APPLICATION OF ENVIRONMENTAL WEIGHTING SYSTEM FOR QUANTIFICATION OF MINIMUM FLOW IN WHANGANUI RIVER

by

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ABSTRACT

Environmental weighting system is a technique for measuring the environmental sensitivity of reduced river flows. A points system with seven environmental categories was used to arrive at scores indicative of a location's sensitivity and commensurate with the maximum permissible volume of abstraction. The same score is used to estimate the environmentally prescribed flow or minimum flow.

This study deals with the applicability of an environmental weighting system to the quantification of a prescribed minimum flow using the Whanganui River as a case study. The minimum flows in Whanganui River have been subject to considerable debate since the construction of a series of intakes on several headwater streams in the early seventies for the purpose of increasing water volumes for the ECNZ power generation at Tokaanu and nine hydroelectric power plant stations on the Waikato River. In 1977, the NZ Canoeing Association requested that a minimum flow be fixed which in 1983, culminated in a recommendation of 22 $m^{-3}s^{-1}$ minimum flow at Te Maire in December and January. A review of these flows was carried out in 1987 and the minimum flow was increased to 29 $m^{-3}s^{-1}$ from December to May following a Planning Tribunal Hearing in 1989-90.

The results showed that one of the flow allocation methods was very restrictive to ECNZ operations while strongly favouring the requirements of fisheries and other instream uses. Two other options were examined under the demand conditions in the Whanganui River. They provided for an environmentally prescribed flow which was similar to that proposed by the Planning Tribunal Determination (1990), but each had slightly different abstraction proposals to meet suggested flows.

Under New Zealand conditions the technique was found to be useful in identifying the environmental constraints of competing demands for river water. However, in an already regulated flow regime the outcomes were hypothetical but still meaningful.

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CHAPTER 1

INTRODUCTION

The planning of water resources today now involves a miscellany of professional disciplines giving an indication of its growing complexity. What was yesterday's simple resource exploitation process has now evolved into an allocation system recognizing all legitimate and rightful use of the limited bounty from nature.

Perhaps what is changing attitudes on resource use is partly the increasing awareness that what was done before is mostly responsible for the decreasing quality of the environment today. Aquatic ecosystems are one of those where development for domestic, industrial, irrigation and hydropower development programs combined to put severe burdens on the common sources of water.

The situation on the Whanganui River is a typical case. The Tongariro Power Development (TPD) began diversions from the upper Whanganui catchment to the Waikato River in 1971. In 1977, the New Zealand Canoeing Association, concerned with the reduction of the flow in the river, requested the then National Water and Soil Conservation Authority to fix a minimum flow. After a series of public consultations, the body recommended in 1983 that the Whakapapa River should have a required base flow of 0.6 m^3s^{-1} measured from the Whakapapa footbridge, and a minimum flow at Te Maire of 22 m^3s^{-1} from 1 December to 14 February and at Easter with 16 m^3s^{-1} at all other times.

However in 1987, the National Authority again requested that the Rangitikei/Wanganui Regional Water Board review the flow recommendations. A Special Tribunal was set to hear public submissions and its recommendations were confirmed by the Board.

recommendations. A Special Tribunal was set to hear public submissions and its recommendations were confirmed by the Board. This decision was appealed to the Planning Tribunal, and after protracted hearing, a determination was made and subsequently upheld after appeal to the High Court. After the Planning Tribunal Hearing, the decision was made to set the minimum flow at 29 m^3s^{-1} from December to May at Te Maire, along with the increases in the compensation flow at the Whakapapa from 0.6 to $3m^3s^{-1}$.

The most important elements of river hydrology which experience change because of water abstraction have been identified by Heerdegen (1988) as follows:

1) *Reduced mean flows* - The 1983 regime registered the mean flow at Whakapapa River at 2.3 m^3s^{-1} and at Te Maire at 68.5 m^3s^{-1}. These figures sharply contrasts with pre-diversion levels of 15.1 cumecs and 89.1 cumecs under natural conditions.
2) *Reduced minimum flows* - A minimum flow of 0.6 cumecs was designated with the imposition of the 1983 regime. Compare this with the natural occurring minimum flow of 5.8 cumecs and the natural average annual low flow of 8.5 cumecs.
3) *Absence of seasonal variation in the base flow* - The setting of a minimum flow resulted in less seasonal variation although higher winter flows still occur. Inflows from tributary streams which are not controlled have the effect that the flows at points downstream are more affected by seasonal variations.
4) *Negative surges* - These occur when flow goes down below the base flow of 0.6 cumecs causing the possibility of trout being stranded.

5) *Periodic releases of water into the river* - This possibly results in artificially induced flow causing disruption to the normal stream behaviour.

6) *Reduced number of peak flows* - Because freshes are intercepted by the diversion structure, floods become fewer. (The Tribunal however did not consider this effect as deleterious in terms of reducing the river's capacity to transport sediment loads).

7) *Reduced peak flows* - The same effect is attributable to this change as the above.

8) *Truncated recessions* - Faster recession and increase in flow lessens the capacity of the river to carry fine sediments further downstream of the river. This is caused by diversion through tunnels which have limited capacity.

9) *High natural flow* - This causes the river to lose some of the biota and could cause scouring and armouring of the river bed.

It is a view held by the Planning Tribunal that the purpose of fixing a minimum flow is to minimize the harmful effects of water diversion from the river attributable to the above factors. It is not clear, however, as to what extent these effects have to be minimized to consider the resulting environmental damage acceptable.

In 1988, there were 37 water rights in effect allowing discharge of waste into the river or its tributaries. Fourteen of these have outfalls upstream of the junction of the Ongarue and Whanganui Rivers at Taumaronui. Additional rights are being sought by Taumaronui and Whanganui City itself, subject to their compliance to water quality standards.

The Planning Tribunal, however, do not see this as one of the variables in the setting of a minimum flow. Their assessment concludes that "dilution alone cannot possibly change the situation as high bacterial count is attributable to the sewerage problem which requires many more times the water being diverted to significantly improve water quality".

One important determinant that must be considered is the value of the fishery in the river. Prior to diversion, evidence was compiled showing that trout, both brown and rainbow, were present and caught in the catchment as well as the native fish such as eel and lamprey which are an important dietary item of Maori. The decline of these species could not be definitely attributed by the Tribunal to abstractions alone as there are other factors such as forest cover, diminution in the number of Maori along the banks and other changes which are known to cause the decrease. These changes include the removal of riparian vegetation which increases sediment load, and the loss of natural habitats for rest and feeding which reduces the suitability of the river as a native fishery.

Reduction in the trout fishery is attributed to the following (DOC, 1988):

1. intake structure prevents spawning trout migration to headwaters;
2. trout are carried along the diversion tunnel to lake Otamangakau, making their return to the river impossible;
3. loss of habitat due to lower water levels; and
4. reduced invertebrate food.

Aside from the numerous considerations mentioned above, other factors that must be dealt with may include the quantity of periphytons for the invertebrate food source, water temperature, sediment transport and disposition and wildlife.

The purpose of this study then, is to investigate the flow requirements relative to the river environment so as to improve the understanding of how river flows affect a wide range of activities and the natural life on which they depend on. The starting point of the study is an existing EWS framework already being used in North Yorkshire, England for managing abstractions which are subsequently used in agriculture (Drake, 1987). This framework is modified to suit local conditions and involves consultation with selected experts from the Department of Conservation. Specifically the study will attempt to achieve the following objectives:

1. develop an environmental weighting system (EWS) for the Whanganui River which can be used for classifying different locations within the catchment;
2. test the applicability of the EWS as a generalized approach to management of river abstractions;
3. set suggested minimum flows using EWS and analyze the results compared to other methodologies used in Whanganui River; and
4. explore other possible variations with the use of the EWS for determination of minimum flow.

CHAPTER II

REVIEW OF LITERATURE

2.1 INTRODUCTION

The term "minimum flow" is usually associated with other technical expressions such as minimum desirable discharge and minimum acceptable discharge. By definition, however, it has always been accepted that desirable discharge must satisfy both the minimum acceptable discharge and other constraints comprising the demand side such as domestic water supply: irrigation, industrial use, removal of waste water, navigation, hydro-electric power generation, recreation and water sports, water for landscaping, and many others.

Often, where there is no regulated abstraction, minimum flow has always been taken as a residual after stream discharge has been allocated to the different demand sectors. Such practice became unpopular and efforts have been taken to establish an accepted approach to determine stream discharges without incurring damage to the environment, particularly to the delicate riverine ecological balance.

Approaches from country to country, however, differ and the setting of a single minimum flow is but just one way of keeping the rivers flowing. Most prominent in the literature are techniques developed in Europe and America - particularly those from Britain and Czechoslovakia and the United States.

2.2 CZECHOSLOVAKIAN SYSTEM

Minimum acceptable discharge in Czechoslovakia is the remaining flow after priority has been given to all other water needs (Volker 1988). While its quantity must be sufficient to sustain normal biological life in the river and its close environment, it is not a priority over common water use, defined by the Czechoslovak Water Act as water use for which no license is required from the water authorities. This includes: bathing, washing, extraction of water without mechanical devices.

2.2.1 Setting of Minimum Acceptable Discharge

Values of minimum acceptable discharge are evaluated according to the following principles.

2.2.1.1 For streams influenced by reservoirs

The minimum flow released from the reservoir is that which was exceeded 355 days per year prior to the erection of the dam (Q_{355}).

2.2.1.2 For Downstream of the reservoirs

In the reaches downstream of the reservoirs the value of the minimum acceptable discharge is gradually reduced in the direction of the point where the influence of the reservoir on the flow is no longer as certain. Downstream of this point the value of the minimum acceptable discharge is determined according to the principles established for other streams.

2.2.1.3 Other streams

Streams that remain unaffected by diversion or any form of intervention, the minimum acceptable discharge is set at half the sum of the 98 percent minimum monthly flow and the 100-year minimum daily flow. The flow must not be smaller than Q_{364} and need not exceed Q_{355}

The Q_{355} and Q_{364} day exceedance values have been used by the Czech water authorities as the basis for granting water licences and thus becoming determinants of minimum acceptable flow. The practice of establishing the benchmarks came as a result of the Czech authority's observations and experience and the flows have a close relationship with the findings of hydrobiological surveys it conducted. Studies seem to indicate that the distribution of the different species of water fauna is to a great extent dependent upon flows in the *355* to *364* days exceedance range.

It should be noted above that the 100-year minimum flow has been used to establish flows on unaffected streams (classified as other streams) which may be expected to yield very low acceptable flows - and thus may have some serious flaws if used. Practitioners, however, consider the 100-year minimum flow only as a control value and that the 98 percent minimum monthly flow is actually accepted as the 'characteristic flow' and is used to state water balance and minimum acceptable discharge in the country.

2.2.1.4 For Lower Water Classes

For lower classes of water however, such as class IV, (the lowest in their standards) the value of the minimum acceptable discharge is increased to the value of flow exceeded *355* days of the year.

There are also situations when the minimum amount of water in the streams are governed by other external factors such as international borders when the minimum acceptable discharge is fixed by agreement. In other cases such as when there is only very small flow or flows which cannot be measured accurately, the regulation of the minimum flow does not apply.

Other constraints, such as groundwater levels and use of water for landscaping/amenity use, call for control of water rather than discharge. Construction of wells can often satisfy the need.

2.2.2 Demand Grouping

In summary, many water demands are divided into two groups: use of the water course itself and water extracted from the river for use elsewhere:

Group I : Use of Watercourse

- Navigation
- Recreation and water sports
- Disposal of waste water
- Fish and poultry farming
- Minimum acceptable discharge
- Hydropower generation

Group II : Abstraction:

- Drinking water supply
- Industrial water
- Irrigation water
- Stock Water
- Water for other purposes

It is evident that the use of watercourse itself is being given priority over abstractive utility. Users under Group II understandably have to adjust their requirements based on what remains of the flow mindful that surplus water supply may or may not be available. Observe that minimum acceptable discharge is taken as a single value of flow which theoretically must remain in the river regardless of the existing use for the watercourse.

In addition, groundwater abstraction is already taken into consideration when evaluating regional balances of water resources. While there is an overestimation of consumptive use at times, the complexity of hydrogeological conditions in the country justifies allowing planners to err on the conservative side.

2.3 EUROPEAN COMMUNITY MEMBER COUNTRY APPROACHES

2.3.1 Initial Approach

As a step towards having a common approach towards determination of minimum flow a group of experts collected and evaluated data from EC member countries (Volker, 1988). Simplified yet functional general recommendations were made as a result of the study:

1. Small mountain rivers - 0.2 of the average minimum discharge; for shorter periods even smaller values and in exceptional cases zero value.
2. Larger rivers with fairly constant flow - 0.5 of the average minimum discharge is used as the value of the minimum flow.
3. Other cases - 0.8 to 1.0 of the average minimum discharge.

This procedure of determining the minimum flow however remains subject to the prioritization set by policies of ECE-member countries. Priority is almost always toward utilization with high economic value.

2.3.2 Revised Approach

Sometime in 1974, a new approach was developed by another group of ECE scientists by bringing more attention to the water balance and water needs. It was generally considered then that the minimum acceptable flow for each stream had to satisfy all quantitative and qualitative constraints and requirements.

This meant that the minimum acceptable flow must:

1. Guarantee a flow of water sufficient to prevent stagnation of water, formation of mire, and centres of infection dangerous to public health;
2. Insure sufficient dilution of dispersed pollution resulting from unorganized discharges /riparian dwellings or pollution or other media;
3. Maintain the biological balance of the natural aquatic environment;
4. Ensure the necessary flows for unorganized water supplies including watering of livestock;
5. Prevent sedimentation and other flow phenomena which could modify the morphology of the stream bed;
6. Preserve natural beauty - spots/waterfalls, tourist site etc.

The same group of scientists also recognized that determination of minimum acceptable flow is a complex problem whose solution depends on the assessment of local phenomena. They recommended that this can only be ideally resolved at town and country planning level such that a universal approach toward defining acceptable flow may not be realistic.

In 1981 a group of Russian scientists came to a similar conclusion (Volker, 1988). Their report recommended that minimum flow should be sufficient to avoid formation of clay and mud zones in the stream bed. Other CMEA member countries also used various measures to determine minimum acceptable discharge, namely that - *minimum acceptable discharge should maintain good hygienic conditions, keep the water at a certain level and satisfy the water supply of isolated riparian dwellings.*

2.4 METHODS USED IN THE UNITED STATES

2.4.1 Instream Flow Quantification Methods

On the other side of the Atlantic, the United States Bureau of Land Management has developed a different approach to the technique of instream flow quantification. Its involvement in adjudications concerning federal reserved water rights to maintain the values of rivers led to development of various techniques which are both technically and legally tenable.

Instream flow requirements were determined by several methods to quantify the claims made by the US government for federal water reserved rights under the Wild and Scenic Rivers Act of 1968. The scenic (aesthetic), recreational and fish and wildlife values are primary reasons for which instream flows are claimed. Water quality is, however, so strongly related to these values that instream flow for waste transport and protection of water quality were also included in those claims.

Information/data requirements for instream flow estimation includes:

1. quantity and timing of available flow;
2. factors affecting quantity (impoundments, diversions, return flows, discharges, groundwater inflows);
3. existing water quality;
4. watershed and channel conditions;
5. factors influencing instream water quality (return-flows, waste-water discharges, inflow quality); and
6. other pertinent data on instream water uses (fisheries, recreation, navigation, aesthetics, etc).

The initial step in determining flow requirements involves identification of the purposes requiring a specified flow. Identification must be based on the statutory purposes set out in the legislation creating the reservation, i.e. the Wild and Scenic Rivers Act. To illustrate, one particular river may have values for fish and wildlife, scenery and recreation which may have to be protected, thus, validating the purpose for which the minimum flow must be set. Other reasons for minimum flow may include waste transport and maintenance of water quality should upstream waste discharge/s occur - the latter because of the relationship of water quality to fish and wildlife, aesthetic and recreational values.

2.4.1.1 Instream Flow Incremental Methodology

First attempts to quantify instream flows for fisheries habitat involved using the single transect Manning equation technique (BLM, 1979). Under the trial proceedings, too many weaknesses were found in the assumptions which could not stand close scrutiny in the courtroom. This led to the introduction of yet another technique called the

Instream Flow Incremental Methodology (IFIM) which was introduced by the US Fish and Wildlife Service.

The IFIM (sometimes referred to as the multiple transect method) predicts the amount of potential fish habitat available for each life stage of the species as a function of flow. It is based on the premise that the suitability of a species' habitat can be prescribed by measuring selected physical variables in the stream. This is done by first characterising the stream hydraulically and biologically through field investigations, and then applying various applicable computer programs to analyze the data.

Data analysis is usually carried out through a computer program called Physical Habitat Simulation (PHABSIM) including several other sub-programs (WSP, IFG4 and HABTAT) (Garn, 1986). The first two sub-programs are hydraulic simulations of which only one is needed. HABTAT then combines the hydraulic data with biological criteria to predict potential available habitat (expressed in weighted usable area, WUA) in the given reach for the life stages of the target species at various flows. WUA represents the portion of the area that is optimum habitat for the selected species and life stages. A curve relating WUA with flow may be developed for each life stage of target species.

2.4.1.2 Montana Method

Another method developed to determine instream flow to support spawning is the Montana Method (Tennant, 1972;1976). Users may find the approach of this office method quite simple and easy to apply for qualitatively evaluating instream flows for fish and wildlife. Tennant established eight flow classifications by analysing a series of field measurements and observations. Each is assigned a percentage or percentage range of the average annual flow (QAA). Seven of the classifications characterize habitat quality for fish and wildlife and the eighth provides for a flushing flow. *The percentage of flow for habitat quality ranges from less than 10 percent (severe degradation) to 60 to 100 percent (optimum range). The flushing flow classification equals 200 percent of QAA.*

The Montana Method requires that a QAA be calculated from an existing or synthesized data. A flow recommendation is established by selecting the desired classification and multiplying the QAA by the corresponding percentage or percentage range.

The method is simple to apply, and so, the potential for inadvertent misuse because it does not account for specific species/life phase habitat requirements. Also QAA alone does not describe short or long-term changes in flow rates, seasonal variability or channel geometry. Accordingly, Tennant cautions that site evaluations should be conducted to determine if the percentages of QAA assigned to classification require modification. These adjustments are not usually being applied once conditions be found typical of streams in the country.

2.4.1.3 Maximum Spawning Area Flow

Office methods seem to be preferred in the United States. Similarly designed for users with preference for such an approach are the Maximum Spawning Area Flow (Method A) and Maximum Spawning Area Flow (Method B), both were developed by Osborn (1982). Their limitation is on the applicability aspect of the techniques since only one flow condition can be analysed leaving other flow possibilities unexamined.

2.4.1.3.1 Method A

Method A is a simple approach which attempts to estimate the flow which should give the best spawning habitat characteristics in terms of quality and quantity. The maximum spawning are (QMSA) is derived from velocity and depth criteria as determined from existing information on basin and streamflow characteristics.

2.4.1.3.2 Method B

A variation of the approach, known as Method B, provides for the estimation of maximum spawning area (MSA) as a function of bankful discharge and requires actual measurement of channel geometry. It is expressed as square feet per 100 linear feet of stream reach. Although the method estimates the maximum area available for spawning, it does not take account of the quality of habitat for spawning.

The premises of methods A and B are:

1. Streams flowing within comparable bed and bank materials exhibit consistent relationships among width, depth and velocity as functions of discharge; and
2. Basin characteristics are related to channel and flow characteristics that can be related to spawning preferences.

2.4.2 Instream Flow Quantification Methods - a Discussion

Instream flow analyses are based on the theory that changes in riverine habitat conditions can be estimated from a field or synthetic data base as demonstrated by the above methods.

Generally, the methods used in the US for instream flow quantification are comprised of three principal components.

1. Physical Projections - The collection and assessment of geomorphic and/or hydraulic data to forecast or summarize a range of hydraulic and related conditions (e.g. channel shape, water depth and velocity, channel width, wetted perimeter, substrate composition, fish cover and upwelling).
2. Fish Habitat Criteria Analysis - The determination of the behavioural responses of fish to channel morphology, or flow related variables (e.g. channel shape, water depth and velocity, substrate composition and upwelling).
3. Fish Habitat Projections - The combination of the first two components to project the availability (area) and/or quality of habitat for species/life phase under investigation within study sites as a function of flow.

Accordingly, instream flow evaluations are intended for use in those situations where the flow regime and channel structure are the major factors influencing riverine habitat conditions. It is also important that actual conditions are compatible with the underlying theories and assumptions of the above techniques. Water chemistry, temperature, light, and other variables known to influence habitat quality are assumed not to change significantly or limit the species/life phases under the study. It is always advisable to consider additional methodological approaches if it is determined that these variables would vary significantly with flow.

The validity of any analysis depends on how well the assumptions are met. The IFIM is based on the assumption that the physical model represents the range of physical conditions pertaining to the seasonal utilization of the stream reach by the species of interest. It is assumed that the fish criteria reflects the species/physical relationships regardless of the assumptions. An investigator should review basic hydrological characteristics for the study area as a standard for determining whether the hydrological component of instream flow analysis falls within the expected range of natural hydrological conditions. Biological criteria must also be representative of the species and system evaluated. Accordingly, these evaluations should be conducted on an interdisciplinary basis by both biologists and engineers (hydraulic).

It appears that each of the methods presented can be used independently to generate valid instream flow recommendations if calibrated to the hydrological and biological conditions of the site or area studied. The IFIM, unlike the other methods reviewed, allows for incremental evaluation of any flow within the calibration range of the hydraulic model developed for the site. The Montana, QMSA and MSA methods provide limited evaluations of average conditions and can also be used for comparisons with IFIM.

Experienced users of these techniques have come to the conclusion that once models are adjusted to the species and catchment of interest, QMSA and Montana methods should be used to develop recommendations in areas where competition for water is minimal. Where there is strong competition for the resource, an approach similar to the IFIM is being recommended for supporting a complex evaluation of all flow options and responses to the various species/life phases. The selection of the specific methodology will depend upon the quality and availability of hydrological and biological data and more importantly the resources to carry out the investigations.

Generally, the three methods based on habitat derivations may have considerable application if limiting factors are confined only to fisheries. However, hardly any fisheries have become the sole determinant of minimum flow for any stream. Wider-based approaches for flow quantification consider fisheries only as one of the recreational interests which must be addressed by the flow recommendation. Population and economic pressures definitely bring a wider representation of interest into the picture which compete for the limited resources of our rivers. Often different views are so extremes that courtrooms have become a common venue for resolving the differences. The majority of these conditions arise when demand for diverting streams grows due to increasing needs for hydropower which in turn conflicts with stream-based recreational interest. In an effort to resolve disputes, laws such as New Zealand's Resource Management Act (1991) were enacted to encourage the development of competent trade-off evaluation. This should evolve into a greater understanding of the relationship between river flow and recreation quality and value, by employing the best methods available.

2.4.3 Assessment of Flow Effects

Assessments of the relation of streamflow to recreation have created a variety of settings for a variety of purposes and variety of disciplinary perspectives. Studies have focused on determining minimally acceptable flows or on the relation of flow to recreation over the full range of flows. A better understanding of recreation quality, economic value, aesthetics, and carrying capacities and their relationship to streamflow and needs should give a clearer view of how these factors are interrelated. To date, studies have focused on water-dependent activities such as boating, (using numerous craft, including rafts, canoes, drift boats and kayaks), fishing, swimming and on other water-enhanced activities such as camping, picnicking and hiking.

A fundamental distinction can be drawn between the study of 1) direct or short-term effects of flows on recreation in general or on specific recreation attributes such as quality of rapids, fishing success, scenic beauty or boating travel times; and 2) indirect or longer-term effects, such as maintenance of gravel bars for camping, control of encroaching vegetation to ensure scenic visibility, or the maintenance of channel form and function for fish habitat.

