation sections of a river which apparently seem totally unsuitable, or at best unattractive. For example, the lower Ashley River, a wide braided river which virtually dries up in summer, is heavily used by the residents of Christchurch, because it is close to the city, rather than because it is ideal for picnicing, camping, paddling, swimming, etc. At the same time, other rivers which appear ideally suited to a given use—the upper Grey River for white-water canoeing for instance—are little used because of remoteness from a population centre.

INSTREAM USES AND DISCHARGE

Since most water resource development projects in New Zealand have as their main impact a change in flow regime, establishment of relationships between instream uses and water discharge is an obvious need. It has for many years been established that aspects of river morphology such as water surface width, mean depth, and mean velocity, are controlled by discharge (Leopold et al, 1964), and more recent work has demonstrated that aspects of more significance for instream uses—minimum passage depths over riffles, the joint frequency distributions of depth and velocity, the extent of riffle, pool and run subenvironments—can also be related to discharge (Jowett, 1982; Mosley, 1982b; Mosley 1983a; Stalnaker and Arnette, 1976).

On the other hand, many of the factors listed in Table 1—particularly those in sections A, B, C and E—are unlikely to change in response to a change in flow regime. Even those factors in section D which relate specifically to water character may change only to a minor extent. For example, water chemistry and bacteriological and physical water quality may be related primarily to catchment condition, and water temperature changes to only a limited extent with changing discharge (Jowett and Mosley, 1983). In particular, the aesthetic character of a riverscape is probably controlled more by the surrounding terrain and vegetation than by the river channel or the water flowing therein (cf. Eggar et al, 1979).

Discharge-related changes in the river environment may occur in two main ways. Firstly, a major change in hydrological regime, such as elimination of flood peaks, may cause the basic structure of the river to change. Dolan et al (1974), Graf (1980) and Howard and Dolan (1981) have described how the rapids, bars and beaches of the Colorado River in the Grand Canyon have changed their morphology in response to upstream impoundment; Petts (1979) has reviewed a variety of structural channel responses to regime change; and Jowett (1980) has predicted the effect on the channel of the upper Clutha River of diversion of much of the main river inflow while side streams continue to introduce sediment to the channel. Secondly, a regime change, caused by abstraction of a constant small discharge during the irrigation season for example, may not affect the floods which are responsible for the basic structure of the river. Instead, the new pattern of flows will be distributed in the pre-existing channel so that such factors as depths, velocities, and areas of water in riffles and pools will differ from those that would be associated with the natural regime (Curtis, 1959; Mosley, 1982c).

Rigorous analysis of the first type of channel change—structural change—is not possible, although an experienced engineer may be able to make a reasonable qualitative assessment of likely responses (Co-operative Instream Flow Group, 1982).

In principle, the second type of change—adjustment of modified flows to a pre-existing bed—is subject to analysis, and has been successfully dealt with by many researchers using the incremental method of instream flow analysis. However, the emphasis has been very much upon water depth and velocity: other discharge-related factors like the amount of riparian and instream cover, the extent of pools suitable for swimming, the number and severity of rapids, and passage depths at potential limiting points on riffles have barely been considered (Mosley, 1982b; 1983a; 1983b).

Discussions of instream flow evaluation have also paid little attention to flood flows, because the most serious impact of flow manipulation occurs at low flows, and because much of the American work has reference to streams with stable hydrological regimes. However, recent work by G. J. Glova (pers. comm., 1982) on the Ashley, Hurunui and Rakaia Rivers tends to suggest that flood flows may limit fish standing stocks, although the precise mechanism is not necessarily well defined. The Ashley, which is little affected by floods for much of the year, has the highest biomass per unit area, while the Rakaia, which experiences large floods, particularly during the spring-autumn period, has very much the lowest, and it is inferred that disturbance of the stream bed gravels by floods in the Rakaia has significant adverse effects on fish habitats and limits food production and hence, indirectly, fish populations. Additionally, the floods have a direct impact on fish survival by causing body damage or involuntary downstream displacement of fish to the sea. This may have a particularly severe impact on stock of anadromous salmonids, because fry that are carried to sea prematurely by a flood have a very much lower rate of survival than those that are able to move slowly down-river, feeding and growing in size along the way; adult returns in succeeding years may consequently be severely reduced.