Methods used to evaluate the direct effects of streamflow on recreation quality can be grouped into four categories. The first relies mainly on the judgement of experts who have in the past studied other rivers. This can be supplemented by on-site investigation or by informal interviews of selected individuals. However, with this approach there is no systematic on-site or photo-based evaluation of alternative flow conditions at the time of the study or any concerted attempt to survey the user population. The second approach uses the systematic determination of alternative flow levels by a small number of judges, where each judge evaluates each flow level over a course of a relatively short time. Of particular importance here is the use of range of controlled flows provided for assessment by planned dam releases. The third approach is to employ a formal survey of a sample of the user population. The fourth approach is mechanical measurement, with little or no judgement reflected in the dependent variable (e.g. floatability, suitability) since it only measures the sound level of flow in decibels.

2.4.3.1 Expert Judgment

Use of formal surveys to obtain user-judgements can be subdivided into five categories. Four of the categories are based on whether user-responses are obtained for:

1. experienced flow where each respondent only experiences one flow level;
2. alternative flow levels depicted photographically;
3. alternative flows described verbally;
4. impacts of alternative flow levels (e.g. catch rates) and lastly
5. visitor use levels at different flow rates.

Reliance on the judgement of experienced individuals is a common and relatively inexpensive technique; although study results, however, are not often published for outside review. In order to develop recommendations to maintain quality recreational experience, experts rely on data obtained during site visits and selected interviews with knowledgeable managers and users. For each of the recreation activities (e.g. kayaking, rafting, tubing, canoeing etc) six to ten people may specify, in a *Delphi*-type process, the minimum and maximum flow levels and the optimum flow range on relevant stretches of the river.

2.4.3.2 Systematic Assessment

For systematic assessment of alternative flow levels, the conditions to be evaluated may be represented photographically or actually experienced. Photos are particularly useful when it is otherwise impossible to visit and experience the various flow levels within a sufficiently short enough time span that the judge's evaluation criteria do not change. In either case, the same individuals judge each flow level for whatever activities are at issue and record their impressions and evaluations in either a formal questionnaire or monitored group discussion.

The approach using photographs was used in two California studies. Litton (1984), assessed the scenic quality of the Toulumne River with photographs taken at different flow levels and locations and then subsequently, using his knowledge as an architect, to assess visual quality. In a similar approach, EA Engineering, Science and Technology (1990), assessed the swimming suitability along the Clavey River near its confluence with Toulumne River by capturing on videotape, members of the study team as they swam in different flow levels from 8 to 365 cfs. A panel of six judges then rated the varying conditions for swimming suitability.

The presence of dam structures offers a unique opportunity to alter stream levels for analysis of optimum flows. The controlled flow approach was achieved with the cooperation of dam operators in the Tennessee area where participants tested flow levels from 1,200 to 4,000 cfs. Boating enthusiasts comprised the discussion group and arrived at an ideal flow beneficial to each form of recreation. A variation of this technique was used in the Hells Canyon Section of the Snake River (Bayha and Koski, 1974), where a multi-agency study team carried out the evaluation with a multi-disciplinary team representing hydrology, fishery and recreation. By using flow levels ranging from 5,000 to 27,000 cfs released from Hells Canyon Dam, recreation impacts were monitored at each level.

Another field evaluation similar to flow-testing was conducted by a power corporation in the 3.5 mile-long stretch of Moosehead Lake (Giffen and Parken, 1991). Boating assessment for six flow levels ranging from 900 to 5,500 cfs involving 15 persons in raft, kayaks and canoes was undertaken. Notes were taken twice - discussions were encouraged after the initial run and then individual observations were compiled for the succeeding ones. For review of the flows and their observations, videotape was taken of the key stretches. Using similar techniques, fishing was tested using six different levels ranging from 600 to 1,600 cfs where anglers' comments were recorded onsite although the analysis was only done once.

2.4.3.3 User Survey

The majority of published literature on flow effects to recreation refer to the use of user surveys employing on-site interview, or mail questionnaire. These studies are also sub-categorized as to whether: 1) photographic media; 2) verbal descriptions; 3) actual flows to represent conditions of interest; 4) flow level impact to respondents were described and 5) questionnaires were used or observations were merely taken into account.

While most of these studies focused directly on recreation or scenic quality, several measured the economic value of river recreation. The economic value of such recreation can be influenced by both the changing recreation quality at alternative flow levels and the changing number of users. It is the economic measure of the quality effect, not of the use or quantity effect that is most closely related to measure obtained in studies focusing directly on recreation quality. If an estimated relation of economic value to flow is primarily or wholly influenced by the quality effect, that relation can be confidently assessed with direct recreation quality measures.

One user-survey approach is to record the actual flow experienced by users during the trip about which they are questioned, and then statistically relate user responses to measured flows. This requires a much larger sample of users than does field evaluation where each participant experiences all levels over a short period, but still has the advantage of being tied directly to on-site experience. This approach was used by Moore et.al. (1990), in a mail survey of recent visitors to canyons in the wilderness of Arizona. Visitors were queried as to whether they preferred the flow volume they encountered or would have preferred higher or lower flows. Responses were compared with gauged flows at the time of the visit to understand visitor preferences. Duffield et.al.(1992), used an onsite survey on two Montana rivers to estimate additional willingness to pay for their current recreational experience. Bishop (1987) surveyed Colorado River recreationists (Grand Canyon rafters and anglers) by mail about their additional willingness to pay for their recent trips. In both studies, willingness to pay was statistically related to flows experienced during the trips.

Photos were also used in surveys by providing the public with the usual means to assess likeability of different environmental features. Ribe (1989), Shuttleworth (1980), Daubert and Young (1981) combined photographs with contingent valuation to estimate the willingness-to-pay of floaters, anglers and shoreline users in the Cache La Poudre River in Colorado. The same river's scenic beauty relative to instream flow was also assessed using photographs (Brown and Daniel, 1991). Here both investigators combined video and sound on the assumption that the latter plays an important role in the perception of the aesthetic value of a river. Ratings were scaled to an interval-scale of scenic beauty that was regressed on variables describing flow and other scenic features.

Some studies have used verbal description of flows to represent alternative conditions to respondents. For example, an economic study surveyed users of nine rivers on the west slope of the Colorado Rockies (Walsh et.al., 1980). Respondents were asked their willingness to pay for recreation given current conditions, and then for the changes in that willingness to pay at five different instream flow levels described as percentages of bankful flows. In the Colorado River, a contingent valuation study by Bishop et.al., (1987) sought from users, after valuing their actual trips, their willingness-to-pay for six scenarios that differed in both the amount and daily fluctuation of flow, and in associated conditions of rapids and camping beaches. In non-economic studies, users of the Dolores River in Southwestern Colorado (Vandas et.al., 1990) and river guides of the Colorado River through the Grand Canyon (Shelby et.al., 1992) were questioned about boating quality at alternative flow levels.

Rather than describe alternative flow levels to study participants, some studies have described flow-dependent recreation attributes. For example, two economic studies (Johnson and Adams, (1988), and Harpman (1990)) asked respondents to express their willingness to pay for alternative catch rates. Resulting recreation values for catch rates were related to flow using flow-dependent fish production models.

2.4.6.5 Formal Survey

A survey on the use of river reaches as flows change over the season can also provide a measure of the popularity of alternative flows. However, this method is difficult to apply because use is sensitive to many influences in addition to flow levels, and often users do not anticipate what flow level they will need for the trip. Even assuming flows are known ahead of time, all other influences must be isolated from the impact of flows. While use levels have been measured in conjunction with several studies so far mentioned, investigators have generally used it to check on other methods rather than as a primary method for assessing recreation quality.

Mechanical measurement of descriptive effects have also been extensively used in the past studies. Several studies on sound, an aesthetic feature of rivers, used a decibel measurement to provide a purely mechanical measure. Hawkins (1975) measured sound levels and flow rates in several streams in Utah, and Garn (1986) adapted this methodology to measure sound output at various flow levels on a river stretch in New Mexico. The non-linear relationships they found indicated the point at which additional flow contributed little to sound output.

Comparing these methods, reliance on the judgement of a small sample of experts has the advantage that it can be quickly and easily applied, efficiently focusing most study effort on those most likely to understand the issues and relationships. This method is particularly pertinent where there are few users to interview (perhaps because of remoteness) and where direct observation of various contemplated flow levels is not possible. The principal drawback of relying on a small sample of experts is the potential for bias and the resultant ease with which important considerations may be overlooked or distorted.

Systematic experience-based evaluation of alternative flow levels over a short time span is an efficient and powerful approach. Except for potential order effects, it places all important flow levels on an equal footing. Furthermore, experiencing the flow affords the possibility that impacts otherwise ignored or considered unimportant can surface in the course of the study. Controlled flows are superior to photographic representations for complex activities such as boating and fishing, but carefully obtained photos may adequately represent the scenes for assessment of scenic quality alone.

In some applications of this approach, there has been a tendency to restrict the sample to a small number of study members rather than opening the evaluation up to a larger number of participants. In addition to potentially enhancing the validity of study results, wider participation enhances public knowledge and acceptance of a study. In any case, careful consideration of response mood is needed; group discussions, while easy to arrange, are probably less effective than comments recorded separately by each participant in response to a specially prepared questionnaire. Group discussions may provide useful additional information, but should occur after the questionnaire is completed.

User surveys employing statistically relevant samples, if properly designed, have the advantage of avoiding biases that may be unavoidable among small groups of experts or participants in an assessment of controlled flows. User surveys also allow the estimation of economic value, but because user surveys are complex, they require competent questionnaire design and sampling procedures.

Users, however, differ in their experience with various flow levels. More experienced users are also more likely to be able to go beyond just the overall effect of flow on specific rapids, camping site safety concerns, and other aspects of recreation experience.

Measures of the effect of flow on recreation quality alone do not indicate how important those effects are. Although the importance of change is commonly measured with economic study, significant, carefully delineated change in recreation quality may or may not be worth much to users.

Two approaches to measuring the economic value of instream flow are to ask each respondent about a series of verbally or photographically depicted flow levels, or to ask each respondent about only one experienced flow level. The former approach tends to focus a respondent's attention on comparison of alternative flow levels. If recreation quality is at all sensitive to flow, this multiple-flow, comparative approach is more likely to yield results indicating responsiveness of economic value to flow. In contrast, the method where each respondent is asked about a recent trip (an experienced flow level) does not tend to emphasize flow differences and allows other important factors (e.g. weather and crowding) to play a larger part in their response. If a significant relationship is found between flow and recreation value, when each response refers to an actual trip and the respondent is not aware that flow level is the key variable of interest, the result is considered robust (Brown et.al., 1992).

2.4.4 Multi-objective Programming

Two basic water resource management problems are those of quantity and quality of water supply. Outright, one may easily classify the first as a multi-objective programming concern considering the question of allocating a limited water resource to a variety of uses. For example, take the case of a river where flow can be divided between irrigation, hydropower and other instream uses. The primary goal may be to maximize the net national income that can be derived from the scheme. This requires valuation of different water uses and formulation of definitive operational objectives.

Multi-objective programming is best illustrated as a planning tool in the Rio Colorado project undertaken by the Massachussetts Institute of Technology (MIT) group in the early 1970's. Rio Colorado is a river originating in the Argentinean Andes and flowing for about 1100 km to the Atlantic Ocean. The primary objective of this project was to examine alternative development plans for the river basin and to understand the economic, social and environmental effects of these alternative options. The river cuts through different political boundaries which brings another dimension to the problem.

The decision variables selected were of the form: which projects should be built; how big they should be (that is how much water they should use); when should they be built; and how should they be operated. The proposals included hydro-electric power generation plants, irrigation projects and inter-basin transfers of water.

Three models were developed for the project. Projects were screened using a multi-objective linear programming optimisation model, developed to generate a set of non-inferior solutions. The question of scale and operational rules were determined by passing the solution generated by the screening model through a simulation model to check for operational feasibility (that is, the ability to cope with day-to-day operation) and question of timing were solved by a sequencing model.

Cohen (1978) suggested that ideally a single model, able to address all the relevant issues, should be used. This would have been practicable only under two conditions: 1) if all data were available at an equal level of detail; and 2) if the size of the resultant model were computationally feasible. In this example the initial screening model used about 50 years of deterministic streamflow data to produce the initial set of non-inferior solutions. The simulation model used stochastically generated daily data to test for operational feasibility. A combined model of this size is computationally impossible.

The main difficulties of using this technique is the prerequisites needed to value all costs and benefits attributable to the scheme. Valuation techniques already mentioned can be used to determine the economic costs involved. The big advantage, however, is gained by the avoidance of biases ascribed to survey. With this technique, an interactive model can be developed allowing flexibility on the part of the planner to examine different approaches to the planning of water resources development.

2.5 NEW ZEALAND METHODS

Most of the techniques used in New Zealand are adaptations of the methodologies developed in the United States, primarily those devised

Table 2.1 - Human Instream Uses (Mosley, 1983)

Contact Uses	Non-Contact Uses	Associated (Water Enhanced) Uses
Paddlind/wading	Angling (bank and boat)	Sightseeing and aesthetic value
Angling (wading)	Boating(non-powered), rowing, flat water canoeing	Nature study, bird Watching
Swimming	Sailing	Picnicking
Tubing, drift diving*	Flat water power-boating	Hunting or shooting
Water- Skiing		Tramping (non-riverbed routes)
White water rafting and canoeing		
Tramping (via riverbed jetboating routes)		Horse and trail bike riding
	Camping (for water supply, washing and bathing)	

by the Fish and Wildlife Services. Mosley (1983) put into perspective the importance of taking into consideration the needs of species like fish, rather than human (anthropocentric) needs alone, because the former provides a basis for human instream use - like angling.

Mosley (1983) came up with a number of factors which he used as a basis for describing the character of a particular river, (see Table 2.1). He then related each human activity to each of the characteristics to establish dependencies, i.e. how any of these so-called factors affects any particular activity.

2.5.1 Fishery Considerations

In New Zealand there are about 40 species of fish present in the country's estuary, river and lake system (Mc Dowall, 1978). A good number of these species - lamprey, eels, five whitebait species/galaxids, seven introduced salmonids, the so-called "coarse" fish (perch, tench and rudd), and estuarine kahawai, mullet and flounder - are of direct use for recreation or food. There are also other endemic species, like torrent fish and bullies which are considered part of the New Zealand heritage and are regarded as having their intrinsic value (Mosley, 1983).

Given their importance, fisheries become a primary consideration when setting minimum flows. Since some local species were identical to those in the United States, initial tests were conducted using probability-of-use or habitat-suitability curves developed for those species in the US. However certain shortcomings were discovered during the trials which stressed the need to modify the suitability curves to suit the local conditions. The apparent lack of a relationship between the "weighted usable area" and the actual populations of a number of endemic and introduced fish species was observed during the initial tests of the methodology. This is attributed by Smith (1979) to factors such as channel morphology (the relative number of riffles, pools, runs, backwaters and frequency of channel change), flow regime, food supply, competition and instream cover. As such it is generally accepted that habitat preference data needed for the application of the incremental method may only be reliable for those rivers for which data are collected (Glova and Duncan, 1983; Tierney, 1982). A word of caution is also given when using data collected from sub-optimal habitats (Mosley, 1983).

2.5.2 Wildlife

Terrestial animals also use rivers for drinking water and for lines of travel while river margins are favoured as areas for grazing. Satisfying this requirement is therefore simply and easily attained - the mere presence 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.

It is generally accepted that rivers become more negotiable as flow and level drops (Mosley, 1983). 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.

Birds, ducks and geese are another terrestrial species that depend on rivers for breeding, food and habitation. This can be linked to human recreation needs since they become essential to the success of recreation during the hunting season. Water levels must be sufficient to ensure that continued availability of habitat for these creatures exists during critical stages of their life cycles.

Growing concern is being voiced over the bird population as evidenced by the issuance of Conservation Order such as that on the Ahuriri River. This action was compelled by the importance given to the waterway by the concerned authorities for habitat and breeding of wetland birds. This produced a greater effort to understand bird proclivity in terms of microhabitat preferences for each of their activities - loafing, feeding, nesting (O' Donnel and Moore, 1983; Robertson et.al., 1983). While there are other considerations as well, these preferences are almost always affected by river flows.

This effort went a little further by developing the idea that impacts of river development may be predicted through changes in the areal scope of microhabitats which in turn may be caused by changes in natural flow and the water level. Theoretically, it is possible to develop a 'weighted usable area' or preference curve for each family of birds under study.

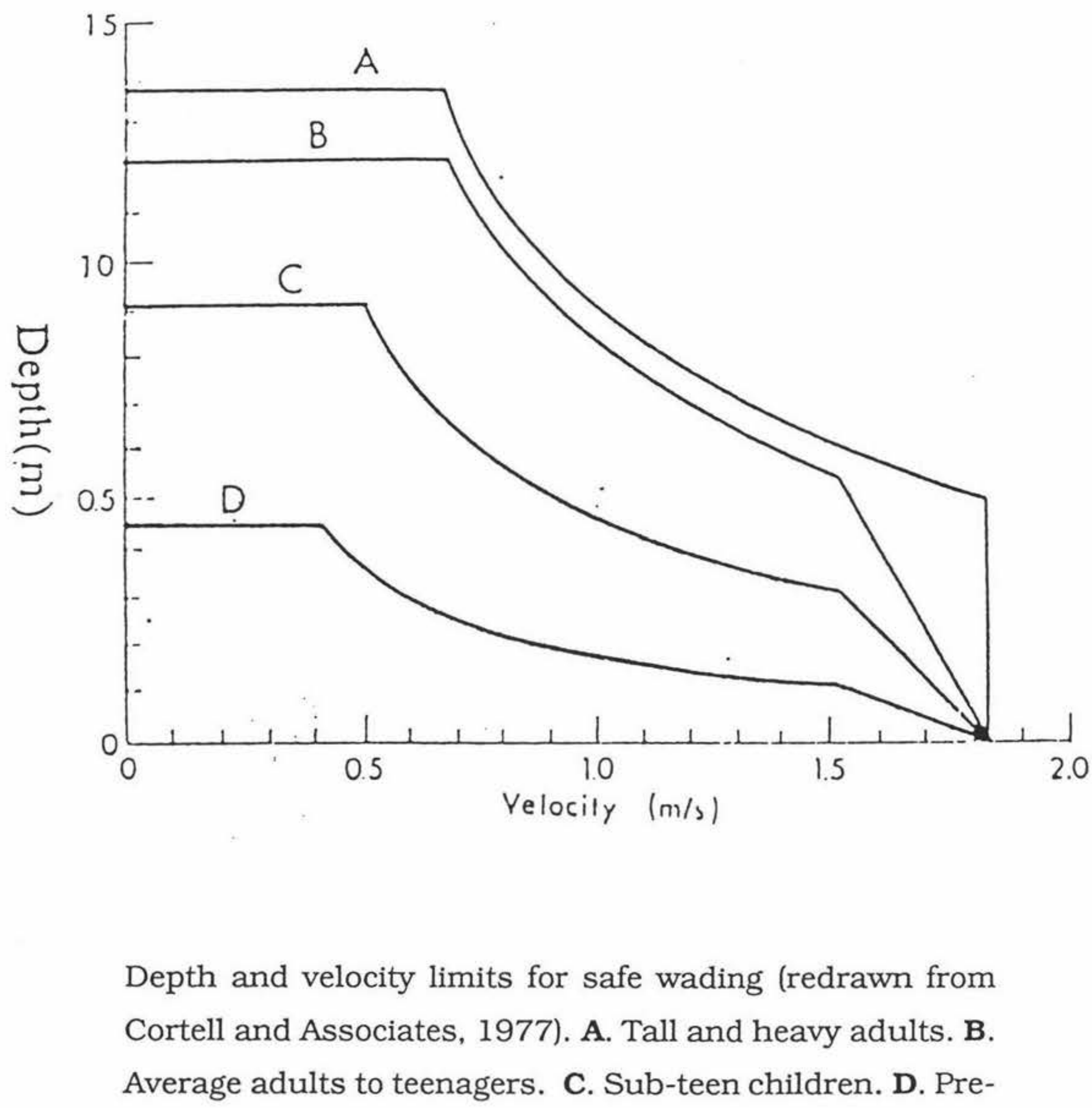
2.5.3 Human Needs

While previous sections discussed species to which people can relate their personal gains, New Zealanders carry out a broad range of sports and recreation similar to those of the North American type. Table 2.1 lists several instream uses with their related (water-enhanced) usage. Table 2.2 also lists various flow requirements for human instream use. Cortell and Associates (1977) initially proposed the criteria which were then revised by Mosley (1983) based on his own experience of New Zealand conditions. While the instream incremental flow method for fisheries used substrate, velocity and depth as criteria for habitat suitability for each life stage and species, humans may differ on their appreciation of flow depending on their age grouping and physical attributes. This is particularly the case in contact uses where body size and strength are needed to counter 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 may vary with age and body weight. Figure 2.1 presents detailed depth-velocity limits for various age and size groups.

In summary, the use of quick office methods (such as the Montana) in New Zealand is generally avoided and was criticised by Fraser (1978) as certainly lacking foundation on known requirements of aquatic organisms or other in-stream uses.

The incremental approach (IFIM) has been highly favoured on the other hand and results were used to establish relationships between discharge and different stream usage. Jowett (1982) identified optimum flow regimes for Clutha and Tekapo Rivers. Mosley (1983) used the method to assess conservation order applications for the Ahuriri and Rakaia Rivers.

Figure 1.1



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

Table 2.2 - Summary of Requirements for Human Instream Use

Activity	Water surface width(w), depth(d), Velocity (v) requirements in metric units			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 standard 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>50m. For diving from bank, d > or = 2.0m.
Tubing/drift diving	w 5.0 d 0.3 v -	w - d - v	w 20.0 d 0.8-1.5 v 1-2	As for paddling/wading. For "white water"form of sport, as for rafting/canoeing.	No hazards- overhanging or 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 > 1m.
White water rafting and 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 in riffles of gravel and not angular to minimize wear and tear.	As for tubing and drift diving except class II or IV on International Scale. Slots between rocks >2.0m.
Tramping (river bed routes)	w - d - v -	w - d 1.2 v 1.8	w - d - v -	Gravel bed desirable for easy travel. Alagal 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 minimize needs for water crossings. Floodplain or terrace surfaces present for easy travel. Water Temperature > 10 c Bottom visible.

	Water surface width(w), depth(d), Velocity (v) requirements in metric units			Preferred Sediment Requirements	Preferred Other Requirements
	Minimum	**Maximum**	**Preferred**		
Angling (bank)	w - d - v -	w - d overbank v -	w(as for fish d habitat v preference)	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 of boating (non-powered)
Boating(non-powered), rowing and 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 < 1.5	Sand bed preferable. No snags on stream beds.	No snags in stream. Easy access to river. No hazards as 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 (high-power)water skiing	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 Hazard weirs, submerged piles, overhanging trees, etc., Bottom visible.
Camping (for water supply and washing and 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 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.

2.6 CONCLUSION

Setting of minimum flows in Czechoslovakia apparently evolved from their experience of managing abstractions by establishing a certain environmental bottom line level. The country's Water Authority imposes restrictions based on minimum acceptable discharge derived from hydrobiological surveys. These surveys indicated the relevance of flows exceeded 355 days a year (Q_{355}) and to 364 days a year (Q_{364}) to a number of aquatic species. It is not clear though as to what particular species these flow levels are intended for or even for which stage of species life cycle such flows would be useful. However, these flows are consistent with the findings of other studies here in New Zealand (Jowett, 1993) which established that the mean annual low flows are highly correlated to the availability of habitat in large rivers while slightly higher flows are required for smaller rivers.

In the United States several methods were developed which can be classified either as flow quantification or flow assessment. The former involves the determination of flow requirements for single or several purposes. It is also decided when and by how much water is required for instream use. Flow assessments on the other hand, obtain the information regarding the preference of river users through direct surveys. These are more applicable to recreational users who often have their own set of standards depending on their level of skills.