Flood flows have an impact on wildlife too. For example, many birds nest on gravel bars in the braided rivers of the South Island, and are clearly at the mercy of floods which might inundate and destroy the nestting sites. It has been suggested that an impact of reducing flows in such braided rivers will be to force birds like the wrybill plover to nest on low bars near to the remaining side channels, rather than at sites just above the level of medium freshes; this will increase the frequency of nest destruction (O'Donnell and Moore, 1983). On the other hand, a larger flood will clear the river bed of vegetation which may harbour stoats and cats, and so decrease predation on both young and adult birds and increase the area available for nest sites. (Although lightly vegetated gravel bars are also used by chicks to seek cover from other predators like black-backed gulls (D Hadden, pers. comm., (1983)).

Human instream uses, too, are not immune from the effects of flood flows. The possible hazards for recreationists of rapid increases in discharge in the residual upper Clutha River are discussed by Jowett (1980) in his study of the Luggate-Queensberry power development, and few years go by without trampers being drowned while attempting to cross rivers in flood. More recently, several rafting and canoeing parties have run into difficulties because of rapidly rising rivers, particularly on the Tongariro and Motu Rivers. No doubt many other parties experience dangers like this, but because no injury or death occurs, their experiences never make the headlines.

In an unpublished report on recreation in the Motu River, I have briefly considered the hazards that floods represent to rafters. Professional rafters consider a flow of 350 m^3/s at the mouth to be the upper limit for safe navigation of the Motu River (B. Blewett, pers. comm., 1982). Discharge may increase, during the rising stages of a flood with a two-yearly recurrence interval, by up to 780 m^3/s in only two hours at the river mouth (mean flow of 92.5 m^3/s and a "normal" summertime low flow of around 25 m^3/s) (J. Riddell, pers. comm., 1982). At the head of the upper gorge, where the mean flow is 15 m^3/s and the "normal" summertime flow is barely sufficient to float a raft, the river flow may increase by up to 63 m^3/s in two hours. During the period 1960-81, the river experienced eight floods with discharges more than 50 times greater than the preceding low flow, and more than 50 with discharges 20 times greater. The mean interval between freshes and floods was 9.6 days over this period, although periods of up to 46 days were experienced without a significant flood. On average, there are 11.6 floods each year which exceed 350 m^3/s at the mouth, although during the October-April recreation season the average is only 4.2 per year. There is, therefore, a relatively low chance of an individual rafting party, taking 3-4 days to traverse the Motu River, experiencing a hazardous flood, but with many thousands of people now rafting the Motu, it is a near certainty that each year several parties will do so. In the gorge sections of the river, there are few places to take refuge, and the dangers inherent in pressing on to find a refuge below the gorge have been shown to be great.

DISCUSSION

The objective of any study of the relationship between streamflow and instream uses is likely to be the specification of some flow or range of flows which (in order of preference) optimise, permit, or do not destroy the instream uses. There is a wide variety of methods of specifying instream flow needs, ranging from methods which are little better than educated guesses based on minimal data, such as the "Montana" method of Tennant (1976) recommended for interim use in New Zealand by Fraser (1978), to the incremental method (Stalnaker and Arnette, 1976). Fraser (1978) considered that "any expedient or quick measure not founded on known requirements of the aquatic organisms or other instream uses involved will fail to produce results and, therefore, will stimulate rather than resolve controversy". The Montana method is an example of such an expedient method which simply defines certain percentiles of the mean monthly discharge as unacceptable (<29%), poor to fair (30-74%), acceptable (75-99%) or optimum (100%) (Fraser, 1978). The inadequacies of this approach are suggested by the water management plan for the Ashburton River by the South Canterbury Catchment Board (Scarf, 1983), which selects the 30% mean monthly flow for each month as the intended residual flow, with no effort apparently being made to ascertain whether the flows that result are actually sufficient for the instream uses found in that river system.