The US techniques are found more sophisticated than their Czechoslovakian counterparts. What prompted the development of the US techniques is the degree of competition involved in the allocation of the resource. Since the deliberations are often held in courts, it necessitates methods which are legally and technically defensible. One disadvantage of the technique, is the apparent high cost of using it since revalidation is often required.

The major shortcoming of some of the quick US methods (such as the Montana) and the Czechoslovakian methods is the apparent lack of a theoretical basis underpinning the assumptions which underlay the choice of particular flow percentile ranges. In practice most resource allocation processes are less confrontational than the Whanganui River Minimum Flow Hearing was. The application of Czechoslovakian and other US methods, such as the Montana, facilitates this without the necessity of going through lengthy computations.

CHAPTER III

ENVIRONMENTAL SENSITIVITY

3.1 BACKGROUND

One of the most important matters to consider when investigating a methodology is the choice of an appropriate conceptual and theoretical framework on which to base the approach. The concept of the environmental weighting system (EWS) is based on the theory that environments have a certain lower threshold level above which changes can proceed without serious damage being imparted to them. The threshold level is, by default, the level on environmental sensitivity.

3.2 THEORY OF ENVIRONMENTAL SENSITIVITY

Environmental sensitivity is a theory pertaining to the unique attribute of any particular location and which reflects its capacity to tolerate change. In terms of aesthetics, for instance, Masteller et.al. (1977), postulated a relationship between changes in streamflow and the aesthetic quality of stream environment. Here, Masteller attempts to establish a methodology to determine those streams, or sections of them where no flow fluctuation other than normal should take place because of their extreme aesthetic sensitivity. In this respect he wanted to determine the permissible range of flows where changes could be tolerated.

It can be discerned from his literature that the aesthetic sensitivity of different stream locations varies and would depend mostly on peoples' appreciation of visual beauty. Environmental sensitivity on the other hand does not limit its scope to the aesthetic aspect but the general character of the environment as well. This may include the physical attributes of the place and the type of ecology that exists within it.

Since all the processes that operate within a certain environment determine its character, any interruption of these natural process can disturb the balance that has long been established. The Auckland Regional Council (1991) stated that human changes have had a major impact on the type of plants and animals (reduced species diversity) with only very tolerant species being found after the changes. In some cases, there may be large populations of these tolerant species because of reduced competition with other species from reduced population densities.

In *lotic* ecosystems for example, Hart (1990) wrote that upland streams, particularly the headwaters, are characteristically forested and well shaded from the sun. Because of this, limited primary production can occur within the stream itself. The primary food source in these systems is particulate organic matter (e.g. bark, leaves etc). Consider a situation where a logging corporation was permitted to cut down trees in the head-waters of a river. This in effect would deny the macroinvertebrates their source of sustenance and development. Eventually the fish community which depends on these macroinvertebrates would feel the pressure and migrate somewhere else or reduce their numbers commensurate with available food.

The lower stream sections which are considered *autothropic*, since community respiration is supported predominantly by organic matter fixed *in-situ* may however, stand a better chance of supporting their community since it is considered self-sufficient in food. The water in this area is usually shallow and clear allowing the growth of aquatic plants such as macrophytes, epiphytes and algal films on rocks (Hart, 1988). Contrasting the two reaches (upper and lower), the two may be differentiated in terms of their threshold to change. Environmental sensitivity is used in this study, as an indicator of this capacity for change which is the main theory underpinning the methodology used in the determination of a minimum flow. In practice this was operationalized by applying the concept of weighting to a combination of environmental categories subsequently used as the means of measurement.

3.3 EFFECTS OF RIVER REGIMES ON THE ENVIRONMENT

The normal pattern of flows during a year is called river regime (Shaw, 1988) which includes both low and high flows, the latter of which are known to contribute to shaping the morphology of the river. Floods, for example are instrumental in creating and changing channel shapes and configuring the direction of changes which ultimately influence the characteristics of flows, an important factor for any activity within a river.

River regimes can either be temperature dependent or rainfall dependent (Shaw, 1988). As suggested by their names, temperature dependent regimes are usually those which depend on snowmelt to produce water which then flows down a particular stream or river. In equatorial, tropical and mid-latitude regions with no high mountains, rivers are rainfall dependent, with seasonal rainfall variations having a direct influence on river regimes.

3.3.1 Environmental Sensitivity and River Regime

Perhaps among the different flow regimes the base flow or dry-weather-flow is more closely related to the sensitivity of any reach of a river. Drake (1988) postulated that natural frequency of low flow would not be damaging to the environment on the basis that those aspects which are sensitive to low-flows would not be present if they were susceptible to events of such frequency. Artificial reduction of flows below the dry-weather-flow would appear to the river environment as the occurrence of an event and, as more flow was abstracted, the more severe the event would appear.

Drake considers in theory that the community of different species existing at the natural low-flow level are present primarily because they are capable of sustaining life under such minimum flow conditions. The protection of this flow is vital for the retention of these features by minimizing the pernicious effects ascribed to abstraction.

The theory on low-flow and the environment has been conceptualized into an approach in an effort to protect this vital river regime. Although an element of subjectivity is involved, it is considered an acceptable approach utilized not only in the US but in the UK as well. The outcome in the UK, where it was applied extensively by the North Yorkshire Water Authority, is quite encouraging despite the intensive use of its water resources and considering the environmental enhancement which has been achieved.

3.3.2 Low-Flows

Droughts, which occur periodically, are considered rainfall deficiencies (Shaw, 1988) and result in low-flows. Low flows are one of the main concerns of water authorities and companies as their occurrence generally stimulates demand thereby making management of the resource more complicated.

But even without drought, low-flows can occur during the dry season and what usually remains in the channel represents the base-flow of what is naturally coming from the groundwater source. Often there is only a very limited amount of groundwater depending on the geology of the catchment and the amount of precipitation which occurred during rainy periods. This important relationship traces the link of precipitation and lithology to all forms of life present within a river or stream or even their riparian fringes.

Low flow indices are indicative of the degree of severity of low-flow which occur in different durations and magnitude. Their use in planning is recognized since they provide an indication of the potential effects of dry periods to economic as well as environmental elements.

Given a record of river flows, several features of data sets can be abstracted or derived to determine the characteristics of low-flows. These may be called low-flow indices and three groups have been outlined (Beran and Gustard, 1977). These are indices derived from the flow-duration curve, consideration of the low-flow spells, and frequency analysis of the annual minimum series of low-flows.

3.3.2.1 Flow-Duration Curve

This curve gives the duration of occurrence of the whole range of flows in the river (Shaw, 1988). Flow deficiency is usually read from the lower end of the graph and is set by selecting a particular flow. Hydrologists suggest several ways of creating indices with the flow-duration curve including flows exceeded 95 percent of the time (Q_{95}), and the percentage of time that a quarter of average flows are exceeded which generally lies between 85 - 90 percent exceedance.

Q_{95} is also a good basis for showing the differing geological properties of two catchments. For example, a catchment with 45 percent of the average daily mean flow equivalent to Q_{95} when compared to a catchment whose Q_{95} is only 16 percent of the average daily mean flow would indicate that the former is comprised of much more porous material than the latter.

3.3.2.2 Low - Flow Spells

This is an extension of the flow-duration curve index designed to accommodate the weakness of the former indexing. It uses a continuous record of daily mean discharges where the number of days for which selected flow is not exceeded defines a low-flow spell.

To illustrate, Q_{95} is initially selected as base line for a particular index. Having established this flow as the lower limit, the number of passing days without exceeding the base line before a low flow spell is declared is also selected. Thus, if flows do not exceed Q_{95} within this selected number of consecutive days, a dry spell is declared.

3.3.2.3 Frequency of Low-Flows

This index is discussed in Chapter IV as it is adopted as method to derive the dry-weather-flow.

3.3.3 Precipitation and Low-Flow

Shaw (1988) states that the flow extremes from precipitation is more easily defined and recognized than flow extremes from the lack of it, but the lack of it has varying significance in the different climatic regimes in the world. For flora and fauna of arid zones, prolonged periods of low precipitation may hardly show strain since this condition often is not significantly different from its normal or average rainfall. The same may not be said of normally humid areas where serious water deficiencies may cause extensive crop failures and thus, portend the prospect of food shortages.

Sensitivity of an environment may then relate to where it is situated - either in moisture rich or moisture poor zones. In the former, it is expected that vegetations would thrive well and that even in its aquatic systems barring the presence of destructive pollutants and other limiting factors, rivers and streams are anticipated to host a diverse and abundant fish population.

Under a normal hydrological regime of the river, low flows are usually associated with periods of low precipitation and high evapotranspiration. This could occur even during an average water year but there are moments when the conditions can be more pronounced than the average conditions.

The normal dry periods may last from 2 to 4 months each year, beyond which drought may set in. Given this situation, aquatic life may begin experiencing severe strains whose magnitude may depend on the extent and severity of the dry periods. Elliott (1975) have shown in his study that abnormal increases in temperature during low-flows can interrupt the normal life processes of the fish population leading to stunted growth and reduction of the fish population. Abstractions are known to simulate drought events without giving proper attention to this instream requirement.

Precipitation is created by a complex process involving condensation of water vapour to form liquid droplets. Weather patterns are likewise responsible for producing precipitation. These are associated with high and low atmospheric pressure systems and associated fronts and troughs. Conversely, any land mass dominated by the occurrence of high pressures is dry and less humid and thus, less sensitive. Places often under low pressures may result in humid conditions producing an environment conducive to plant and wildlife and thus, highly sensitive.

3.3.4 Evapotranspiration

In the hydrological cycle evaporated water is one of the more difficult parts to account for. Evaporation specially in dry areas is substantial and it accounts for the large difference between river flow and actual precipitation.

In winter, when evaporation naturally drops below the summer rate, surface water finds its way to the rivers bringing increased discharge (Shaw, 1988).

Evaporation is usually considered from two main aspects:

1. from open water surface i.e., rivers, reservoirs, lakes ($\mathbf{E_0}$)etc.
2. the second is from the vegetation transpiration denoted as E_t. Thus E_t is the total loss of both evaporation and transpiration from land surface and vegetation.

While both are equally important parameters to reckon, the study does not dwell on its contribution to the flow equation since only net abstractions and releases are considered. Further, this would greatly simplify the analysis to be done of the recommended flow regimes.

3.4 PROTECTION OF NATURAL LOW-FLOWS

As already mentioned in the early part of this section, low-flows determine the type of aquatic life sustained under such flows. Under the harshest conditions of summer, water in streams tends to increase in temperature. This is because the lower flow velocity increases travel time and the shallower depth increases the surface area to volume ratio. These conditions can be very harmful to some fish species in particular rivers.

Aside from the impact on fisheries, low-flows in the Whanganui River are also found to aggravate the foul odour emitted by the river (DOC, 1988). This is caused by the accelerated decaying of organic material as a result of increases in temperature. Increase in temperature also reduces the solubility of oxygen in water as it attempts to decompose the organic materials. This then results in unwanted smells as anaerobic processes become dominant in decaying the organic materials.

Beside those reasons easily perceived by our senses, there are other important considerations why natural low-flows must remain protected. Perhaps one of the most apparent ones is the preservation of the stream's natural features which is hard to value by itself. For this reason any methodology devised should integrate this concept to make it a relevant to the real issue.

Since low-flow is a seasonal event of a river regime, this may imply the use of a certain time-frame. Drake (1987) used this concept to limit the amount and frequency of abstraction within particular streams. In addition to limiting the amount of abstraction on a seasonal basis he also derived an environmentally prescribed flow which should be imposed as a residual flow; otherwise the natural low-flow is observed.

Jowett (1993), in an instream habitat survey of Wellington Rivers on instream habitat survey, also expressed the relationship of low-flow to habitat availability. According to the author, the habitat availability increased parabolically with the flow reaching its optimum at median or lower flows for the larger rivers and above median for the smaller. Thus, minimum flow assessments based on habitat guidelines suggests that "minimum flows" should be relatively higher in smaller rivers.

Furthermore, he was able to establish that the minimum flow for adult trout habitat are related to the average depth and mean annual low flow, whereas the flow requirements for food producing habitat was related only to average water velocity.

In his study his minimum flow assessments were related to mean annual low flow, median flow, average water velocity, catchment area and average river width. He managed to establish that the relationship with mean annual low flow explained over 80 percent of the variation in the flow assessments and provides a convenient method of estimating low flow requirements for habitat maintenance.

3.5 THE CONCEPT OF ENVIRONMENTAL WEIGHTING

Environmental weighting (EW) is the concept used for numerically quantifying environmental sensitivity to give a commensurate amount of permissible abstraction. Drake (1988) conceptualized this subjective approach of quantifying sensitivity after recognizing that a system based on rigid scientific principles is not possible.

Similar to the base-flow concept used by the United States Fishery Services (USFS), the idea is to use some environmental parameters which can be assessed subjectively by experts as to their sensitivity to abstraction. These parameters are then ranked ordinally based on the weighting provided by the experts themselves.

This information was then related to the flow-duration curves initially to arrive at allowable changes in flow regimes. This is expressed in terms of number of days flows are allowed to shift (the horizontal difference, as measured by % exceedance, between two flow duration curves) along the time axis. Drake (1988) developed this concept to cover a wide range of applications in water management, including the classification of different environments as an aid in making resource decisions.

Transformed into an equation, the minimum flow can be expressed as:

$$EPF = f(ES)$$

Where:

EPF = Environmentally Prescribed Flow

ES = Environmental Sensitivity.

Environmental sensitivity on the other hand can be expressed as follows:

$$ES = f(X_1.....X_n)$$

Where:

$X_1......X_n$ = Environmental Categories

3.6 SUMMARY

Environmental sensitivity measured by an appropriate environmental weighting system is the main basis of this study for determining of minimum flows. The environmentally prescribed flow (EPF) is estimated from a pre-determined relationship between the EPF and the EWS. While there are several factors upon which the sensitivity of a particular environment can be measured, the EWS of the North Yorkshire scheme uses seven environmental categories and with minor adjustments is suitable for use on the Whanganui River situations.

Environmental sensitivity is in theory the threshold level of any location or area to adapt to any introduced change naturally occurring or otherwise. Since the primary concern of this study relates with river ecology, the response of different riverine elements to flow alterations will be placed in focus. However, it is important to note that the assessment of these responses is based on a subjective approach where the quality of output may depend mostly on the knowledge of the respondents and the objectivity of those consulted.

CHAPTER IV

METHODOLOGY

4.1 INTRODUCTION

To create a clear perspective of the manner in which this research is pursued, the principles, methods and procedures employed are discussed in this part of the study.

This section also looks into how various techniques used to determine minimum flows are applied in the Whanganui River system. The intention behind this is in part to better understand how the Planning Tribunal came to terms with the complexity of evidence and how the recommendations produced from each suggested technique might have affected the decisions of the Planning Tribunal.

The assessment will then focus on how the Planning Tribunal treated the flow recommendations from the evidence presented. Techniques such as the instream flow incremental methodology (IFIM), were carefully scrutinized during the Hearing. Several points were raised over their validity which was reflected in the Tribunal's decision to avoid giving full weight to the output of these models.

A detailed explanation of the methodology applied in this study, including its development, is also discussed in this section so that the assumptions of the models can be considered.

4.2 RECOMMENDED APPROACHES

Stalnaker (1976) suggested the use of a system-based approach to water resources planning which considers the interrelationship of the economic, social and physical elements as well the biological, elements involved. The approach is described as a practice which defines and attacks a problem explicitly in terms of the following elements:

1. an objective or several objectives;
2. alternative means or systems by which objectives may be accomplished;
3. knowledge about the costs or resources required by each alternative;
4. a mathematical or logical model which describes a set of relationships among the objectives, the alternative means of achievement, the environment and the resource requirements; and
5. a guideline for choosing the preferred alternative which usually relates the objectives and costs in some manner; for example, the maximizing of achievement of objectives for some assured or given budget.

In water resources planning, this approach translates into identification of objectives along with associated boundary conditions or constraints, which in turn are transformed into optimal plans for development. In general, water resources planning is a technique of public investment decision-making (Grigg, 1990). Consequently, there has been an upsurge of interest and concern in recent years over water allocation and instream requirements for maintaining the integrity of aquatic riparian ecosystems.

While not all the above elements are present in this study's methodology, an attempt has been made to strike a balance between competing demands for limited stream flow. Satisfying each of the demands requires a multi-objective perspective characteristic of system-based planning.

Relationship between objectives is reflected in the concept of an environmental weighting system which is founded on the "perceived" characteristics of important elements of the system's ecology. This has totally eliminated the necessity of using sophisticated models which attempt to relate each natural factor to the others. The objectives are explicit in the sense that the environmental categories utilized in the methodology represent each interest demanding a portion of the flow. In effect, these objectives are limited only by the availability of water flowing in the stream itself and its tributaries. However, as the ensuing part of the study shows, sorting out the objectives reflects the values of the river/stream users.

4.3 WHAT THE METHODOLOGY SHOULD ESTABLISH

When an instream flow methodology workshop was held, it was recognized that development of methodologies was only an aid to establishing maintenance flows (PNWRBC, 1974).

> *Concern was felt that recommended minimum flows should be within the stream's present natural flow, that critical flow should be stated, more favourable, enhancement flow should also be given... Enhancement flow should be stated to account for future flow from reservoirs/diversions and water rights being dropped or changed, etc; in order to ensure more instream flow for fish. If the critical survival flow is not stated, then decision - makers may not*

know in effect if lowering a flow below a certain minimum is critical. And they could err costing them their fisheries.

A workshop ad-hoc committee was organized to determine on what the evaluation methodology it should and it subsequently stipulated that emphasis should be given to the following needs:

1. The need for concentrated support for early determination of a) stream resource maintenance flows under existing programs, and b) instream flows for recreation, water quality aesthetics, etc,
2. The need for development of low cost methodology for determination of:
   - 2.1 stream resource maintenance flows where existing methodologies are not applicable (warm-water fisheries, large streams, salmonoid rearing, white sturgeon etc.,); and
   - 2.2 instream flow for recreation and aesthetics, etc.
3. Need to develop a creditable program including a methodology for evaluation of impacts and benefits for increments of flow.
4. Need to develop recommendations for improvements to legal and institutional systems for control of interstate and intra-state water for above purposes (PNWRBC, Ad-hoc Instream Flow Study Evaluation Committee, 1974).

The State of Idaho Water Resources Board's view of the matter is quite plain when it expressed on behalf of other instream users that most instream uses exist within a range of tolerable flows.

Most in-stream uses have an 'extinction point', a minimum volume of water below which that use cannot exist. Similarly, most in-place water uses have a 'flood-point' where excess flows or levels effectively extinguish that water use. Somewhere between these two point lies an optimum, being that flow or level at which water use is maximized. Water to sustain or enhance in-stream use is often sought for diversion to augment food and fibre production, or to enhance commerce. A successful methodology should balance these competing demands. Where a broad methodology is contemplated which will identify net gains (or losses) at all possible flow allocations, the particular purpose of the methodology is to identify that flow distribution which delivers the maximum benefits (Trumbull & Loomis, 1973).

4.4 FEATURES OF A FUNCTIONAL METHODOLOGY

Stalnaker (1976) named several of the attributes which he associates with a functional methodology and they are as follows:

1. analytical comprehensiveness - that is all the relevant factors of the subject being evaluated;
2. secondary impacts of actions and changes in a factor being assessed; and
3. ability to relate one factor to the other factors in natural resource evaluations.

"Ability" in the last paragraph suggests the competence to include in a system or model for evaluation of resource allocation, all factors said to be relevant so that the mutual or relative effects of variables can be gauged. Also it is necessary that all especially sensitive factors pertinent to natural resources are apparent (e.g. the 'limiting factor concept' of the fishery scientist or the 'auditory component' of streamflow aesthetics). Finally, the methodology should be valid, reliable, feasible and meaningful.

Admittedly, these are stringent criteria that even the best of the present methodologies barely possess (Stalnaker and Arnette, 1976). They are viewed rather as representative characteristics of an ideal methodology from which the advantage and disadvantages of the actual methodologies can be ascertained. By applying all these criteria then, a comprehensive analysis of all existing approaches can be facilitated. These criteria can be used to determine the weak points of any methodology and then address them, in effect reducing their number or narrowing the field of research.

It is important in this regard that the planner has an idea of the intended application of the methodology. From this the appropriate approach to adopt can be determined and choice made regarding the degree of precision that can be employed relative to the amount of time and the resources available.

4.5 FLOW FIXING METHODS USED IN THE WHANGANUI RIVER

4.5.1 Physical habitat simulation (PHABSIM)

This model was used by Morhardt to simulate biotic conditions on both the Whakapapa and Whanganui Rivers (NZ Planning Tribunal, 1990). The model produced information about the physical nature of the rivers and an index of the quantity of habitat available for stream-dwelling organisms.

An indicator of habitat suitability, based on trout preference, is the weighted usable area (WUA). It was established that for most of Whakapapa River, WUA peaked at a flow range of 1 -4 $\mathbf{m^3\ s^{-1}}$. Only once was this indicator maximised at a flow range of 4-6 $\mathbf{m^3\ s^{-1}}$.

In addition, there is no implication that abstractions alone are responsible for reductions in trout population although it was accepted that they are a limiting factor. It is further claimed that frequent occurrences of high flows during freshes may be damaging to recently emerged fry, a condition which is not necessarily affected by the intake structures or other abstractions.

However, Scott disputed these findings, citing certain cases where results from the PHABSIM model were not believable, particularly on its ability to predict trout habitat (NZ Planning Tribunal, 1990). To support this, cases for the Mataura and Ahuriri Rivers were mentioned, pointing where WUA for these rivers were found to be optimum at extremely low flows. Nevertheless these findings were found by experts to be unacceptable in respect of those rivers.

4.5.2 Instream Flow Incremental Methodology (IFIM)

Stephens used this approach to estimate the flow requirements for fisheries on the Whanganui River (NZ Planning Tribunal, 1990). To estimate the impact of changing discharge, runs on simulated flows of the Whanganui River at Kakahi was carried out. At flows of 17.5 $\mathbf{m^3 s^{-1}}$ and above, conditions were acceptable for the protection and maintenance of aquatic life and fishery values. Flows below 10 $\mathbf{m^3 s^{-1}}$ were considered to provide unsatisfactory conditions and he recommended that the minimum flow at Kakahi should be at least 12.5 $\mathbf{m^3 s^{-1}}$. This flow approximates the mean annual 7-day low flow measured at Piriaka (near Kakahi). On the same basis, he suggested that the minimum flow on the Upper Whanganui River below the intake structure should be 0.51 $\mathbf{m^3 s^{-1}}$.

Stephens also proferred the following interpretation of the model's findings:

1. regardless of whether correlation between measured variables (depth, velocity, substrate and fish crop) is high, it does not necessarily imply causation;
2. measurement of velocity at 60 per cent of the depth has certain weaknesses which must be considered; and
3. the assumption that an increase in flow means an increase in habitat availability invariably holds true.

4.6 PLANNING TRIBUNAL'S INTERPRETATION

Based on the presentation of the experts using two different models, the Tribunal concluded that such findings "do not provide a safe basis" for them to make decisions on the effects of prescribed minimum flows. However, some consistencies were observed and that is where there is agreement between models and a consensus is said to be drawn. For example, both models showed better trout fishery conditions preceding diversion at Oio - a reduced trout fishery is now experienced between the intake and Oio. The models confirmed that flows below 10 $\mathbf{m}^{3}$ $\mathbf{s}^{-1}$ at Kakahi would provide an unsatisfactory reduction in trout fishery habitats in a stretch of the river where there has been and continues to be a valued trout fishery.

4.6.1 Commentary

Physical Habitat Simulation (PHABSIM), is an attempt to relate the physical structure of the stream, streamflow, water temperature and water quality in order to establish optimum habitat conditions for aquatic life. In the United States and elsewhere, the approach is considered to be the most defensible considering the present understanding of aquatic life behaviour which in turn impacts on the primary production, and secondary production and ultimately fish population (Garn, 1986)

The term "Physical Habitat" or recreational river space refers to that area of the stream which meets the velocity, depth, substrate and cover requirements of a specific stage of a species of fish or recreational activity such as boating or swimming (Milhous, et.al., 1987). They state explicitly that the approach is proven effective if the intention is to compare between two alternative strategies. But should there be only one management strategy and only some statement is needed on the fishery and recreational space of the river or stream, the system is said to be less effective (comparison of "existing" to a proposed action is a two alternative situation).

The Instream Flow Incremental Methodology (IFIM) is based on the same concept although the focus is more on fisheries and excludes the recreational use. Mathur *et.al.*, (1985), Scott and Shirvell (1987) stated that although it is reasonable to assess instream flow needs on the basis of the amount suitable for habitat, there was no evidence of correlation between species abundance and the amount of suitable habitat.

Jowett (1992) also supported this statement, pointing out that the use of inappropriate habitat curves could give rise to misleading estimates of species abundance. Some of the early habitat curves seem to describe (for brown trout) resting habitat rather than feeding habitat and even now there are significant differences between brown trout preference curves derived in New Zealand and curves derived in the United States (Raleigh et.al., 1984).

Mosley (1983), further suggested that habitat preference data needed for application of IFIM may be reliable only for the river or type of river in which data were collected. In addition to this, there are possibilities that collections were made under sub-optimal conditions which would require caution to be applied.

Milhous et.al., (1987) also advanced the difficulty of predicting the fish population considering the stochastic nature of habitat suitability in each life stage of a particular species. Considering the time lag between the moment observation are made and the occurrence of the limiting factor, which could be as long as several years, identification of any limiting event becomes even more problematic.

4.7 ENVIRONMENTAL WEIGHTING SYSTEM (EWS) AS STUDY METHODOLOGY

Apparently there are difficulties in obtaining reliable results from the above-mentioned methodologies since the true relationship between the selected variables and fish population is quite difficult to establish and differs from place to place. EWS essentially simplifies this by using expert knowledge regarding flow and fish preference, aesthetic and recreational requirements. Although also used in the US, the UK experience is more documented.

The granting of abstraction licenses, based on daily low-flow statistics in North Yorkshire, England became a problem primarily because of the inability of distinguishing between the frequency and duration of repeated abstractions (Drake, 1987). To remedy the situation a change in approach was adopted whereby limitations were imposed on the frequency and magnitude of abstraction, while at the same time protecting very low flows from further decreases. This was accomplished by setting a maximum permitted volume of abstraction during the dry months and the prescription of a minimum flow below which no abstraction would be permitted. To achieve this operational objective, a numerical weighting system was developed to measure the sensitivity of the environment to a reduction of river flow, particularly during naturally occurring low flow periods.

The people who developed the methodology, after consultations with appropriate bodies and individuals, came to the conclusion that it would not be possible to develop a numerical system based on rigorous scientific principles. It was decided to develop a system using a subjective approach, embodying the experience and opinions of those individuals and organisations connected with water abstraction and environment.

4.7.1 Environmental Categories

The system which was developed in the UK considered the environment under the following six environmental categories:

1. fisheries
2. angling
3. aquatic ecology
4. terrestial ecology
5. amenity, and
6. recreation.

For a given location in the river system, a points score was assigned to each category. The individual scores were added to give the environmental weighting (EW) which then became the overall expression of the relative sensitivity of that location to abstractions during periods of low flow.

It was recognized that each category was not independent of the others. For example, good quality water may be likely to contain good fisheries, be high in amenity values and offer recreational opportunities. For this reason, consideration was given to the use of a mutually exclusive system where the highest scoring category was used as a measure of the environmental sensitivity of the location. However, it was decided that an additive system would be preferable since it could demonstrate that specific account had been taken of all environmental factors.

Prior to development of the EW scheme for North Yorkshire, 39 organisations were consulted for their views. These organisations represented a wide range of interests relating to water abstraction and river environment, and included both local and national bodies. This is a time-consuming process but the results obtained from the UK consultations are utilized in this study of Whanganui by fitting the framework on the conditions of the latter.

In general, the responses which were obtained from the UK organisations reflected a general appreciation of, and concern for the inter-relationships between water abstraction and the river environment. Using the results of the consultation as a starting point, an EW scheme was formulated which reflected, as far as possible, the views and opinions which were expressed.

4.7.1.1 Fisheries

It was apparent that the tolerance of fish species to changes in river flow, depth and water quality, resulting from river abstractions, varies from one species to another. The approximate scale of tolerance increases from salmonoid (or game fish) to coarse fish, ie. salmonoid species are the most sensitive. Therefore the score assigned to fisheries was related to the species of fish which were present at a particular location.

4.7.1.2 Angling

The effects of abstraction on angling have been measured in terms of the intensity of angling activity rather than the species involved. Although some measure of quality of angling would have been desirable, no adequate measure could be found. Angling intensity was split into subjective groupings of heavy, moderate and lightly fished, and separate scores were assigned to each group.

4.7.1.3 Aquatic Ecology

Aquatic ecology was considered to be related to the quality of river water. Therefore, the existing classification system for a biological water quality index was adopted as a measure of the sensitivity of aquatic ecology to water abstraction. However, an aquatic Site of Special Scientific Interest (SSSI) was given a fixed score regardless of its water quality.

4.7.1.4 Terrestrial Ecology

Terrestial ecology was scored according to the existence of designated sites. The scores were related to the type of site such as national nature reserves, SSSIs, sites for protection of flora and fauna and green form sites.

4.7.1.5 Amenity

Amenity was divided into groupings of high, medium or low amenity value although it was recognized that it would be difficult to determine the appropriate grouping for a particular catchment. Hence, for example, a catchment within a national park was assigned a high amenity value, whereas a non-designated amenity, such as a riverside walk was assigned a low amenity value.

4.7.1.6 Recreation

Recreational amenity was related to water-borne activities and was sub-divided into two main groupings - canoeing and sub-aqua, and other water-borne activities.

Recognizing that environmental factors could occur which had not been specifically included (like Maori values) a further miscellaneous category was added to permit the user to score additional issues up to a defined maximum score.

The scores for each environmental category were initially selected according to the perceived sensitivity of each category to artificial reductions in low flow.

Multidisciplinary consultations and discussions were carried out to arrive at the assignment of appropriate scores for each category and sub-category.

To use the system, any person (similar to DOC-experts) with considerable knowledge and presently involved with studies on the river could be asked to perform the rating. The resulting framework and scoring system is exhibited in table form (Table 4.1). The maximum possible score is 63.

4.8 MAXIMUM PERMITTED VOLUME OF ABSTRACTION (MPV)

The determination of an allowable abstraction volume sets the amount of water that can be diverted from the river during the driest periods of the year. This method recommends the granting of abstraction rights only if such a volume is not exceeded. MPV is related to EW on the basis that catchments with high EW should have a relatively low volume of permitted abstractions (MPV).

In determining the relationship between volume and EW, the value of MPV was expressed in terms of normalized units to account for rivers of different sizes. Dry-weather flow (DWF), defined as the mean of the series of annual minimum 7-day flows, was adopted as the river flow statistic for the method. Normalization was obtained by dividing the abstraction volume by the value of DWF. With volume expressed in megalitres, and DWF in megalitres per day (Ml/d), the unit of normalized volume is days, ie. 1 unit = the volume of water obtained during 1 day at flow rate of 1 DWF. Hence actual MPV is given by expression:

$$MPV = MPV_{normalized} \times DWF$$

The next step was to make an assessment of the effect of the annual volume of licensed abstraction upon the duration of a given low flow. Assuming that 100 percent of the licensed abstraction takes place over a 60-day period, with an abstraction volume of 4 units, the average abstraction during the period would be 1/15 DWF. If this rate of abstraction was deducted from the natural flow duration curve, the

TABLE 4.1 (Proposed EWS Framework for Whanganui River)

Environmental Category	Tolerance Group	Comments	Score
			Minimum of 1 Maximum of 16
Fisheries	Game (Salmonid)	Trout	
	Upper River		
	Middle River		
	Lower River		
	Estuarine/Tidal		
Angling intensity	Heavily fished		6
	Moderately fished		3
	Lightly fished		1
Aquatic Ecology	Aquatic SSSI		16
	Biological water quality:		
	B1A		13
	B1B		10
	B2		6
	B3		2
	B4		1
			Maximum of 8 Minimum of 1
Terrestial Ecology	National Parks/Forest Parks		
	Reserves		
	Natural Vegetations		
	Farmlands		
	Other Sites		
Amenity	High	National Parks	8
	Medium	Specific sites	5
	Low	Riverside Walks	1
			Maximum of 3 Minimum of 0
Water-borne recreation	Canoeing		
	Rafting		
	Jetboating		
Miscellaneous	To allow sufficient flexibility in weighting system to account for special circumstances not already defined.		Max 6

1\ Key to Biotic Indices:	
B1A	Clean: Trout Abundant
B1B	Moderately Polluted: Trout and course fish
B2	Polluted: Trout rare
B3	Heavily polluted: Course fish rare
B4	Grossly polluted: Fishless

resulting net flow duration curve would be shifted along the time axis. The amount of the shift would then represent the increase in the number of days on average that low flows would occur as a result of the abstraction.

Flow duration curves for several stations in the study were constructed and the average shift in the number of days of low flow for a volume of 4 abstraction units was about 7 days, although rivers with high base flow rates and particularly flashy rivers respectively gave extreme shifts of 19 days and 2 days.

Relating the shift in days to the individual river types, it was considered that a normalized MPV of 4 units should be the maximum applied to the majority of environmentally sensitive rivers.

It should be mentioned that these values were derived using rivers subject to intense competition for in-stream water considering the agricultural applications for which the water being extracted serves. However, because not all streams may be in such high use - demand conditions, it is suggested that for smaller, less competitive demand situations twice as much abstraction should be permitted during the driest periods of the year. This sets the MPV to a value of about 8 units.

These values were checked using sub-catchments in the North Yorkshire region where abstractions ranged between 0.2 units to about 3.5 units. For areas where there is intense pressure to irrigate, normalized volumes of abstractions tended to be in the highest band of values (Drake et.al, 1987). These places also had relatively high EW scores. Taking these matters into account and considering their experience and knowledge in the use of spray irrigation in their environmentally sensitive catchments, values ranging from 3 to 4 units were recommended.

4.9 WEIGHTING SCHEMES

Goodman (1985) stated that weighting schemes are both feasible and widely practiced. They provide procedures for aggregating scores for separate dimensions into a total score - similar to evaluation of policy alternatives.

Goodman has reviewed a number of studies dealing with weighting of objectives and component parts of objectives (factors).

4.9.1 Consensual Weighting

Consensual weights represent a consensus among experts or the official decision of an authoritative group which are constructed from empirically established trade-off curves for the affected parties and the subjective judgement of the relative importance of each group's trade-off curve.

4.9.2 Formula Weighting

Formula weights provide for example, a weight for an impact obtained by the product of the people affected, the intensity of impact and probability of impact.

A formula weight is best exemplified by an ordinary statistical regression equation $Y = a_1 + b_1X_1 + b_2X_2$ where variables X_1 and X_2 are said to have an additive impact on Y.

4.9.3 Subjective Weighting

Justified subjective weightings imply that the criteria for assigning weightings are explicitly spelled out. Procedures using subjective weightings are quite prevalent. They may be assigned to objectives, dimensions, impacts or alternatives and by decision - makers, expert judges, representatives of interested parties or samples of the relevant general public. Subjective weights may be assigned by simple score assignment process, a trade-off matrix, paired comparison trade-offs, indifference curves or delphi procedures.

Subjective weighting is adopted in the environmental weighting system primarily because of its relative simplicity and ease of application. Since the assignment of scores made by individual experts may vary significantly, a quick determination of its median value is adopted to assign a single score to categories and subcategories of the environmental components.

4.10 METHODOLOGIES USING WEIGHTING SCHEME

4.10.1 The Goals Achievement Matrix

A great deal of similarity to the environmental weighting system is found in this planning technique. The different environmental categories used in this study somewhat resemble the use of different operational objectives to achieve the ultimate goal of optimizing benefits.

The novel aspects of this method are, firstly, that it seeks the degree to which all alternative achieve the operational objectives identified earlier in the planning process. It is then intended that the degree to which each alternative achieves an objective can be given a numerical value. In addition, each objective is given a numerical weighting to reflect its relative importance to the community, and these are used to weigh up the level of goal achievement (Hobbs, 1981). Secondly, the method identifies the various groups in the community and also gives them numerical weightings to reflect the relative importance of each goal to each group.

4.10.2 Development Potential Analysis

This method is an effort to systematize and quantify the potential of different region by presenting them as a surface. Its similarity to the environmental weighting scheme is manifested in the use of subjective weightings for identified objectives and the scoring of them same using a common scale.

Le Heron and Heerdegen (1978), describe the procedure of the technique as follows: First, the potential of each part of the region is derived from a number of potential surfaces, each of which is related to some index or standard that measures achievement of an objective or objectives. Thus, the potential for housing may be thought of as a landscape potential, an agricultural potential, servicing potential, residential environment potential, annoyance potential, job access potential or a rail access potential.

The region is divided into sub-units ranging from a few hundred $\mathbf{m^2}$ to a few $\mathbf{km^2}$, the scale depending on the type of planning being undertaken and the limitations of data and the analytical tools. The potential is calculated for each factor, e.g. shopping access, job access and then scales are used to standardize the measurement. For example a scale of 0 to 100 can be used to convert factor scores into single scores which then become additive in terms of their values.

The next procedure is to survey the preference of individuals for a list of objectives by means of ranking. The highest score shows greatest desirability and while access to jobs may be more important to some than access to shopping areas this may not always be so and others may prefer to be closer to shopping malls than job areas. Potential scores are then multiplied to the assigned weightings and a single score for each sub-unit is determined.

Alternative strategies may give different weightings for each factor, e.g. a strategy for protection of farmland may give higher weighting to the factor of agriculture/land productivity than to factor such as accessibility.

4.11 DERIVATION OF THE ENVIRONMENTAL WEIGHTING (EW) SCHEME

Because the scope of this study necessitates the design of an appropriate EW scheme, the North Yorkshire framework is, nevertheless, used for the Whanganui River. It requires some adjustments and revisions to make it more pertinent to this area. For this reason a semi-Delphi approach is adopted to gather all the necessary information from experts involved in the study of the River and its tributaries. A brief background on the approach is given below.

4.11.1 Delphi Method

The Delphi method is a technique for obtaining the most reliable consensus of opinion from a group of experts using a series of questionnaires. Answer forms are interspersed with controlled opinion feedback (Dalkey and Helmer, 1963). It was developed in the 1950's when the RAND Corporation of the USA used it to forecast events regarding the potential effects of nuclear bombs as seen from the Soviet perspective rather than from that of the American military armaments industry.

In the succeeding years of the sixties, technological forecasting became its focal area of application, specifically for the advanced technology of the United States. It evolved into a very useful tool for planners in almost every part of the world. In one of its largest applications in Japan, several thousand people were involved in the consultations.

The Delphi method, in its original form has the following elements:

1. structuring of information flow;
2. feedback to the participants; and
3. anonymity for participants.

In this study, adoption of the process involved making appropriate contacts with officials of the Department of Conservation in Whanganui. Those who were consulted were informed of the methodology being followed. Respondents were carefully selected from a pool of experts whose involvement in studies of the river were considered substantive. To eliminate the 'bandwagon effect', usually experienced when in open conference, individual questionnaires were handed out for them to fill in. Discussion took place with them prior to the form filling to outline the technique. Collective or joint answering of the questionnaire was discouraged.

The procedure followed here is the basic Delphi Technique as it is more-or-less characterized by the three attributes already mentioned. Andrews et.al.(1976) noted the increasing use of this technique for evaluation of natural resources which are regarded as difficult to measure directly. The technique is characterized by a repetitive process of inquiry ensuring that all relevant aspects of the subject are covered. This applies to all areas or subject of interest either true or hypothesized.

One particular and yet very critical element of the methodology is using the knowledge or experience of respondents who must be experts. Experts on recreational use, recreation specialists and resource managers are the most valued respondents to weigh up the potential impact of natural resource changes on recreation (Andrews, 1976).

It is to be expected that experts will express their own judgements and opinions on the area of inquiry (or even the methodology or technique being advanced). Because of this it is essential to summarize the feedback and re-present it to them for reassessment and if possible for re-ranking of their previous assessments. Ideally this process should continue until their answers are consistent and it can be assumed that consensus has been reached. It is not unusual to have as many as four iterations in this process.

To ensure awareness among the respondents of the technique being applied in this study, a brief backgrounder on the environmental weighting scheme was attached with the survey questionnaires (see Appendix 5). Discussions with the DOC co-ordinator was also carried out to clarify certain points of the technique which may have caused some vague answers. An 'informal' discussion among selected experts (but individual answering to the questionnaires) was encouraged to maximize the possibility of consistent responses thus lessening the iterations necessary.

An example of this approach was an assessment of 'recreation opportunity spectrum' conducted by the Technical Committee of Water Resources Research Centers of Thirteen Western States in the United

States (1974). First, the prime public goal (recreation opportunity) was disaggregated deductively into 'subgoals' through content analysis of public responses to open ended questions regarding social goals. These subgoals were then related to 'indicators' of the state of subgoals. A Delphi Method was used to accomplish this (Andrews, 1976) in the same manner as the environmental weighting scheme related the numerical indicators to the state of the general environment. By doing so, a system was developed to identify different environmental elements and weighting them for quantitative analysis.

4.11.2 Revision of North Yorkshire EW Scheme

The present framework of an EW scheme for the North Yorkshire Water Authority is considered to be applicable to the purpose of this study despite some minor alterations to suit the local conditions. This greatly shortened the amount of consultation required to construct a new framework. The values held by different organizations dependent on the flows in the river should be reflected in the framework. One of the greatest strengths of the approach is the ability to synthesize different knowledge and experiences into a single methodology, resulting in a quicker and with care, reliable manner of quantifying the flows required for environmental protection and different instream uses.

Functionally the river has been divided into three parts - the upper, middle and lower reaches. While this division is arbitrary rather than based on physical boundaries, it greatly simplifies the application of the technique. Past studies of the river use this terminology. The upper reaches are usually referred to as the stretch from the headwaters down to Taumarunui, the middle reaches cover the area from Taumarunui to Pipiriki while from Pipiriki to Whanganui is known as the lower reaches (DOC, 1988).

Most of the refinements to the method are confined to the three environmental categories which define the Whanganui River system - fisheries, terrestial ecology and water-borne recreation. It is in these areas that most of the field work was focused to ensure that the framework represents the actual conditions existing in the river basin. Categories on angling, aquatic ecology, amenity and recreation are the same as those of North Yorkshire's in effect allowing the adoption of the same scores for the Whanganui River.

4.11.2.1 Fisheries

There are major differences between the UK model and the framework developed for Whanganui River except for the sport fish species of brown trout and other salmonoids which are used as the baseline of environmental sensitivity. Previous surveys of the Whanganui have revealed the presence of the following species: brown trout, rainbow trout, lamprey, shortfinned eel, longfinned eel, common smelt, banded kokopu, shortjawed kokopu, inanga, koaro, torrentfish, redfinned bully, common bully, upland bully, craws bully, yellow-eyed mullet, grey mullet, kahawai, black flounder and the yellow belly flounder. The respondents provided the weighting scores and sorted out the species into different tolerance groups.

It was established that there were numerous juvenile brown trout in the upper reaches of the Whanganui River at Kakahi while eels are particularly abundant at Whanga Peki and Kakahi (DOC, 1988).

Records of species occurrence and knowledge of their distribution are based on electrofishing surveys. More extensive surveys have been carried out in the headwaters while the less accessible middle reaches and western tributaries have received comparatively little attention.

Indices of fish abundance in larger headwater tributaries were also assessed using drift-diving, found to be an effective method for counting medium and large trout (>25 centimetres long) but probably incapable of dealing with small trout or native fishes including eels.

Based on these surveys, Richardson and Tierney (1982) established that the greatest fish density was in a 1.7 km stretch from the Whakapapa/Whanganui confluence to the Kakahi rubbish tip area.

To preserve the overall weighting recommended for each environmental category by the model, ranking scores of each subcategory are given upper and lower bound limits. That is, fisheries tolerance groups are rank scored from a high of 16 to a low of 1, depending on the perceived sensitivity of each group.

Since expert-opinion often differs significantly, median scoring may be adopted as an alternative to averaging, thereby eliminating excessive distortion of the weightings provided for the final framework.

4.11.2.2 Terrestial Ecology

This category represents plant and animal life along the stream's riparian fringes. DOC (1988), in its submissions to the Planning Tribunal claimed that the River ranks highly among New Zealand's river systems.

In the upper reaches, the River is host to a terrestial species called blue duck (*Hymenolaimus malacorhynchos*), one of the country's endangered species. In the same document, the Department of Conservation expressed their belief that long term diversity, balance and the inter-relationships of the species present is vitally linked to water quality and quantity and to flows in general.

In addition, the middle reaches have become part of a new national park and have experienced a resurgence of interest by tourists and those using it for recreation.

Considering the sensitive features of the catchment, the terrestial ecology of the river can best be represented using the following sub-categories: 1. national parks; ii. reserves; iii. other areas of natural vegetation; iv. farmlands; and v. other sites.

Since the blue duck habitat is only found on the upper reaches of the River, use may be made of the 'other sites' category and given a maximum score of 8. During the ranking of the sub-categories under this item, respondents were advised to weight each item from their perception of any environmental category's sensitivity to water abstractions. Therefore, the maximum rate of 8 may not have been necessarily ascribed to any item if it was found to be unwarranted.

Again, median scores are adopted as the representative weight of each sub-category.

4.11.2.3 Water-Borne Recreation

The New Zealand Jet Boat Association (1983), stated that the river system contained a wide variety of scenery and fauna as well as navigable water, from the faster flowing rock strewn river bed below Taumarunui, to the magnificent steep rock-sided gorges above Pipiriki together with rapids and slower flowing lower areas.

Among the recreational activities highly valued in the river there is jetboating, canoeing, and rafting. These leisurely pursuits are affected by flow reduction to varying extents depending on the capability of the craft to navigate the river without damage being incurred to their hulls. Jetboaters for example can negotiate very shallow areas by reducing their loads. Rafting on the other hand, is more seriously affected by flow reductions since the level of satisfaction depends on the availability of white water which, according to experienced rafters, provides thrill to the sport. These factors are considered by experts when scoring the sensitivity of water-borne activities to abstraction. Median scores are to be adopted in the EWSof this category in the same manner as the other three revised categories.

4.12 COMPUTATION OF DRY-WEATHER-FLOW

Investigation of flood flows has always dominated the literature although there is now an increasing interest in studies of low flows, particularly because of their importance to analysis of drought occurrences. Matalas (1963), stated that the principal requirements for annual minimum discharges are that:

1. the distribution should be skewed;
2. have a finite lower limit greater than or equal to 0; and
3. be defined by a maximum of 3 parameters.

Data availability constrains the third requirement as insufficient record often does not allow statistical analysis to be carried out. Shaw (1988) demonstrated that the Gumbel distribution of the smallest value is one of the most reliable approaches, and because of its simplicity, is recommended for the assessment of the frequency of annual minimum flows.

To run the computations, at least 20 years of Annual Minimum Daily Mean Flows should be obtained for best outcome. Then the annual minimum values are ranked from highest to the lowest. Gringorten and Weibull plotting positions maybe used to transform the data into a frequency curve.