The purpose of referencing residual instream flows to the mean monthly flow, rather than to the mean annual flow, is to follow the natural flow regime more closely. However, Figure 4 demonstrates that in a typical New Zealand rain-fed river like the Ahuriri this purpose is not achieved. In most months, flows naturally fall below the mean monthly flow, whereas the 30% mean monthly flow is usually only about half of the naturally occurring base flow. A procedure appropriate to stable snowfed rivers in the continental United States may be of little relevance to New Zealand conditions, and reference to the instream uses that occur in the river, to their requirements, and to their timing through the year is necessary to assess whether the "optimum" or "minimum acceptable" flows specified by the Montana method are realistic or not. Orth and Maughan (1982, p439) concluded that this method should be restricted to "reconnaissance-

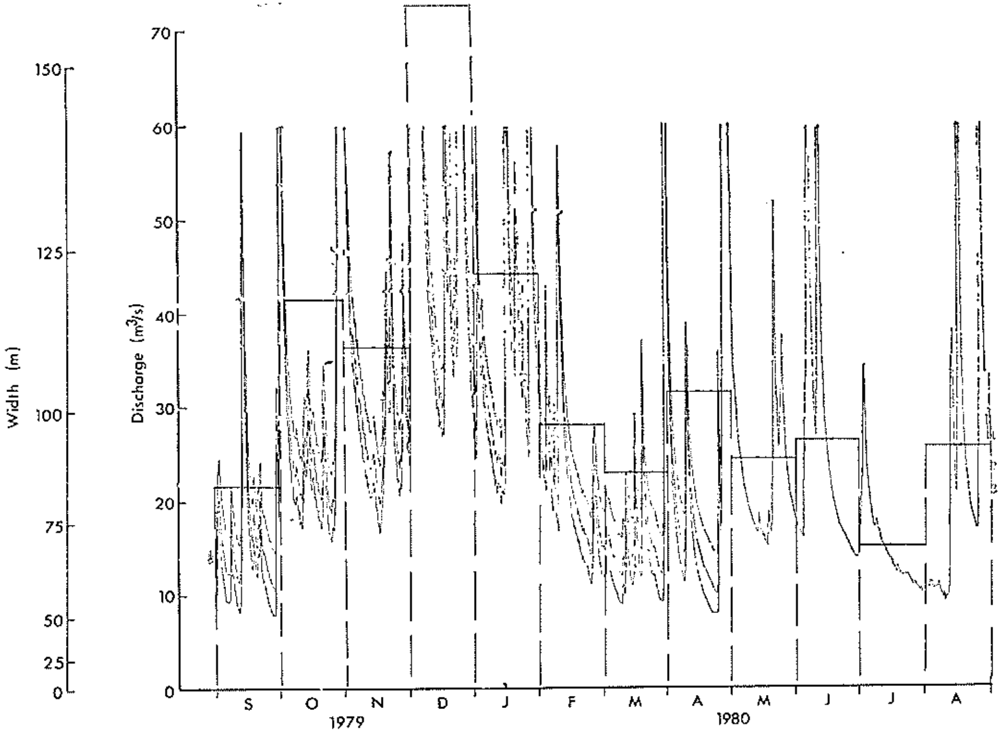

FIG. 4—Flow hydrograph for the Ahuriri River for 1979-80. The top line shows the natural hydrograph, and the lower two show the hydrographs that would have resulted with 4 and 7 m^3/s abstractions (down to a limit of 8 m^3/s) during the irrigation season. Flood peaks are truncated at 60 m^3/s. Water surface width W is related to discharge Q by the equation $W = 18.5Q^{0.5}$, and the width axis is scaled so that is can be read directly from the hydrographs. Horizontal bars show monthly mean flows.

level planning", because it does not provide information on the effects of altered flows on habitat.