A probability distribution for low flows having a fixed lower limit is equivalent to the EVIII distribution in reverse and is given by:

$$P(X) = \exp\left(-\frac{X-\epsilon}{\theta-\epsilon}\right)^{k}$$

where ε = is the minimum flow ≥ 0, and $X \geq \varepsilon$, Θ is called the characteristic drought, with $P(\Theta) = e^{-1} = 0.368$ and k is the third parameter. If the minimum flow is assumed to be 0, the formula reduces to a two-parameter distribution:

$$P(X) = \exp\left(-\left(\frac{X}{\theta}\right)^{k}\right)$$

To determine the parameters of the distribution, Q_m and s_m of the population and the standard deviation of the sample ($_m$ *and* σ_m)are required. The quotient $_m/\sigma_m$ is a complex function of k, while an estimate of $1/k$ can be read from Gumbel's EVII distribution table and an estimate of Θ is given by:

$$\hat{\theta} = \frac{\bar{Q}_m}{\gamma\left(1+\frac{1}{k}\right)}$$

where τ is a gamma function found in standard tables.

For the EVII distribution, $(X/\Theta)^{k}$ is made equal to e^{y}. Taking logarithms of the equality:

$$e^{y}=\left(\frac{Q}{\theta}\right)^{k}$$

$$y = k \ln Q - k \ln \Theta$$

and

$$\ln Q = \ln \Theta + (1/k)\, y$$

For the probability range of $0.001 \leq P \leq 0.999$, the variate y lies in the interval $2 > y > -7$. This makes it possible to use the flood probability function for drought merely by changing the sign of y to $-y$ (Gumbel, 1963).

4.13 SUMMARY

Apparently the application of most notable approaches such as the PHABSIM and IFIM gained little recognition from the Planning Tribunal during their deliberations. One reason perhaps, is partly due to the limited successful application of the methodology in New Zealand. Even the experts in the field attested to the weakness of the approach which they attribute to the lack of understanding of all factors contributing to the formation of ideal habitats for fisheries.

The EWS may overcome this methodological inadequacy by consulting with appropriate experts who have personal knowledge of the river's characteristics. Experience has shown that this approach has led to reliable results, eliminating the need for extensive studies similar to the verification of fish preferences which often is necessary when using IFIM and PHABSIM models.

Also with the inclusion of other environmental factors in EWS, there is a wider basis for calculation of flows unlike in other approaches where fisheries is used as the sole determinant. Stalnaker (1977), view this as rather incomprehensive requiring a separate evaluation for other factors as well, thus creating the potential for higher expense.

To sum up, the overall methodology first involves the revision of the North Yorkshire EWS. Determination of EPF and MPV using the revised version of EWS came next and followed by subsequent analysis of the potential effects of this flow regime to fisheries, navigation and ECNZ operations. Since the premise of the methology is that the flows recommended will be favourable to the environmental categories considered, the impact of flow recommendation on ECNZ is uncertain. Should the flow recommended using the methodology not be found viable for reasons like being financially damaging to the ECNZ, an attempt would be made to formulate an abstraction pattern consistent with the principle of protecting the low-flows at the same time not being severely detrimental to the ECNZ scheme.

CHAPTER V

RESULTS AND DISCUSSION

5.1 INTRODUCTION

In this chapter the results of consultations with the experts in the Department of Conservation (DOC) are discussed and included in the Environmental Weighting System. The meetings with DOC experts were made initially during the process of revising the environmental weighting scheme (EWS) and ultimately in the application itself. The DOC-coordinator played an integral role in modifying the EWS based on the North-Yorkshire model and then in its subsequent use for quantification of environmental sensitivity along different reaches of the Whanganui River.

This discussion is limited to the feedback obtained from the experts on the EWS itself and is a result of consultations where other issues cropped up which DOC-experts perceived to be important for the framing of a valid EWS. Their comments were considered during the final outcome of the weighting which ultimately influenced the flow recommendations arising from the EWS analysis.

It should be noted that the DOC-coordinator had already supplied, in summary form, the ratings made by him and his colleagues. It was then assumed that a certain form of consensus had been reached among the experts concerned.

The EW Table is consist of 7 environmental categories namely: i) fisheries; ii) angling intensity; iii) aquatic ecology; iv)terrestial ecology; v) amenity; vi) water-borne recreation; and vii) miscellaneous.

Within each environmental category there are tolerance groups (e.g. for fisheries tolerance group is comprised of Game (Salmonids), Upper, Middle or Lower River inhabiting fish). Each species within a particular grouping is considered equally tolerant to flow alterations as the rest of that group where it is classified.

Comments column on the other hand, allows for additional information to be inserted regarding each tolerance group. The Upper River Tolerance Group for instance, includes species as the upland bully, torrent fish, crans bully, red-finned bully and blue-gilled bully.

A score, which is the median score from the group of DOC experts, is allocated to each Tolerance Group. The selected score for each individual Environmental Category is then made on the basis of the dominant characteristics for that reach.

(See Table 5.5 for an example)

5.2 THE WHANGANUI RIVER EWS

The final weighting of the EWS framework showed substantial differences from that of the British model. As already mentioned these were all expected as they reflected the inherent features of the Whanganui River based on the perception and knowledge of those who provided the scores and available information on the river.

Since no attempt was made to obtain first order data, much important information concerning the river was not included. As a result the accuracy of the results may be somewhat lessened. For example, expert respondents admitted that information on the fisheries in the middle and lower river reaches is poor. This has substantial impact on the weighting scheme as it tends to hide valuable information regarding the true sensitivity of those locations, eventually affecting the allowable changes in the flow regime. Suggestions regarding the overall weighting of environmental categories were also made by the respondents. However, after careful consideration of the implications of their suggestions the decision was made to stay with the original weighting. It should be noted the EWS for North-Yorkshire was calibrated for the appropriate environmental prescribed flows (EPF) and that any revisions on the weighting of environmental categories required adjustments of EPF values as well. Major revisions are, nevertheless, possible provided the necessary resources to carry out the different organizational consultations are given. In other words, the restricted consultations made for framing the Whanganui River EWS reflects the very limited resources available.

DOC-expert respondents also made valid comments regarding the importance given to politically motivated designations which tend to undermine the true value of river features. For example, in North Yorkshire, National Parks were much preferred over other amenities such as wildlife sanctuaries simply because most respondents to the North yorkshire EWS were not appreciative of the true value of wildlife.

Overall, however, the results can be considered to be acceptable for the purpose of managing abstractions in the Whanganui River. The flow estimates are somewhat conservative, however, considering the conditions imposed on allowable changes in flow regimes as measured by the appropriate flow-duration curves.

What follows are the discussions on the different environmental categories and sub-categories which figured in this study.

5.2.1 Fisheries

The experts rated fisheries highly in terms of their response to flow changes and expressed similar preferences to the North Yorkshire experts. Salmonids were rated by experts both in Whanganui and North Yorkshire as the most sensitive species implying that they can be used as an indicator of any particular reach's tolerance to flow changes.

Local experts, however, confidently claim that native fisheries have higher tolerance to change in their environment, thus reflecting the lower scores given to them. Salmonids, such as rainbow trout, are found mostly in the lower and middle reaches of the Whanganui River and are valued heavily for recreational use such as angling. Fisheries was grouped and scored by the DOC-experts as shown in Table 5.1.

Fisheries in general can be affected by flow either directly or indirectly. Four main parameters are said to affect them and were identified as flow, temperature, velocity and depth. Temperature affects fish physiologically Fry (1991) and also its growth (Brett, 1979). Cranshaw (1977), also stated that sudden changes in temperature, e.g. thermal discharge or extreme daily fluctuations may cause acute physiological stress. The extent of its effect depends on both the degree of temperature change and the acclimatization temperature of the species.

Certain temperature changes are, however, tolerated as long as the change remains gradual enough to allow metabolism to adapt (McCarter, 1988). It is also recognized that seasonal changes in water temperature depress or enhance growth rates and influence other aspects of metabolism.

Table 5.1 -

Tolerance Group	Comments	Score
Game (Salmonid)	Rainbow Trout	16
Upper River	Upland Bully Torrent Fish Crans Bully Red-Finned Bully Blue-Gilled Bully	12
Middle Lower	Smelt	6
Lower River	Koaro Bullies Inanga Short-finned Eel Catfish	6

For each species, tolerance levels differ especially for trout, which are considered more sensitive to changes in temperature. See Tables 5.2 A and 5.2 B.

Table 5.2 A (Source: Mc Carter, 1988)

Summary of Thermal Preference and Tolerance Data (C) for Brown Trout (*Salmo Truta*)					
Optimum Temperature and the Author		**Final Preference - Upper/Lower Limits and the Author**		**Lethal Temperature and the Author**	
10	Pentelow (1939)	12	Spigarelli et.al. (1983)	23	Bishai (1960)
12	Swift (1961)	12.2	Reynolds and Casterlin (1979)	23	Cherry et.al., (1977)
15.5	Wingfield (1940)	14.3 to 17.4	Cherry et.al., (1977)	26.4	Alabaster and Downing (1966)
		17.6	Ferguson (1958)		

A significant spread (about 5 C) in the range of 'optimum temperature' can be observed from the above data while a similar gap in observed values can be found in the 'final preference' levels. As far as lethal temperature is concerned, the data show a variation of only about 3.4 C between lowest and highest observations.

It is hard to attribute these differences in temperature levels to particular factors but it can be speculated that acclimation is one of the reasons for the differences in observations.

Table 5.2 A shows that although brown trout exhibit a wider band of survival temperatures between the optimum and lethal levels, its ultimate level is only about 26.4 C. This can be compared to the rainbow trout which thrives in an optimum of up to 17.2 C, has a final preference of 19.2 C, with a lethal temperature level from 23 C to 27.5 C. Note that the spread between the optimum and the final preference is a narrow 2.0 C, suggesting the sensitivity of the species to temperature fluctuations which can be caused by flow changes.

Table 5.2 B (Source: Mc Carter, 1988)

Summary of Thermal Preference and Tolerance Data (C) of Rainbow Trout (*Salmo Gairdneri*)					
Optimum Temperature and Author/Authors		**Final Preference -Upper and Lower Limits and Author/Authors**		**Lethal Temperature and Author/Authors**	
11.6 - 15.7	Garside and Tait (1958)	11 - 18	Kwain & McCauley (1978)	23	Bishai (1960)
16.5	Wurtsbaugh and Davies (1977)	11.3	McCauley et.al., (1977)	24	USEPA (1976)
17	Papoutsoglou et.al., (1978)	14.2	McCauley and Huggins (1979)	25	Black (1953)
17.2	Hokanson et.al., (1977)	14.7	Peterson et.al., (1979)	25	Hokanson et.al, (1977)
		18	Cherry et.al., (1975)	26	Bidgood & Berst (1969)
		18	Javaid & Anderson (1967)	26.2	Kaya (1978)
		18.5	McCauley and Pond (1971)	26.5	Albaster & Welcomme (1962)
		19.2	Cherry Et.al., (1977)	27	Craigie (1963)

As far as the trout population of the Whanganui River is concerned, researchers agree that brown trout and rainbow trout can be stressed at temperatures higher than 20 C to which fish response depends not on temperature alone but also on the duration of acclimation (McCarter, 1988). Nonetheless, the lethal temperature is not of much concern here, but rather the deleterious effects of the sub-lethal temperature which increases disease susceptibility (Clifton-Hadley, 1986), reduced growth rate (Elliot, 1975), and reduced angler success (Alabaster, 1986).

The respondents also confirmed that any increase in peak annual temperature resulting from abstractions in the Whakapapa River is unlikely to have a serious impact on the growth and condition of the trout population.

To sum up, there is general acceptance that the temperature change due to flow alterations can affect fisheries in the Whanganui River although it is unlikely to be lethal. Rather, sub-lethal temperature's long-term effect on the growth and condition of the trout fishery is likely to be of much greater consequence (Mc Carter, 1988).

In effect, DOC experts attribute the sensitivity of fisheries to flow alterations because of its contribution to the variability of physical habitat. Fish preference for instream dwelling is an established function of flow and other physical parameters of the river. For this reason, flow calculations can be based on this premise if the aim is to reserve part of the discharge for maintenance of environmental integrity. Experts agree that the primary reason for prescribing the minimum flow in Whanganui River is to maintain ideal habitat conditions not only for resting and spawning but food production as well.

One way of directly tackling this is by using an approach, such as the IFIM which employs different criteria for each species and life stages. Stephens used this in Whanganui River albeit somewhat less effectively because of perceived weaknesses in the assumptions (NZPT, 1990).

5.2.2 Terrestial Ecology

Another environmental category revised to suit the conditions of the Whanganui River is terrestial ecology. Here the classification of sub-categories includes National Parks and Forest Parks where it is said that interactions between plants, animals and even humans takes place. Experts posit that the riparian vegetation in these areas offers important sanctuary for wildlife which in turn provides an opportunity for tourists/recreation seekers to appreciate the scenery.

General relationships between river flow and terrestial wildlife however has not been established yet. On a purely hypothetical basis Kadlic

(1976) proposes four kinds of relationships which he represents graphically. (See Fig. 5.1). In situations B, C, and D kadlic considers that there is no biological basis for determining the flow except for coming up with a decision on the desired level of the wildlife population first. He considers that the inverted U in (A) still holds true and that if there is not much concern with the actual size of the population, the aim is simply to achieve the optimum or maximum. These curves, however, carry different values for each species in the sanctuary and the combination demonstrated in these graphical relationships only offers more complex decision scenarios rather than affecting the outcome.

The derived environmental weighting system greatly simplified the approach in this situation. The scores listed in Table 5.3 shows how the DOC scientists rated the different sanctuaries for wildlife in terms of their potential for damage for below-normal flows.

Here, the basis for the scores is tied purely to the expert's understanding of the complex cause and effect chain. Kadlic, on the other hand, postulates that there are at least four classes of cause and effect of altered flow regimes:

1. Reduction or elimination of drinking water for terrestial birds and mammals although not all are affected by this.
2. Changes in flow pattern may directly affect aquatic wildlife (such as the blue duck).
3. Lowered water tables may alter riparian vegetation taking away a vital element of habitat for certain animal species.

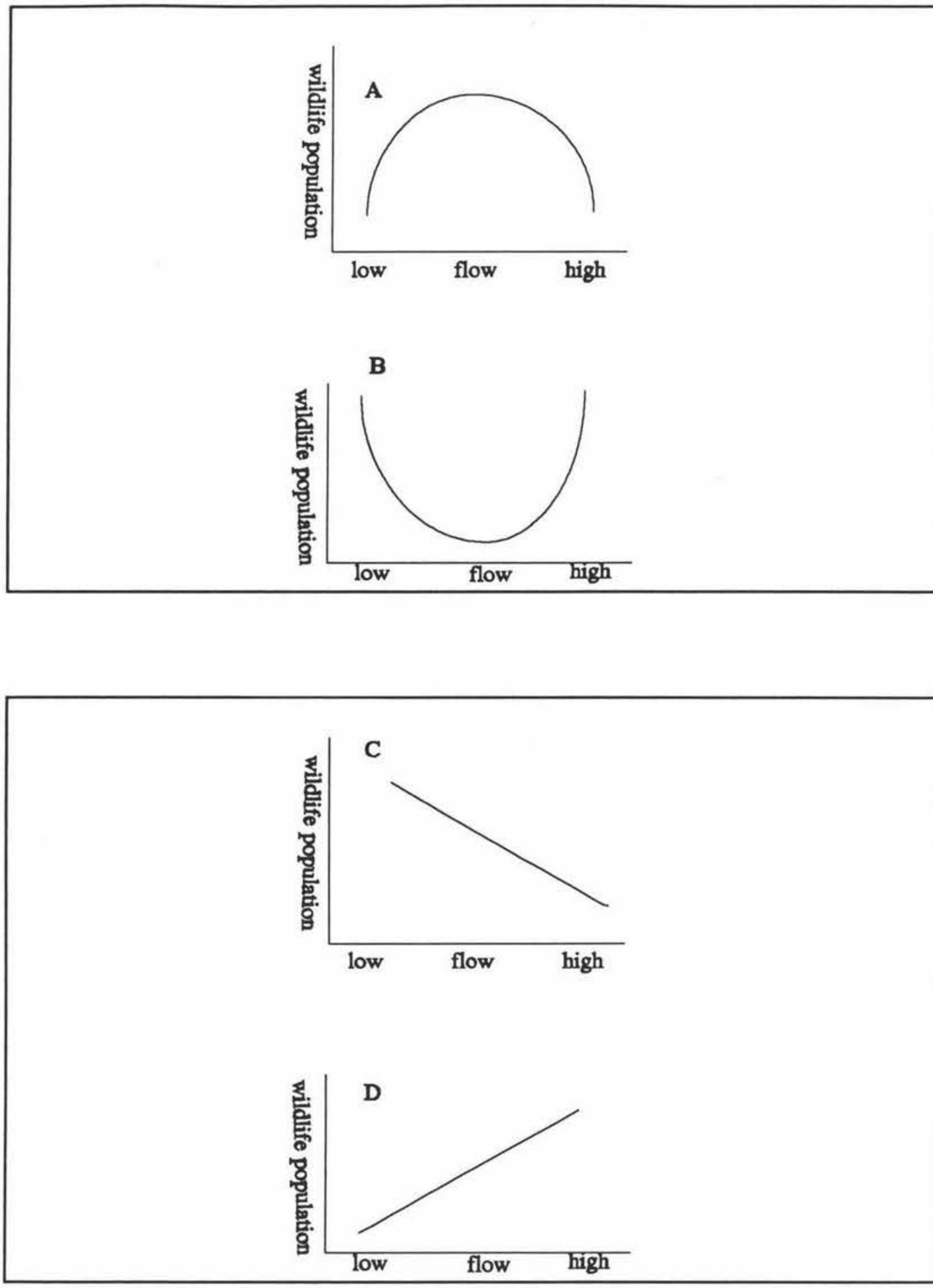

A
wildlife population
low
flow
high
B
wildlife population
low
flow
high
C
wildlife population
low
flow
high
D
wildlife population
low
flow
high

Figure 5.1

4. Changed patterns of flooding may affect wetland habitat such as willows and marshes which depend on floodwater for maintenance.

Table 5.3 -

RATINGS FOR TERRESTIAL ECOLOGY	
Sub-Categories	Scores
National Parks and Forest Parks	8
Reserves	6
Natural Vegetation	3
Farmlands	1
Other Sites	1

The DOC submission (Vol. II, 1988) to the Planning tribunal Hearing on the matter of minimum flow stated since that if the water resources of the Tongariro State Forest were of importance to downstream users, wildlife and recreation, then it would appear equally appropriate to reassess the possibility of increasing water flows in the main tributaries especially the Whakapapa River. It further suggested the desirability of not having any streams in the Tongariro State Forest running dry due to abstractions.

Consideration of these relevant causes and effects led to the conclusion that damage is greater where the density of wildlife stock is the highest. DOC experts perceive that National Parks and Forest Parks carry this potential and thus should be marked highly. During the consultation, the DOC expert raised some important issues like the possibility of basing the sensitivity on the species of wildlife along the riparian fringes, an approach which is somewhat similar with the fishery.

However, because of a lack of information on this aspect, the proposed EWS framework was not changed.

5.2.3 Amenities

The fact that the river flows through a national park represents not only recreational but economic interests as well. The concept of participatory tourism, where the growth of privately-owned river boats are encouraged to serve public needs, is indicative of the potential of the river to deliver significant economic gains to the region other than power generation.

As well, the river not only provides an access to the park but by itself also contributes to the nationally recognized scenic value of the area. The condition of the river also plays a significant role in user scenic/sensory perception (DOC-evidence, 1988). For example low flows result in a higher exposure rate of beds, banks and boulders, an increased level of offensive smell, a reduced visual water quality and a reduction of total environmental quality. Apparently when DOC (1988) conducted their studies they found out that a drop in water discharge below 30 - 34 m^3s^{-1} resulted in sensory detraction and reduced environmental appreciation.

Initially DOC experts were asked which amenities of the river were considered highly sensitive, then moderately sensitive and lastly slightly sensitive. Table 5.4 shows the specific features of the river which the experts identified as falling into these categories.

Aesthetic qualities are perhaps one of the reasons why people patronise a Park for leisure or any recreational activity. When queried on their answers experts seem to relate the sensitivity of the area to the aesthetic qualities it possesses and whether abstractions are capable of ravaging the appreciated features of the river.

National Parks here are once again seen as fitting this description. Raters believe that the natural interface of water and land already represents an irreplaceable scenery which unnaturally low flows can deface. Understandably experience of low flows can be very disappointing to people visiting the Park, a fact which ultimately can impact on the income of people depending on tourism for livelihood.

Table 5.4 -

AMENITY SCORE		
Tolerance Group	Representative Areas	Score
High	National Parks	8
Medium	Specific Sites	5
Low	Riverside Walks	1

Also for practical reasons, it is considered by experts that denying the river of its flows is the same as taking away the Park from the people. The Park is the river. Boat operators claim that their vessels, which in the main is the way most tourists will visit the park, are only capable of negotiating the river given sufficient depth. Reduction of flows by diversion, in this sense, undermines the earning potential of the boat operators. The TPD abstractions have identifiable economic costs as well as easily proven benefits derived from electricity generation. This is compelling enough to accept that abstractions can actually harm the Park and the people depending on it in many ways.

Because of the numerous interests involved, Parks are rated as the most sensitive in the sub-category. For other amenities such as walks and natural reserves, sensitivity was found not to be as high as the National Parks. One of the raters, however, cautioned that these numbers must be treated with great care as what may be important to one person may not be as important to others. An example of this is the relative weighting of National Parks and walks. Whereas some would rate National Parks very highly, some may perceive that walks are more important and thus, must be protected from any activities which could decrease their value. This then is the essence of the exercise as it tries to give weight to those matters considered more important by the majority of users. Because of the complexities involved, most, if not all methodologies rely on a subjective approach e.g., the Battelle Method, the Leopold Matrix etc.

Tables 5.5, 5.6 and 5.7 show the ratings for the Upper, Middle and the Lower traverses of Whanganui River.

5.2.4 Water-Borne Recreation

Three major recreational activities were identified by the experts to be popular in this river. It includes: i) rafting; ii)canoeing/kayaking; and iii) jetboating. Among the three, rafting is considered by experts to be most sensitive to abstraction because of its dependence on quality white water which creates exciting conditions according to those engaged in the sport.

Usually, the Upper Reaches of the Whanganui River is sought for its white water feature while the Middle and the Lower Reaches are more patronized by rafters for its wild and scenic view ideal for expeditionary interests (DOC, 1988).

Table 5.5
Upper Reach EW Ratings

Environmental Category	Tolerance Group	Comments	Score
Fisheries	Game (Salmonid)	Rainbow Trout	(16)
	Upper River	Upland Bully Torrent Fish Crans Bully Red-finned Bully Blue-gilled Bully	12
	Middle River	Smelt	6
	Lower River	Koaro Bullies Inanga Short-finned Eel Catfish	6
Angling intensity	Heavily fished		6
	Moderately fished		(3)
	Lightly fished		1
Aquatic Ecology	Aquatic SSSI		16
	Biological water quality:		
	B1A		(13)
	B1B		10
	B2		6
	B3		2
	B4		1
Terrestial Ecology	National Parks/Forest Parks		(8)
	Reserves		6
	Natural Vegetations		3
	Farmlands		7
	Other Sites		1
Amenity	High	National Parks	(8)
	Medium	Specific sites	5
	Low	Riverside Walks	1
Water-borne recreation	Canoeing		2
	Rafting		(3)
	Jetboating		1
Miscellaneous	To allow sufficient flexibility in weighting system to account for special circumstances not already defined.		Maximum of 6
		Maori Values	(6)
		Historic Values	4
TOTAL SCORE			57

1\ Key to Biotic Indices:	
B1A	Clean: Trout Abundant
B1B	Moderately Polluted: Trout and course fish
B2	Polluted: Trout rare
B3	Heavily polluted: Course fish rare
B4	Grossly polluted: Fishless

Table 5.6

Middle Reach EW Ratings

Environmental Category	Tolerance Group	Comments	Score
Fisheries	Game (Salmonid)	Rainbow Trout	(16)
	Upper River	Upland Bully Torrent Fish Crans Bully Red-finned Bully Blue-gilled Bully	12
	Middle River	Smelt	6
	Lower River	Koaro Bullies Inanga Short-finned Eel Catfish	6
Angling intensity	Heavily fished		6
	Moderately fished		3
	Lightly fished		(1)
Aquatic Ecology	Aquatic SSSI		16
	Biological water quality:		
	B1A		13
	B1B		(10)
	B2		6
	B3		2
	B4		1
Terrestial Ecology	National Parks/Forest Parks		(8)
	Reserves		6
	Natural Vegetations		3
	Farmlands		7
	Other Sites		1
Amenity	High	National Parks	(8)
	Medium	Specific sites	5
	Low	Riverside Walks	1
Water-borne recreation	Canoeing		(2)
	Rafting		3
	Jetboating		1
Miscellaneous	To allow sufficient flexibility in weighting system to account for special circumstances not already defined.		Maximum of 6
		Maori Values	(6)
		Historic Values	4
TOTAL SCORE			51

1\ Key to Biotic Indices:	
B1A	Clean: Trout Abundant
B1B	Moderately Polluted: Trout and course fish
B2	Polluted: Trout rare
B3	Heavily polluted: Course fish rare
B4	Grossly polluted: Fishless

Table 5.7

Lower Reach EW Ratings

Environmental Category	Tolerance Group	Comments	Score
Fisheries	Game (Salmonid)	Rainbow Trout	(16)
	Upper River	Upland Bully Torrent Fish Crans Bully Red-finned Bully Blue-gilled Bully	12
	Middle River	Smelt	6
	Lower River	Koaro Bullies Inanga Short-finned Eel Catfish	6
Angling intensity	Heavily fished		6
	Moderately fished		3
	Lightly fished		(1)
Aquatic Ecology	Aquatic SSSI		16
	Biological water quality:		
	B1A		13
	B1B		10
	B2		(6)
	B3		2
	B4		1
Terrestial Ecology	National Parks/Forest Parks		8
	Reserves		6
	Natural Vegetations		3
	Farmlands		(1)
	Other Sites		1
Amenity	High	National Parks	8
	Medium	Specific sites	(5)
	Low	Riverside Walks	1
Water-borne recreation	Canoeing		2
	Rafting		3
	Jetboating		(1)
Miscellaneous	To allow sufficient flexibility in weighting system to account for special circumstances not already defined.		Maximum of 6
		Maori Values	(6)
		Historic Values	4
TOTAL SCORE			36

1\ Key to Biotic Indices:	
B1A	Clean: Trout Abundant
B1B	Moderately Polluted: Trout and course fish
B2	Polluted: Trout rare
B3	Heavily polluted: Course fish rare
B4	Grossly polluted: Fishless

Canoeists and jetboaters are also affected by low flows to a relatively lesser degree. These water crafts are usually lighter and more maneuverable making them capable of negotiating the shallower parts of the channel where rafts are likely to be grounded. Nevertheless, submissions to the Planning Tribunal Hearing for minimum flows in 1988 indicated that the flow requirements for these three sub-categories are the same and was estimated to be 25 m^3s^{-1} at Te Maire for the Middle Reach. Experts however, believe that rafting, canoeing and jetboating can be affected by flow reduction in the same order.

5.2.5 Angling Intensity

Anglers usually frequent parts of the river where game fish is abundant. Fish density however can be related to the availability of ideal habitats for their spawning as well as food producing needs. This link implies that angling intensity can be an indicator of trout presence in a particular area and may be treated as an indicator of sensitvity.
Experts believe that any modification in the flow regime of these areas can potentially alter the suitability of the channel for fisheries which could diminish their presence.

In places where catch is fewer on the average, it is presumed that the habitat conditions are inferior to those required by the salmonids. These sections of the river are usually refuge to more tolerant native species in effect limiting the adverse effects of diversion. Since abstractions are only expected to have minor effects to the fisheries in these areas, experts rated the moderately and lightly fished areas lower than the highly fished categorization.

5.2.6 Aquatic Ecology and Miscellaneous

This category on Aquatic Ecology merely classifies the river based on the biological water quality index and then scored according to each class. Since the same standard also applies to Whanganui River, the score for each sub-category was carried from the North Yorkshire EWS.

The miscellaneous part is intended to allow flexibility on the EWS. Other considerations not covered by the above environmental categories can be given appropriate weight in this classification and maybe scored to a maximum of 6. Maori values are expected to fall in this category.

5.3 APPLICATION OF THE FINAL ENVIRONMENTAL WEIGHTING SYSTEM

The EWS developed here has been applied to the Whanganui River using Te Maire gauging station because of its importance as the center of most previous studies conducted in the past. Te Maire is reasonably close to Kakahi, where Jowett (1988) studied the habitat preferences of fish species like rainbow trout, brown trout and other important aquatic wildlife. It also provides a common basis comparing the resulting flow recommendations from the EWS to those of PHABSIM and Jowett's two models on fisheries. Another reason for selecting this site is the wide availability of data because it is the site on which the issue of the timing and quantity of water diversion is based. While the EWS framework was used to rate the whole of the Whanganui River, only Te Maire's EW score is needed initially since it is here that the flow recommendations have been based.

The argument on flows is usually founded on the amount of divertible water coming from the Whakapapa River, a major headwaters of the Whanganui River. While some experts have established that no meaningful improvement can be accomplished by reducing the amount of water diverted, others feel otherwise. Some DOC experts argue that even the slightest reduction in mean annual water temperature due to an increase of releases from the TPD headworks can significantly reduce the thermal stress on fish during prolonged dry periods in hot summer seasons.

The scores for each of the river reaches are shown in the attached Tables 5.5, 5.6 and 5.7. It should be noted that the Te Maire area (Middle Reach) was given a score of 51, classifying the place as highly sensitive environmentally. Experts who carried out the scoring believed that the presence of salmonids in the area is sufficient reason to alter the scores of other categories so that the place is classified as sensitive. This then ensures the maintenance of the area particularly by the provision of water requirements for habitat formation.

To accommodate these suggestions, it was recommended that raters make use of the miscellaneous category to emphasize their point. Experts agreed that since this translates to protection of *mana* it is consistent with the Maori values. ECNZ experts also supported this in their submission to the Planning Tribunal (1988) Whanganui Minimum Flows Hearing by stating the following:

a. That the Whanganui River is a good area for trout fishery and is highly regarded by anglers;
b. That it is a vital river which supports other important fishing activities by people in the area.

The upper reaches were also scored sensitive (refer to Table 5.5). Considering the value of the Upper Whanganui as host to rare and endangered species of blue ducks and the presence of the National Park in the area, the score given totalled 57 points likewise qualifying it as environmentally sensitive.

A rather lower score was obtained for the lower reaches reflecting the degree of deterioration that this part of the river has sustained. Past studies conducted by Hoare (1988), indicated that a 50 percent increase in clear flow would have an insignificant effect on the number of days per year that sewage effects from the Wanganui City would be noticeable. From the two measuring sites before the river flows into the city, he established that BOD_5 is relatively high at the Cobham Bridge area an indication of high organic load at times. These are often flushed out instantly, so avoiding strains to the dissolved O_2 content of the water.

The Tables (5.8 A -E) in the following page are the respective readings taken by Hoare (1988) of O_2, BOD_5, pH, and suspended solids as water quality indicators which supports the low EWS score that the lower reaches obtained. The two locations are prior to (Upokongaro) and after (Cobham Bridge) the city boundaries of Wanganui.

From the data it is apparent that the lower reaches, particularly at the Cobham Bridge are highly contaminated with sewerage effluent. It must be emphasized, however that the data shown here were collected prior to completion of the Whanganui City treatment plant, although there is an apparent worsening of water quality even with the completion of stage I because it does not include treatment units.

Hoare (1988), also alluded to the insensitivity of this reach to flow changes. He stated that chemical properties such as Ph, dissolved oxygen and suspended solids concentrations are within acceptable ranges and do not suggest a need for improvement. However, he did not try to predict the possible effects of lowering the flow since he foresaw only possible improvement once the sewerage system of the Whanganui City is put into full operation. He did indicate in his report the inappropriateness of using dilution to solve the bacteriological problem in the river. He maintained that the only answer so far feasible was the completion of the treatment facilities for processing wastewater.

Table 5.8 - A

DISSOLVED OXYGEN (DO) mgl^{-1}		
	Upokongaro	Cobham Bridge
No. of Cases	18	18
Minimum	7.2	7.4
Maximum	11.9	14.5
Mean	9.3	9.6
Standard Deviation	1.3	1.6

Note: These concentrations were found to be in normal and healthy ranges.

Table 5.8 - B

BIOCHEMICAL OXYGEN DEMAND (BOD_5) mgl^{-1}		
	Upokongaro	Cobham Bridge
No. of Cases	15	15
Minimum	0.4	0.7
Maximum	1.6	8.0
Mean	1.0	2.7
Standard Deviation	0.4	2.0

Note: These values are relatively high at the Cobham Bridge site indicative of high organic loads quickly carried away by the flow.

Table 5.8 - C

pH		
	Upokongaro	**Cobham Bridge**
No. of Cases	18	18
Minimum	7.4	7.1
Maximum	7.9	9.2
Mean	7.6	7.8
Standard Deviation	0.2	0.5

Note: The guideline value for this parameter is 6.5 - 8.5 (WHO, 1984).

Table 5.8 - D

Suspended Solids (mg/l)		
	Upokongaro	**Cobham Bridge**
No. of Cases	18	18
Minimum	8	7
Maximum	576	751
Mean	81	100
Standard Deviation	133	185

The degree of contamination by sewerage is best measured by faecal coliform count for the river. These were measured from the same spots as the above data.

Table 5.8 - E

Faecal Coliform Count (#/100ml)				
	Upoko-ngaro	Cobham Bridge Site		
		Total	Before	Since
# Cases	54	56	38	18
Minimum	12	440	440	2500
Maximum	7720	80000	80000	30000
Median	283	3490	2245	11750
L.Quart.	100	1675	1250	6400
U. Quart.	800	8530	3590	20000

Note: Before and after shows the data prior to and post completion of the stage I of sewage treatment in Whanganui River. This stage however, did not include components used for treatment of effluents, thus the higher readings shown here.

5.4 DERIVATION OF MAXIMUM PERMITTED VOLUME OF ABRSTRACTION

The outcome of the consultations conducted with the DOC experts are fully summarized in the attached tables of EWS's (Tables 5.5,5.6 and 5.7). Referring to the score of the Te Maire area, a total of 51 points is accumulated for this particular reach effectively classifying the place as environmentally sensitive.

The annual permitted diversion flows can be estimated using the relationships in Chapter IV. Given an EW of 51 points, from Table 5.9, the normalized MPV for EW equal to 51 units is equivalent to 3 days. The details for computation of dry-weather-flow (DWF) is in Appendix I. The value of this low-flow is 29 m^3s^{-1}.

In the formula (See Section 4.8):

$$MPV = MPV_{normalized} \times DWF$$

The unit of normalized MPV is in days. Converting this into seconds and substituting to the above equation should give the annual amount of water divertible by the TPD.

$$MPV = 3\ d \times 86400\ sd^{-1} \times 29\ m^3s^{-1}$$
$$= 7{,}516{,}800\ m^3y^{-1}$$
$$= \underline{0.238\ m^{-3}s^{-1}}$$

5.4.1 Implications of MPV Restrictions to ECNZ Operations

The total power that can be generated from this amount of diversion can be estimated using the formula:

Power Output (Watts) = P x G x H x E

Where:

- P = density of water
- G = acceleration due to gravity
- H = head of the stations
- E = Overall hydraulic, mechanical and electrical efficiency of the stations taken to be 90%.

Table 5.10 shows the power stations along Waikato River and the static heads available in each of the stations.

To estimate the output derived from 1 m^3sec^1 ex- Whanganui River;

Output in Watts = P(G)(h)(E)

= 1000(9.79)(500)(0.9)

= 4.406 MW

Therefore 0.238 m^3sec^{-1} can produce:

Output = 0.238 m^3s^{-1} x 4.406 MW/m^3s^{-1} x

365 dy^{-1} x 24 hd^{-1}

= <u>9.186 $GWHy^{-1}$</u>

The value of water diverted equivalent to the MPV for power generation equivalent to the MPV can be estimated using the ECNZ forecast of power cost in 1977. Table 5.11 lists the estimated value of water diverted.

Figure 5.2 shows the flow-duration curve as a result of this regime. Table 5.12 shows the post and pre TPD flow with the suggested MPV. This estimate is based on the ECNZ projection of electricity cost for 1987 onwards. It is expected that by applying the equivalent MPV derived from the EWS the flow pattern would be close to its natural mode allowing an average abstraction of only 0.238 m^3s^{-1} compared with about 17.9 m^3s^{-1} under the 1983-1987 minimum flow conditions set at Te Maire (The previous flow conditions involved a minimum flow of 22 m^3sec^{-1} from December to mid-February and 16 m^3sec^{-1} at other times). This pattern yielded at least 70 times the revenue (compared to flow derived from EWS) for the ECNZ at an annual rate of $44.7 million and $43.2 million for scenarios 2A (no new DC link with the South Island) and 2B (with link) respectively.

Table 5.9

Relationship Between EW and MPV	
EW	MPV (Normalized MPVxDWF)
50 +	3 X DWF
40-49	4 X DWF
30-39	5 X DWF
20 - 29	6 X DWF
10 - 19	7 X DWF
0 - 9	8 X DWF

Source: Drake (1987)

Table 5.10

WAIKATO POWER STATIONS	
Station	Static Head (m)
Arapuni	53
Aratiatia	34
Atiamuri	25
Karapiro	30
Maraetaei	61
Ohakuri	35
Waipapa	16
Whakamaru	38
Total Below Taupo	292
Tokaanu	208
TOTAL	500

Source: Ellis (1988)

Table 5.11

Value of Water Diverted		
Year	Cents/KWH	$Million P.A.
1987	5.1	0.47
1988	6.4	0.58
1989	4.3	0.40
1990	4.7	0.43
1991	4.9	0.45
1992	5.0	0.46
1993	5.2	0.48
1994	5.5	0.51
1995	6.3	0.58
1996	8.3	0.76
1997	9.0	0.83
1998	9.0	0.83
1999	9.0	0.83
2000	9.0	0.83
2001	9.0	0.83
2002	9.0	0.83
Average Revenue / Year	$ 0.631 Million	

Clearly the flow recommendations from the EWS scheme would severely restrict the extraction of flow through the Whakapapa intake. The 0.238 m^3s^{-1} rate of diversion would undoubtedly almost restore the river to its natural character although it would allow only minute shifts in the flow-duration curve by 3 days. While this is of interest to environmentalists, the financial viability of the TPD would be severely limited if this criteria were put into effect.

5.5 DETERMINATION OF ENVIRONMENTAL PRESCRIBED FLOW (EPF)

To determine how the EWS can affect their instream uses as well, the minimum flow prescribed as EPF in this methodology needs to be determined. Table 5.12 lists the EPF for particular values of EW.

From Table 5.12 the value of EPF can be directly estimated from the relationship:

$$EPF = A \times DWF$$

Where:

A	=	Low-flow factor
DWF	=	Dry-weather flow with return period of 2.33 years.

Using the above formula:

EPF	=	1.0 x 29.0
	=	29 m^3s^{-1}

5.5.1 EPF on Fisheries

Jowett (1988), used the PHABSIM to simulate habitat conditions in the Whanganui River at Kakahi under different flow and life stages of brown trout. At discharges of over 25 m^3s^{-1} he estimates that the suitability conditions for food production of the species in the river will begin to deteriorate. For spawning, 5 m^3s^{-1} is ideal and there is no sign of rising trend in values of WUA even with the five fold increase in flow. Figure 5.4, which is reproduced from Jowett's (1988) Physical Habitat Simulation of instream food production shows that at Kakahi the optimum weighted usable area of 24 m. occured at a discharge of 15 m^3s^{-1} although the optimum range would be from 14 to 26 m^3s^{-1}.

Table 5.12 - Pre/Post Flows With MPV Restrictions

Month	Pre-TPD Mean-Monthly Flow	Ranked Flow	Post TPD Flow	Average Diverted Flow		Ranked Post-TPD Flow	% of Tim Flow is Equalled Exceeded
January	66.5	137.0	66.26	0.238	1	136.76	9.09%
February	55.5	131.0	55.26	0.238	2	130.76	18.18%
March	50.7	120.0	50.46	0.238	3	119.76	27.27%
April	44.4	120.0	44.16	0.238	3	119.76	27.27%
May	84.8	106.0	84.56	0.238	4	105.76	36.36%
June	120.0	90.8	119.76	0.238	5	90.56	45.45%
July	137.0	84.8	136.76	0.238	6	84.56	54.55%
August	120.0	80.9	119.76	0.238	7	80.66	63.64%
Septembe	131.0	66.5	130.76	0.238	8	66.26	72.73%
October	106.0	55.5	105.76	0.238	9	55.26	81.82%
November	90.8	50.7	90.56	0.238	10	50.46	90.91%
December	80.9	44.4	80.66	0.238	11	44.16	100.00%

Figure 5.2

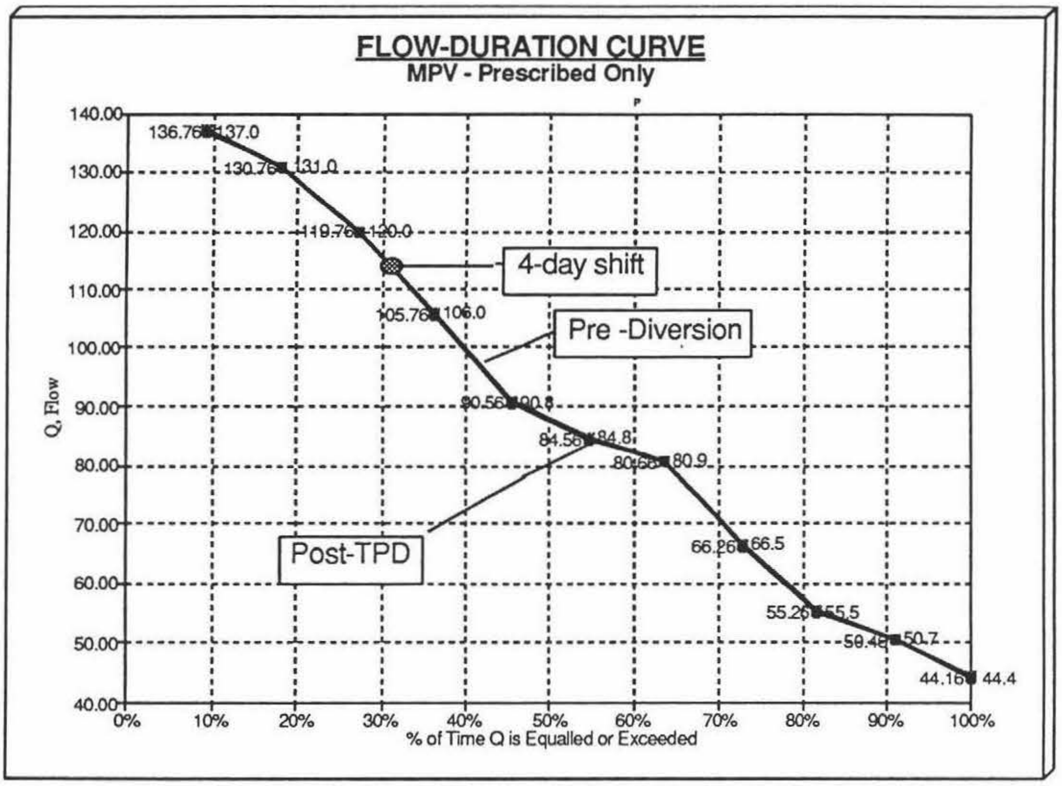

FLOW-DURATION CURVE
MPV - Prescribed Only
4-day shift
Pre -Diversion
Post-TPD
Q, Flow
% of Time Q is Equalled or Exceeded
140.00
130.00
120.00
110.00
100.00
90.00
80.00
70.00
60.00
50.00
40.00
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
136.76
137.0
130.76
131.0
119.76
120.0
105.76
106.0
90.56
90.8
84.56
84.8
80.66
80.9
66.26
66.5
55.26
55.5
50.48
50.7
44.16
44.4

Table 5.13 - Relationship Between EPF and EW

EW	EPF
50+	1 * DWF
40-49	0.9 * DWF
30-39	0.8 * DWF
20-29	0.7 * DWF
10-19	0.6 * DWF
0-9	0.5 * DWF

Source: Drake (1987)

To calculate the equivalent flow at Kakahi (taken from Piriaka) given the discharge at Te Maire, flow records from the two sites were regressed giving an r^2 of about 97 percent (see Table 5.14). Thus, a minimum flow of 29 m^3s^{-1} at Te Maire is commensurate to 21.7 m^3 s^{-1} at Kakahi area. The PHABSIM graphs (see Fig.5.4) confirm that the 21.7 m^3s^{-1} at Kakahi is within the optimum range of food producing habitat conditions although less than optimum WUA for spawning habitat would result. However, the Jowett stated that the spawning habitat is not one of the best features of this part of the Whanganui River.

The results of this exercise cannot be considered to be a solution in this situation since the ECNZ would have to sustain financial losses amounting to more than $40 million annually (if 1983-1987 minimum flow conditions are used for comparison). A compromise solution would need to be found if a lasting solution was being sought. Subsequent parts of the study deal with other possible configurations of EWS applications suited to areas where there is limited flexibility in the allocation of the water resource.