The incremental approach, on the other hand, allows assessment of the adequacy of proposed "minimum acceptable" flows, provided that the requirements of different instream uses have been established and agreed upon. There are a number of steps involved in applying the incremental approach to instream flow evaluation. Firstly, it is necessary to identify the instream uses which are actually or potentially present in a given river. Secondly, the needs for those instream uses—requirements for depth, velocity and so on—must be specified. Thirdly, the relationship, if any, between these requirements and streamflow must be established; e.g. when during the year are the requirements critical, and what are the effects of, and tolerance to, flow extremes (both low and high flows). Many of the factors listed in Table 1 may be eliminated from consideration, because they are not affected by flow regime. The fourth step may take several different forms, depending on circumstances: (1) the impacts of only one specific proposal may be analysed; (2) the flow regime that provides the optimum or minimum acceptable conditions for each instream use may be identified; or, (3) the impacts of a number of different management possibilities may be compared.

As an example of (1), data were collected at six flows of the Ahuriri River and used to establish an empirical relationship between discharge and total water surface area per metre length of channel (Mosley, 1983b). The flow record was then used to show the variation with time of the extent of aquatic habitat under the natural flow regime and with 7 m^3/s abstracted from the river during the irrigation season (Figure 4). Jowett's (1982) identification of optimum flows for fish in the Clutha River exemplifies form (2), and the Co-operative Instream Flow Group (1982) manual describes form (3) in some detail. Although these examples all relate specifically to fish populations, the procedures may, in principle, be used to estimate the variation with time, under natural or manipulated flow conditions, of the area available for any instream use for which the physical requirements can be specified and which are related to discharge.

The final step will depend to some extent on step four, but will probably include an assessment of the impact of a specific development proposal, a statement of optimum and/or minimum acceptable conditions, and a recommendation of a compromise arrangement.

There have recently been several practical applications of the incremental method. The writer has used this approach in submissions to hearings on National Water Conservation Order applications for the Ahuriri and Rakaia Rivers, and Jowett (1982) used the method to propose flow regimes in the Clutha and Tekapo Rivers, and also in the Fraser River, Otago (I. G. Jowett, 1983, *Fraser River hydrology and fish habitat*, unpublished report of Power Division, Ministry of Works and Development, Wellington). Orth and Maughan (1981) successfully used the method to make flow recommendations for the Washita River, Oklahoma, a very different environment from that in which the method was developed. Despite some severe criticism (Mathur et al, 1983), Orth and Maughan

(1983) affirmed that "it is a useful tool, although not a panacea, for managing streams with altered flow regimes". Other recent applications of the incremental method in North America are by Daubert and Young (1981) and Prewitt (1981).

Nevertheless, with present knowledge, rigorous adherence to the incremental approach may be difficult. Specification of the needs of each instream use to an acceptable level of confidence has not yet been achieved, nor have the relationships between many limiting factors and discharge been established. The incremental method deals with the area potentially usable for a given instream use, but actual usage may be far less, because other factors are limiting. On the other hand, habitat which is markedly sub-optimal may be intensely used, simply because nothing better is available. However, the incremental approach provides the best available *framework* for assessing instream flow needs, and it is perhaps the only way to put instream uses on a similar footing to the out-of-stream and other developmental uses. We may never be able entirely to avoid qualitative discussion, particularly where aesthetic appreciation or the intrinsic value of an endangered bird or fish is a factor to be considered, but the imperfections of the approach should not prevent water resource managers from "thinking incrementally", and abandoning expedient methods not based on known requirements of recognised instream uses. Even if rigorous application of incremental analysis is not possible, recognition of the actual and potential instream uses of a given river (Table 3), the factors that control them (Table 1), and whether and to what extent these factors might change in response to a proposed water resource development (eg, Figure 4), will have great value by ensuring that any final decision is made on the basis of maximum information.

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