Table 5.14 Regression of Flows at Te Maire and Piriaka

Month	Regressed Values	Te maire	Piriaka
J	67.77	66.50	34.90
F	55.76	55.50	30.80
M	44.04	50.70	26.80
A	41.70	44.40	26.00
M	95.00	84.80	44.20
J	123.70	120.00	54.00
J	124.29	137.00	54.20
A	119.31	120.00	52.50
S	124.87	131.00	54.40
O	110.23	106.00	49.40
N	95.88	90.80	44.50
D	85.04	80.90	40.80

	Regression Output:		
Constant			-34.440399
Std Err of Y Est			6.56909828
R Squared			0.96220621
No. of Observations			12
Degrees of Freedom			10
X Coefficient(s)		2.92855568	
Std Err of Coef.		0.18353954	

QT = 2.928556QP - 34.4404

Figure 5.3 Actual and Fitted Values of Flow at Te Maire

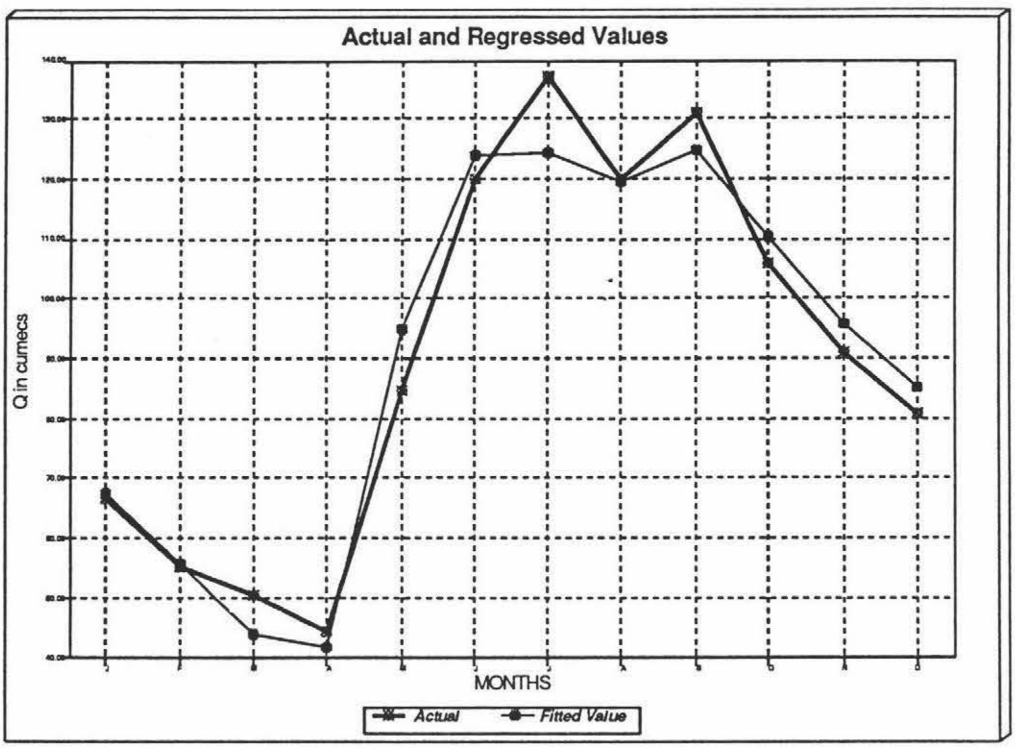


Figure 5.4 a Phabsim Graphs at Kakahi (Food Producing)

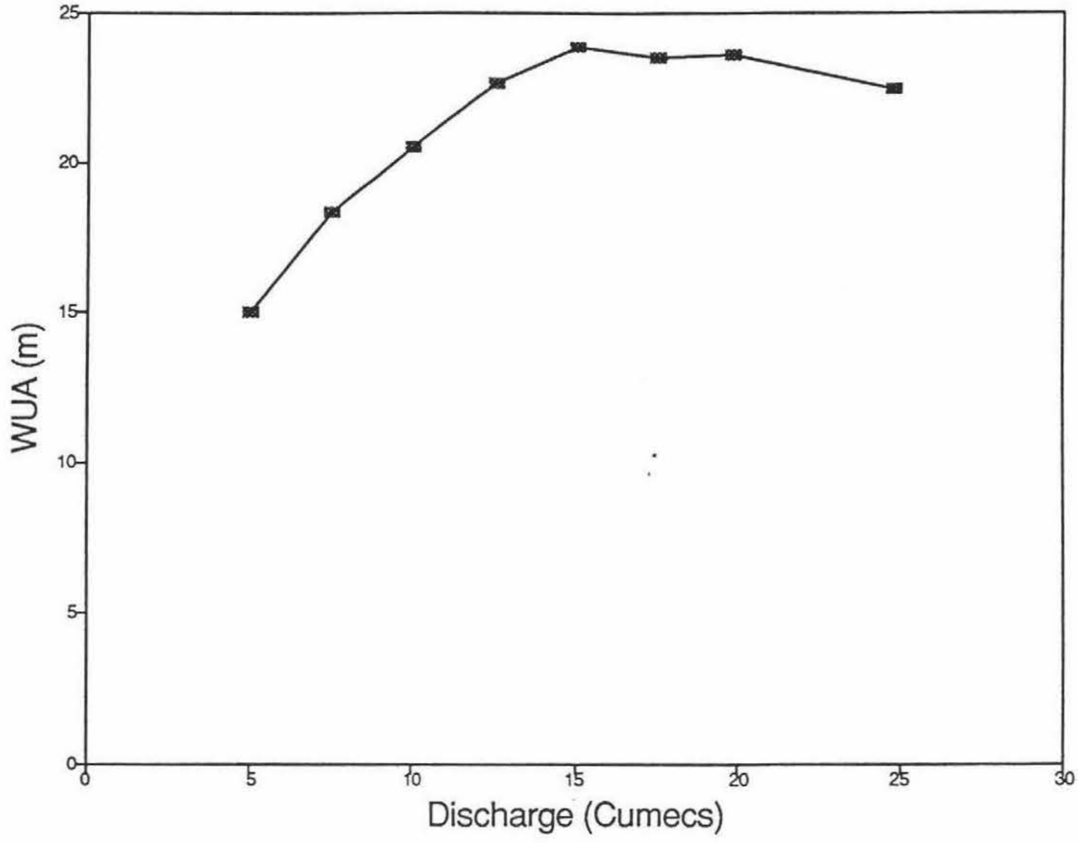
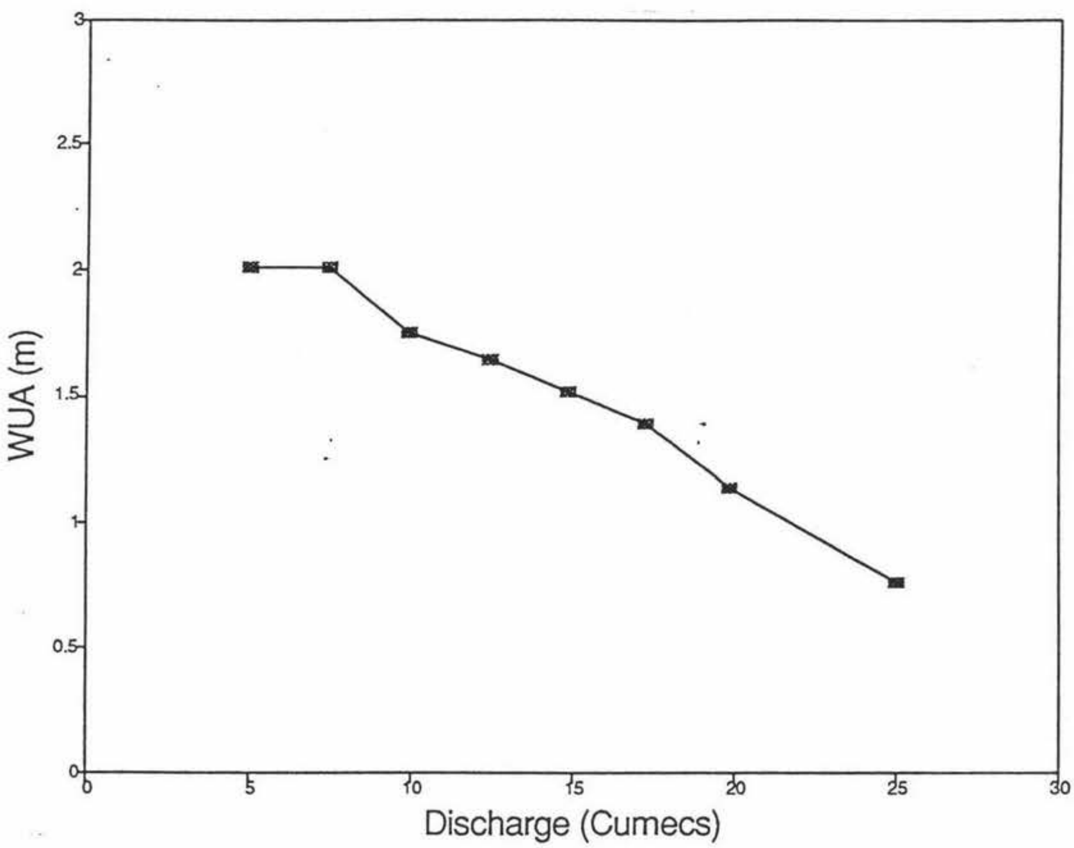


Figure 5.4 b Phabsim Graphs at Kakahi (Brown Trout Spawning)



5.6 OTHER POSSIBLE VARIATIONS USING THE ENVIRONMENTAL WEIGHTING SCHEME

In this section an attempt is made to explore possible variations in the use of the environmental weighting scheme. As observed previously, if MPV is used to restrict abstractions on an annual basis with the intention of protecting low-flows during the dry season, it will effectively cease the diversions needed to operate the TPD. This is attributed to the fact that the 3-4 days allowable shift in the flow duration curve would not suffice in this situation due to the economics of the scheme. Rather, the present situation calls for remedial actions addressed at mitigating the detrimental effects of diversion. Here, a sort of balance must be sought between the requirements of viable hydropower generation and instream needs.

The North Yorkshire case was different in the sense that abstractions can easily be controlled by subjecting licences to conditions or even changed abstraction ceilings. The Whanganui River, however, typifies a situation where developments have already been introduced, in effect narrowing down the extent of problems and the solution that can be addressed. Intake structures, diversion canals, turbines, generators and transmission lines were designed for a certain capacity at a cost which corresponds to its scale. The plant is also designed for a certain economic life and operation below its normal installed capacity can render the installation a financial liability.

By comparison the North Yorkshire system serves only agricultural purposes where the rate and timing of abstraction differs from that on the Whanganui River. The North Yorkshire River is only used extensively six months in a year. The TPD on the other hand is expected to operate year - round interrupted only by occurrence of flows beyond 80 m^3s^{-1} (Ellis, 1988). At flows greater than this, gates are closed to prevent fouling of canals and tunnels by sediments and gates are opened up again after natural flow have flushed the course bed-materials downstream. Also, there is still a need to protect dry-weather flows during summer for both rivers which must be accommodated in their respective flow recommendations.

5.6.1 Option I

It is still possible to use the MPV to protect low flows from March to April without basing them on an annual time frame. In other words, the MPV can be used up during this two months alone while for the rest of the year, the EPF ceiling will apply and that a quarter of what exceeds this flow will be allowed for diversion. While this could result to a wider shifting of flow duration curve (instead of 3 - 4 days originally intended), the available flow for abstractions during the driest months would be significantly reduced, thereby protecting low flows. Table 5.15 shows the resulting monthly flows from this pattern of abstraction and its corresponding flow-duration curve in Figure 5.5. As shown in the earlier computations, DWF is estimated to be 29 m^3s^{-1} and from here MPV is determined using the formula $\mathbf{MPV} = \mathbf{MPV}_{normalized} \times \mathbf{DWF}$. This gives an MPV value of 7,516,800 m^3 (see section 5.4).

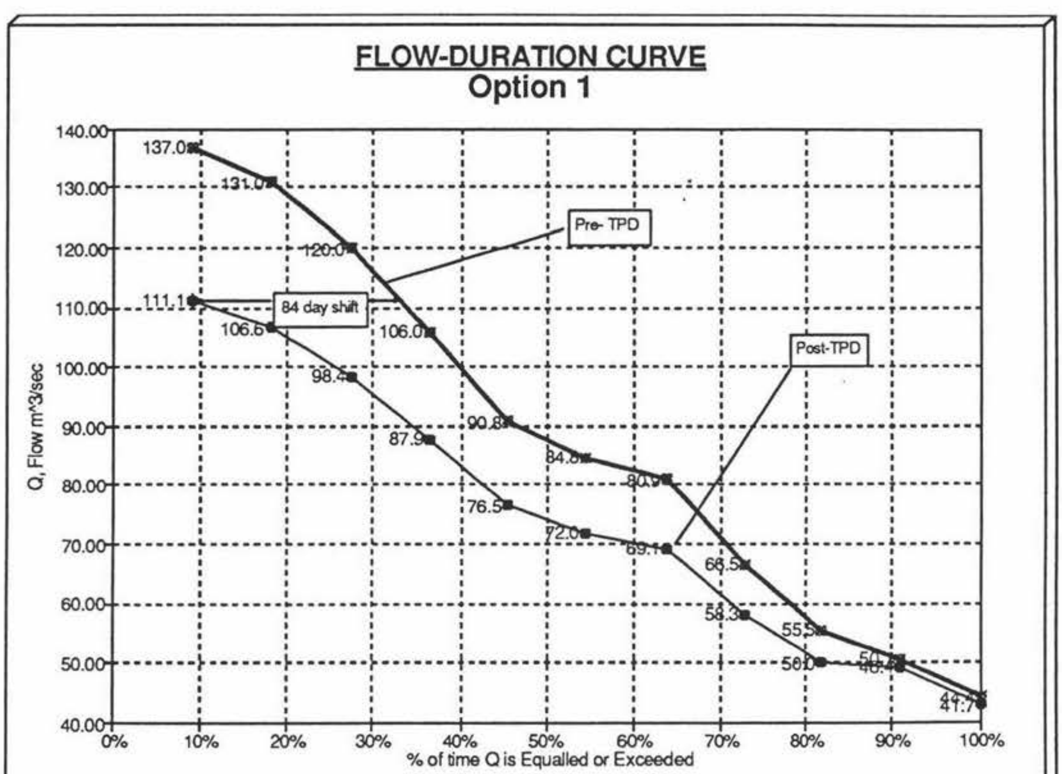
Based on the mean-monthly discharge the average diversion rate would be approximately 14 m^3s^{-1}. Mean monthly diversion is larger for the periods between June to September - 26 m^3s^{-1} may be allowed for July and the slightly lower amount of 24.4 m^3s^{-1} for September. However, this may have to be evaluated further to test the consistency of this schedule with the operational rule of the canals. Note that some water is allowed to flow downstream when discharge exceeds 80 m^3s^{-1}. During its first 13 years of operation some 5,100 m^3s^{-1} days was foregone while gates were closed for this reason (Ellis, 1988).

Table 5.15

Option I Post/Pre TPD Flows

Month	Pre-TPD Mean-Monthly Flow	Ranked Pre-TPD Flow	Post-TPD Mean-Monthly Flow	Mean Diverted Flow		Ranked Post-TPD Flow	%Time Fl Equalled Exceeded
January	66.5	137.0	58.3	8.2	1.0	111.1	9.09%
February	55.5	131.0	50.0	5.5	2.0	106.6	18.18%
March	50.7	120.0	49.3	1.5	3.0	98.4	27.27%
April	44.4	120.0	43.0	1.5	3.0	98.4	27.27%
May	84.8	106.0	72.0	12.8	4.0	87.9	36.36%
June	120.0	90.8	98.4	21.6	5.0	76.5	45.45%
July	137.0	84.8	111.1	25.9	6.0	72.0	54.55%
August	120.0	80.9	98.4	21.6	7.0	69.1	63.64%
Septembe	131.0	66.5	106.6	24.4	8.0	58.3	72.73%
October	106.0	55.5	87.9	18.1	9.0	50.0	81.82%
November	90.8	50.7	76.5	14.3	10.0	49.3	90.91%
December	80.9	44.4	69.1	11.8	11.0	43.0	100.00%
		Average Diverted Flow		13.9			

Figure 5.5 Flow Duration Curve (Option I)



The protection provided by the MPV is now apparent in Table 5.15 and also shown graphically in Figure 5.5. Flow levels are stabilized by this restrictions, even during the months of March and April. The 8.6 million m^3 yields an average diversion of about 1.6 m^3sec^{-1} for the two months leaving an average of 46 m^3sec^{-1} for instream uses.

Improvement in flow regime is dramatic when compared to the 1970-1983 flow situations. The movement of flow-duration curve is now reduced to approximately 84 days compared to 135 days then during 1975-77 regime. Here the minimum flow is set at the value of the EPF which is 29 $m^{-3}s^{-1}$ if available, otherwise the natural flow becomes the residual flow.

5.6.1.1 Impact on TPD

Table 5.16 reflects the estimated revenue that can be generated by the ECNZ under Option I flow regime. These estimates are based on the mean-monthly flows of the river at Te Maire. Perhaps from the point of view of the ECNZ this might be more acceptable than a rigid adherence to the MPV. These values are, however, still below those expected from the 1983-1988 minimum flow conditions which set 22 m^3s^{-1} for December to mid-February and 16 m^3s^{-1} for the rest of the year.

Table 5.16

Valuation of Flow ex-Whanganui		
Year	**Cents/KW-HR**	**$Million/annum**
1987	5.1	27.36
1988	6.8	36.48
1989	4.3	23.07
1990	4.7	25.21
1991	4.9	26.28
1992	5.0	26.82
1993	5.2	27.9
1994	5.5	29.5
1995	6.3	33.8
1996	8.3	44.5
1997	9.0	48.3
1998	9.0	48.3
1999	9.0	48.3
2000	9.0	48.3
2001	9.0	48.3
2002	9.0	48.3
Average Annual Revenue = $ 36.9 Million		

5.6.1.2 Effects on Fisheries

To determine how the flow in this option relate to the fishery requirements, the optimum flow at Kakahi for food producing habitat derived from the PHABSIM model (Jowett, 1988) was used. The model set the optimum range of food producing habitat requirement from 15 to 26 m^3sec^{-1} using depth, velocity and substrate criteria. To obtain a rough estimate of the corresponding flow for the Te Maire area, acomparison of mean monthly flows is used. Table 5.14 shows the regression equation derived from the mean-monthly flows of both locations. There is a limitation though with this estimation model since values far from the mean cannot be satisfactorily predicted as the result of monthly flow averaging.

Nonetheless, by using the regression equation, the flow at Te Maire is estimated to be around 44 m^3s^{-1} when Kakahi is at 26 m^3s^{-1} (the upper limit of the optimum range). Under this option, only the month of April become critical when average discharge was estimated to be 44.4m^3s^{-1}. Note also (Fig. 5.5) that the slide of the flow duration curve is more on the upper band of flow ranges indicating that low-flows would not be so severely affected compared with the 1975-1977 flow pattern (Fig. 5.7).

In terms of improvement in water temperature, any additional release from Whakapapa means a small depression in temperature downstream. While the available models are not used to predict the precise relationship between flow and temperature, a positive correlation between the two variables has been established (Jowett, 1988). Comparing this option to the 1974-1981 flow conditions when the average annual diversion was 19.2 m^3s^{-1}, an extra average flow of at least 5.2 m^3s^{-1} would be left in the river. The model predicted that this would depress water temperatures by about 0.4 C and 0.8 C when water temperatures are 19.9 and 21 C respectively. Jowett (1988) in his first model for predicting trout bio-mass estimated that a decrease of even 0.1 C in annual water temperature would increase trout abundance by 21 % whereas an increase of 0.1 C would decrease brown trout abundance by a similar amount.

5.6.1.3 Effects on Navigation

A study relating flows at Te Maire to the passage requirements of the vessel 'Whakapai' produced a graphical representation of the flow rapid negotiability relationship for the Whanganui River (Oliver, 1988). If Option I was put into effect, negotiability of Rapid No. 84 may only become difficult during the months of March and April when mean-monthly flows are 49.8 and 42.8 m^3sec^{-1} respectively. Under the 1975-1977 flow regimes, at least Wakapai may find it difficult to navigate rapid No. 84 four months a year.

Heerdegen (1988) gave the relationship between depth and discharge in a fitted equation of rapid 84 A and 84 B as:

$$Q = 2.25 + 0.625 \times \text{depth}$$

and

$$Q = 8.720 + 0.045 \times \text{depth}$$

A boat with a draft of 270 mm would then need a discharge of:

$$Q = 2.25 + 0.0625 \times 270$$
$$= 19.8\ m^3s^{-1} \text{ and}$$

$$Q = 8.720 + 0.045 \times 270$$
$$= 20.87\ m^3s^{-1}$$

Theoretically these are the required depth and discharge. However experienced boat operators prefer to have at least twice of this discharge, presumably to allow sufficient clearance between the channel bed and the boat. Since there is no significant abstraction between Taumarunui to Pipiriki, it is safe to assume that the low-flow or even the minimum flow under Option I of 29.0 m^3s^{-1} would improve the navigability of these rapids.

5.6.2 Option II

Another option is to drop the use of MPV totally but continue the imposition of the EPF. In this way, abstraction is allowed year-round although the quantity depends on the amount the EPF is exceeded. Similar to an earlier approach, EPF is always secured initially and a quarter of what exceeds the EPF is allowed for abstraction.
Table 5.17 details the pre- and post-TPD (Option II) flows of the river.

The average annual flow under this option ranges from a low of 41.7 m^3s^{-1} to a high of 111.1 m^3s^{-1}. Fifty percent of the time, an average of 76.5 m^3s^{-1} is available for instream use during which the rate of abstraction would be around 21.6 m^3s^{-1} (see Fig. 5.6). In terms of the average abstraction allowed, the difference between the Options I and II is only about 0.4 m^3s^{-1}.

5.6.2.1 Impact on Power Generation

Appendix III shows the computation of power output under this regime while Table 5.18 shows the monetary value of the electricity produced.

The revenue increase here amounting to about $1.03 million annually when compared to Option I comes from the increased earnings of summer generation. The impact of this gain to the corporate soundness of ECNZ is beyond the scope of this study. Nonetheless, this additional earning is not without a cost to the environment.

Table 5.17

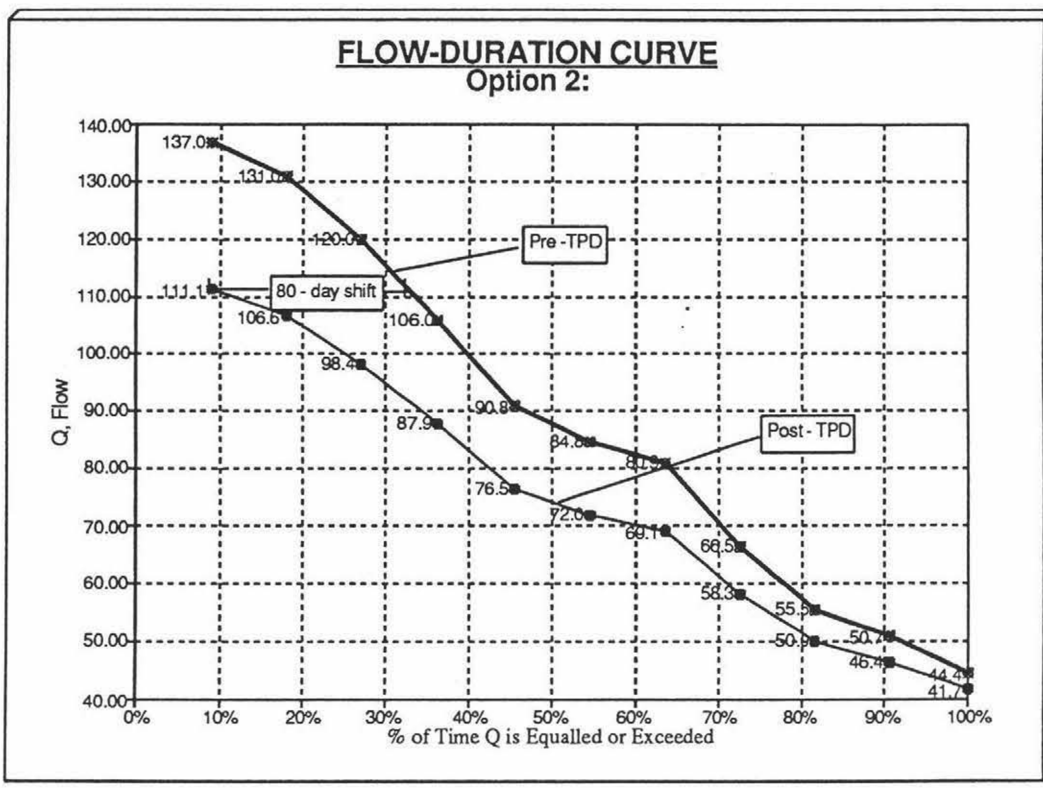
Option II Post/Pre TPD Flows

Month	Pre-TPD Mean-Monthly Flow		Post-TPD Mean-Monthly Flow	Mean Diverted Flow		Ranked Post-TPD Flow	%of time Flow is Equalled or Exceed
January	66.5	137.0	58.3	8.2	1.0	111.1	9.09%
February	55.5	131.0	50.0	5.5	2.0	106.6	18.18%
March	50.7	120.0	46.4	4.3	3.0	98.4	27.27%
April	44.4	120.0	41.7	2.7	3.0	98.4	27.27%
May	84.8	106.0	72.0	12.8	4.0	87.9	36.36%
June	120.0	90.8	98.4	21.6	5.0	76.5	45.45%
July	137.0	84.8	111.1	25.9	6.0	72.0	54.55%
August	120.0	80.9	98.4	21.6	7.0	69.1	63.64%
Septembe	131.0	66.5	106.6	24.4	8.0	58.3	72.73%
October	106.0	55.5	87.9	18.1	9.0	50.0	81.82%
November	90.8	50.7	76.5	14.3	10.0	46.4	90.91%
December	80.9	44.4	69.1	11.8	11.0	41.7	100.00%
			Average Diverted Flow	14.3			

Table 5.18

Valuation of Power Output (Option II)		
Year	**Cent/Kw-Hr**	**$Million**
1987	5.1	28.12
1988	6.8	37.50
1989	4.3	23.71
1990	4.7	25.92
1991	4.9	27.02
1992	5.0	27.58
1993	5.2	28.68
1994	5.5	30.33
1995	6.3	34.74
1996	8.3	45.77
1997	9.0	49.64
1998	9.0	49.64
1999	9.0	49.64
2000	9.0	49.64
2001	9.0	49.64
2002	9.0	49.64
Average Annual Revenue =	$ 37.95 Million	

Figure 5.6 Option II Flow-Duration Curve



5.6.2.2 Fisheries

Based on the flow duration curve of this flow pattern, the total shift to the left of the curve approximates 80 days of change. Like the First Option however, most of the shifts are confined to the upper band of the flow range leaving the low-flow pattern barely altered.

Since the fisheries are more related to the annual low-flows, it is taken that the deleterious effects of abstraction are still minimized under the Second Option. What remains to be carefully considered, is the potential damage that may be caused to fisheries by an extreme lowering of summer flows in the absence of restrictions imposed by the MPV.

A rough comparison can be made by using the United States Fishery Services (USFS) standard for fisheries. It is specifies in the standard that the 80th percentile flow is the necessary minimum for the maintenance of conditions for fish production. Referring to the flow-duration prior to diversion, 80 percentile flow corresponds to about 56 m^3s^{-1} of flow. Note that the Post TPD (Option II), flows for the months of April and March would be critical in this respect and may well fall below the USFS minimum standard.

5.7 SUMMARY

The EWS scores for the upper and the middle reaches of the Whanganui River are classified Environmentally sensitive. The lower reaches, which is close to the city proper of the Wanganui, obtained the lowest score making it insensitive to flow alterations.

The weight of the highest ratings are clearly attributable to these features of the river which the experts seem to value most. A National

Park is situated in the upper parts of Whanganui while the middle stretch is valued primarily for its fish population. To a certain degree, some respondents cannot come to terms with the importance given to the Park which features in two main environmental categories. However, consensus was eventually reached on the value most people place on the Parks which could perhaps easily outpoint the other sub-categories.

If MPV were imposed as an upper limit of allowed volume of abstraction, the TPD's viability would be seriously jeopardized. This leads to a conclusion that although it might directed to an environmentally sound objective, economic ends may unwittingly be compromised. Because of this concern, variations (Options I and II) were studied and found as potential substitutes to the present pattern of abstractions.

CHAPTER VI

CONCLUSION

Many rivers in New Zealand and around the world are now experiencing increased pressure from development as a result of growing population and concommitant economic pursuits. One thing is certain - that the situation is not going to be easier in the times ahead as interest groups for development and ordinary instream use continue to build up their case for a greater share of the flow available in rivers and streams.

The situation in the Whanganui River is no more different than in any others. Construction of the Tongariro Power Development (TPD) diversion facilities was conceived to ensure economic development continued by providing the cheapest source of energy available at the time. As a result, the construction of the abstraction facilities was authorised without any environmental audit and diversion of water went unabated until such time as user groups fist raised the matter in the late seventies.

Clearly this manifests the need to maintain balanced view to resolve the issue of rightful uses. Maybe there is a need for an objective treatment of different factors involved in making the decisions regarding what is considered ample residual flow in the streams or rivers which are so often disdavantaged by abstraction. The early claims of the 'surplus' water from the streams/rivers being totally available for abstraction no matter how much the requirement, is no longer valid. Incidentally, it is this very doctrine that created the problem that this study has examined in detail.

What renders this case a little more interesting though are the attendant constraints brought about by the TPD whose impact on its surrounding area creates an environmental dilemma anything but simple to address. In spite of all the sophisticated models mentioned earlier in the study, the experts themselves profess limited use of such models in consideration of the lack of knowledge and clear understanding regarding the aquatic ecosystem.

After the Planning Tribunal hearings conducted in 1989-1990, the minimum flow was set at 29 m^3s^{-1} from 1 December to 31 May of the following year, derived by using the average of the 7-day annual low-flows measured at Te Maire. This is completely different from the flow regimes suggested by the models constructed for the purpose of predicting the flow requirements of fisheries and recreational needs. This reinforces the concern of experts that estimating flow based on rigid scientific knowledge is possible but certainly not desirable. The environmental weighting system (EWS) is an outcome of this concern and capitalizes on the strength of personal knowledge and experience of individuals who are in one way or another involved in activities related to the river.

The revision of the North Yorkshire EWS proved straightforward and easily replicated elsewhere. Depending perhaps on the degree of precision desired where one may consider the use of more finely calibrated scaling on environmental categories/sub-categories, consultations were not found to be time consuming. The involvement of experts in the process made much simpler to come up with an EWS for the Whanganui River. While there were some concerns initially on the potential for bias by the experts, their response proved that objectivity was observed in the process of consultation. For example, some experts readily suggested that the terrestial ecology category should be given lower weighting as the river is mostly located in gorges in the catchment. However, it was made clear that this was no longer necessary since not all of the river is in the same type of locality. Portions of the river still flow through the flat contours of plains and valleys in the catchment which themselves have their own unique characters that must be weighted accordingly.

Other relevant issue raised by the DOC-expert concerns the highly subjective nature of the approach, making it a questionable tool for decision-making in management and planning of resources. This is not surprising since most of the scientists would prefer a purely quantitative approach when dealing with a problem. EWS, however, evolved from the apparent inability of the quantitative approach to accurately predict fish bio-mass based on the physical habitat simulation (PHABSIM) and instream flow incremental methodology (IFIM) models. Literature also indicates that the weighted usable area (WUA) these models attempts to quantify failed to achieve the correlation with the abundance of fish species in the streams studied. Experts attribute this to the apparent insufficiency of parameters considered in the modelling process. These inadequacies of the model can be avoided by using a much simpler approach which utilizes instead concepts on low flow. Jowett (1993) wrote that the mean annual low flow explained over 88 % of the variation in low flow assessments and provides a convenient method of estimating minimum flow requirements for habitat maintenance.

Based on the EWS ratings, the Upper and the Middle reaches of the river were found to be environmentally sensitive by the experts. The corresponding maximum permissible volume of abstraction (MPV) from the EWS rating is very low when compared to its present regime. The comparative valuation of water used for hydropower generation with and without the MPV produced two very different scenarios in terms of their environmental impact and financial returns. With MPV, the normal pattern of flow prior to abstraction is well preserved and only minimal abstractions from the river would be permitted (See Fig. 5.2). Flow duration curves of pre- and post-TPD under 1975-77 regimes (Fig. 5.7) demonstrate one possible result of abstractions without MPV - with the wide separation of lower flow ranges indicating considerable diffrences in critical flow levels. Clearly in this respect, a value judgement should be exercised to make preferential decisions on the configuration of the abstraction pattern.

Unfortunately, the situation in the Whanganui River no longer provides 'room' for planning. This is typical of a situation where the project has already been implemented (by provision of the generating facilities and ancillary works) forcing planners to formulate remedial actions when problems appear. Here power plants were constructed for a certain capacity of generation so that any radical reduction in the amount of water supplied, through the imposition of MPV, would totally change the economics of the system.

The EWS approach is still applicable in this demand pattern and by making the necessary adjustments, it can be adopted to the situation of a particular set up. In the original EWS approach in North Yorkshire the river is primarily used for agricultural use, with the period of abstraction limited to the six months periods when crops have to be irrigated. In contrast, the practice in the Whanganui River is completely different in that abstractions usually occur year-round interrupted only by events such as floods or exceptionally low flows.

This study generated two options which still utilize the concepts of environmentally prescribed flow (EPF) and the maximum permitted volume of abstraction (MPV). The first of these options imposed MPV during the two months of lowest flows and then for the rest of the year, permitted abstractions of up to a quarter of what exceeds the EPF. The second flow management option made use of the EPF only and again a quarter of what exceeds the EPF cut-off is allowed for TPD abstraction. These two options significantly improved the river's flow conditions when compared to the post-TPD controlled regimes of 1975-1977. These can be appreciated by referring to the flow-duration curves in the Appendix II where it shows that the post-TPD flows of the options generated in this study closely resemble the pre-TPD flows. Most of the shifts in percentage of exceedance time occur in the range of high flows leaving the lower bands barely altered. Both of these options independently recommended a minimum flow equivalent to EPF of about 29 m^3s^{-1}. It should be noted that the present minimum flow prescribed by the Planning Tribunal for the Whanganui River at Te Maire is also 29 m^3s^{-1} with what is in excess of this allocatable for diversion to the TPD.

The study has also shown that the EWS is relatively easy to use not only for quantifying flows but also for classifying locations based on its environmental features. The output, which is a numerical expression of environmental sensitivity, also shows its potential for making environmental classification. Developers of the methodology have successfully applied the latter in their management approaches.

In setting of minimum flow, the 1990 Planning Tribunal decision indicated that:

> *"..the existence of lawful uses of water of the river or stream, their purposes, and the nature in terms of the authorities for them, are all relevant to deciding a minimum flow, but are not decisive.*
>
> *In the setting of minimum flow, the decision-maker is to follow a process or evaluating and balancing all relevant considerations.*

There is nothing in the Water Act to justify giving priority, or placing extra weight or a bias, in favour of Maori values and interests, or Maori rights under the Treaty of Waitangi, or the relationship of Maori people with the Wanganui River. Nor is there any presumption, preference, or extra weighting, independent of the weight which the evidence might indicate, in favour of primacy for an ecological baseline, for priority for instream values, or in favour of retaining the natural flow. Those matters are to be ascribed the weight which they deserve in the circumstances of the particular case."

These pronouncements proved to be consistent with the approach adopted by this study. Environmental weighting through different ecological categories provided a firm basis for ascribing an appropriate bottom line (or ecological baseline) from which 'disposable' flow for out-of-stream uses are reckoned. Although ECNZ interest was not included in this study as one of the environmental categories that can be given appropriate weight, the setting of EPF from the relationship with EWS drew the line where altered flows could not go lower, thus securing initially the minimum need for the environment and then exercising discretion over the excess of EPF. The principle of protecting low-flows was then used as the basis for allowing only a quarter of EPF exceedance to be diverted.

The cost involved in preparing the final framework of EWS is minimal and thereby presents a very good alternative for resource managers to adopt when evaluating flows. Cost can be a variable, however, depending only on the extent of public consultations undertaken, the precision desired and the time available.

The most important conclusion reached by this study is that the Tongariro Power Development (TPD) was conceived, constructed and operated without any considerations of the environmental repercussions. As it is, as long as there is actually sufficient water for power generation, abstractions up to the design capacity of the diversion facilities have the potential of exacting adverse and even irreversible environmental effects. Since the imposition of the 1983 regime and more recent 1990 rules, these facilities are not used to their full or design capacity as often as before. In spite of this, public outcry has continued, urging the changes which finally came to fruition in the 1990 Planning Tribunal Hearing decision. The environmental bottom line has moved upwards and now closely resembles that which this study recommends. Whether the state of the river environment will reflect to that change is a question of time.

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APPENDIX

Appendix IA - Flow Parameters

Annual Minimum Cumecs	Rank r	P(X) Gringorten	F(X) Gringorten	P(X) Weibull	F(X) Weibull	Qm - Q	(Qm-Q)^2
47.20	1	0.02	0.98	0.04	0.96	-17.52	307.06
44.60	2	0.06	0.94	0.07	0.93	-14.92	222.70
40.90	3	0.10	0.90	0.11	0.89	-11.22	125.96
35.20	4	0.14	0.86	0.15	0.85	-5.52	30.50
32.70	5	0.17	0.83	0.19	0.81	-3.02	9.14
32.20	6	0.21	0.79	0.22	0.78	-2.52	6.37
31.90	7	0.25	0.75	0.26	0.74	-2.22	4.94
31.40	8	0.29	0.71	0.30	0.70	-1.72	2.97
31.00	9	0.33	0.67	0.33	0.67	-1.32	1.75
30.60	10	0.37	0.63	0.37	0.63	-0.92	0.85
30.40	11	0.40	0.60	0.41	0.59	-0.72	0.52
29.50	12	0.44	0.56	0.44	0.56	0.18	0.03
29.50	13	0.48	0.52	0.48	0.52	0.18	0.03
29.30	14	0.52	0.48	0.52	0.48	0.38	0.14
29.30	15	0.56	0.44	0.56	0.44	0.38	0.14
29.20	16	0.60	0.40	0.59	0.41	0.48	0.23
29.00	17	0.63	0.37	0.63	0.37	0.68	0.46
28.10	18	0.67	0.33	0.67	0.33	1.58	2.49
27.20	19	0.71	0.29	0.70	0.30	2.48	6.14
26.10	20	0.75	0.25	0.74	0.26	3.58	12.79
24.40	21	0.79	0.21	0.78	0.22	5.28	27.85
23.30	22	0.83	0.17	0.81	0.19	6.38	40.67
21.50	23	0.86	0.14	0.85	0.15	8.18	66.86
19.30	24	0.90	0.10	0.89	0.11	10.38	107.68
19.20	25	0.94	0.06	0.93	0.07	10.48	109.77
18.60	26	0.98	0.02	0.96	0.04	11.08	122.70

Mean = 29.68

Variance = 48.43

S = 6.959

M/S = 4.264

1/k = 0.208 (Gumbel EVII)

Appendix IB - Computation of Dry-Weather Flow

It is assumed that the dry-weather flow has a return period of 2.33 years.

$$P(X) = 1 - 1/2.33$$
$$= 0.5708$$

Substituting this value to the equation:

$$P(X) = \exp(-e^{y})$$
$$0.5708 = \exp(-e^{-y})$$

Taking the natural logarithms;

$$-0.5606 = -e^{-y}$$
$$y = -0.578$$

To solve for characteristic drought, poarameters of distribution of annual low-flow are determined then referred to Gumbel EVIII table for the 1/k parameter. These values are substituted to the equation:

$$\Theta = \frac{Q_m}{\Gamma(1+\frac{1}{K})}$$

$$\Theta = \frac{29.68}{\Gamma(1+0.198)}$$

$$\Theta = 32.32\ m^3s^{-1}$$

In the equation, $\ln Q = \ln \Theta + 1/k\ y$ substitute the above values then solve for Q.

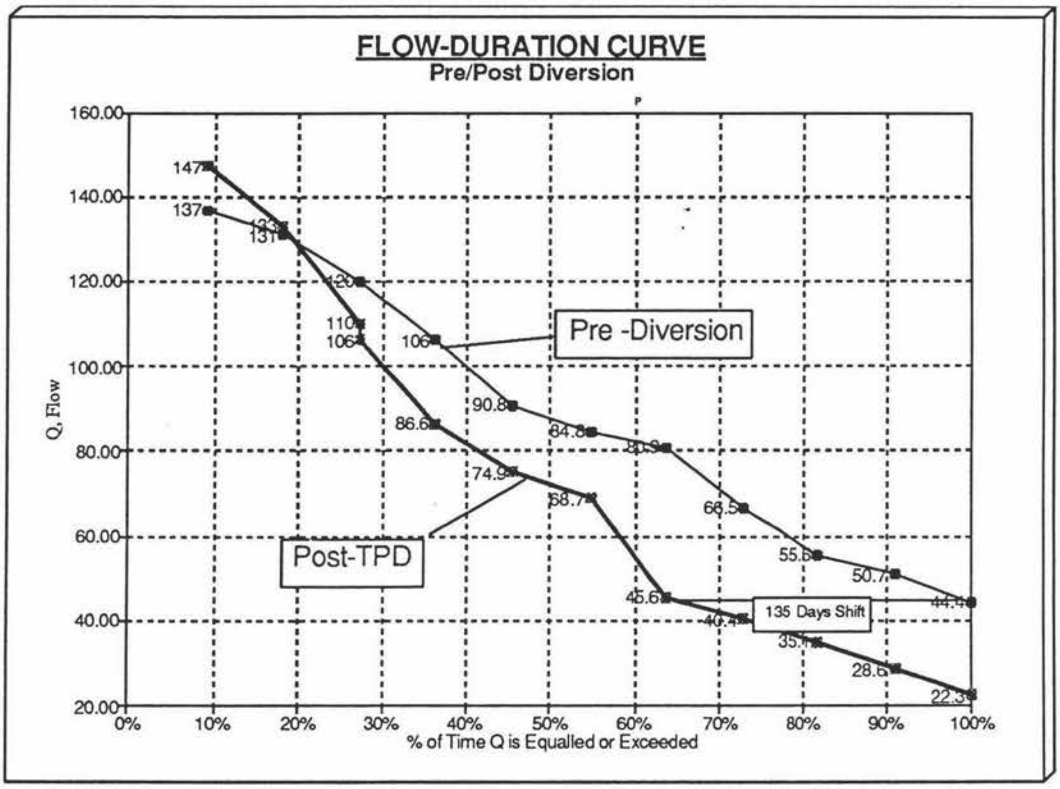
$$\ln Q = \ln 32.32 + (0.208)(-0.578)$$
$$= 3.42 - 0.120432$$

This gives the value of **Q = 28.8 or 29 m ^{3}s^{-1}**.

Appendix II.A Comparison of Flow Patterns 1962-1967(Pre TPD) to 1975-1977(Post TPD).

Pre-TPD Mean-monthly Flow (1962-67)			Post-TPD Mean Monthly Flow (1975-77)		
Rank	Q	% Q = or <	Rank	Q	% Q = or
1	137	9.09%	1	147	8.33%
2	131	18.18%	2	133	16.67%
3	120	27.27%	3	110	25.00%
3	120	27.27%	4	106	33.33%
4	106	36.36%	5	86.6	41.67%
5	90.8	45.45%	6	74.9	50.00%
6	84.8	54.55%	7	68.7	58.33%
7	80.9	63.64%	8	45.6	66.67%
8	66.5	72.73%	9	40.4	75.00%
9	55.5	81.82%	10	35.1	83.33%
10	50.7	90.91%	11	28.6	91.67%
11	44.4	100.00%	12	22.3	100.00%

Appendix II B Comparison of Flow Duration Curves (Pre/Post TPD)



Appendix III - Option II Power Output

Option II Power Output:

Output derived from 1 m^3s^{-1} ex - Whanganui River;

Output in Watts = P(G)(H)(E)

= 1000(9.79)(500)(0.9)

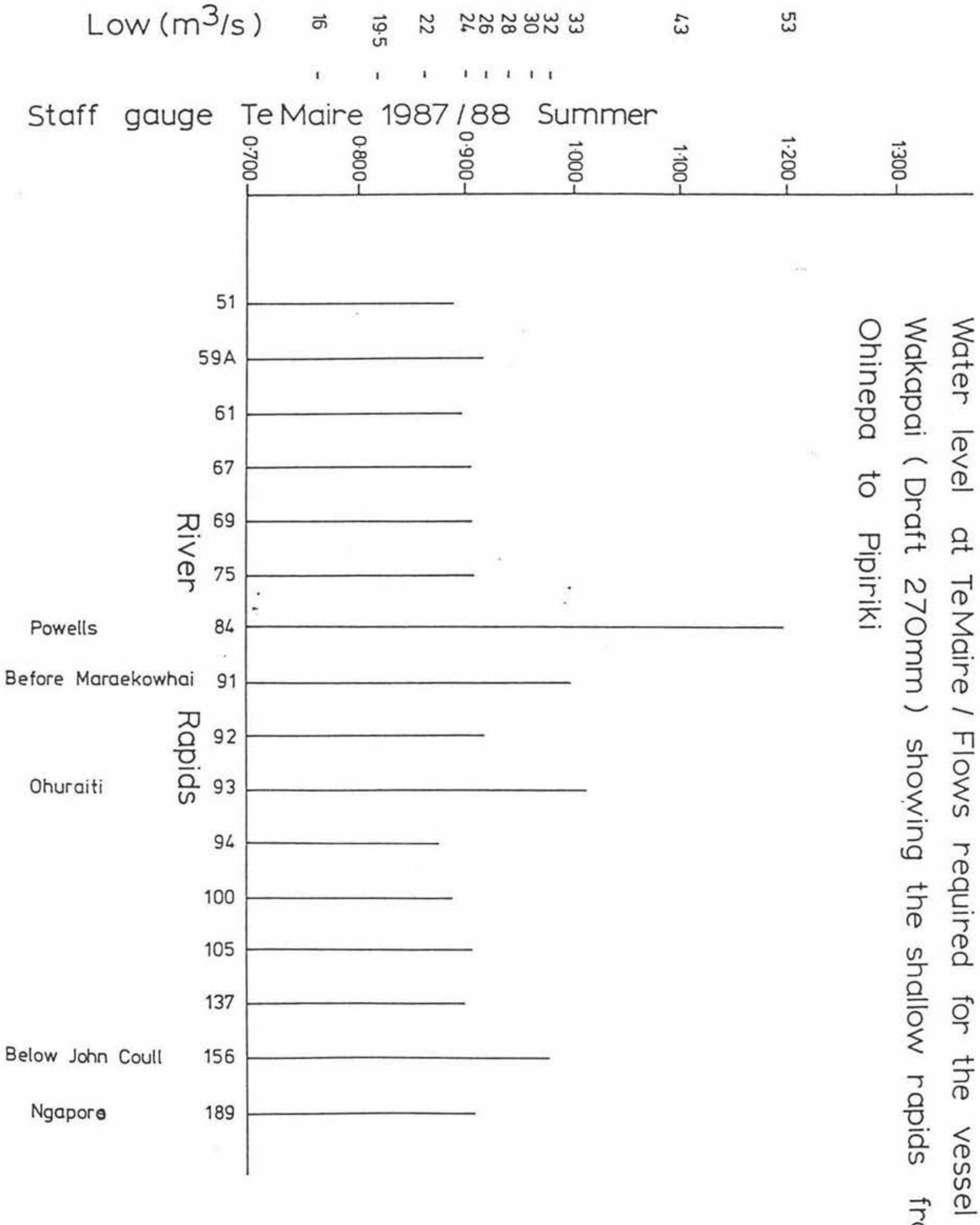
= 4.406 MW

The average discharge under this Option is about 14.3 m^3s^{-1} and the power that can be produced annually can be estimated as follows, assuming 100% utilization of flow:

Output = 14.3 m^3s^{-1} x 4.406 MWm^{-3} x 365 dy^{-1} x 24 hd^{-1}

= 552 $GWHy^{-1}$

Appendix IV - **Graphical Representation of Flow Preference for Rapid No.84**



Information supplied by W. Oliver, March 1988.

Appendix V - Questionaires Used

Dear Person,

I am a masterate student in Resource and Environmental Planning at Massey University. My thesis supervisor, Richard Heerdegen, has referred you to me as a person with whom I could consult regarding my ongoing research work. My MPhil thesis is about the application of an environmetal weighting (EW) system for quantification of a minimum flow in the Whanganui River.

At this point my study needs to revise an environmental weighting scheme, presently being utilized by the North Yorkshire Water Authority in England, as a general approach for managing river abstractions. However, details of the existing fisheries in each segment (upper, middle and lower reaches) of the Whanganui River are lacking. I have attached a sample EW scheme for North Yorkshire and a modified EW scheme proposed for the Whanganui River.

Considering your personal knowledge of the river, would you assist me in compiling the necessary information by:

1. Listing the fish species in the Comments Column of the 'fisheries' category in the attached EW scheme for the Whanganui River.

2. Indicating your choice regarding the sensitivity of existing species in each segment of the river (upper, middle and lower reaches) to water abstraction by weighting the impact from 16 (high) to 1 (low).

3. The category on terrestial ecology proposed for the Whanganui River (refer to the attached EW schemes) is quite different from that for the North Yorkshire model. The revisions listed were necessary because of the different ecological environment and I would appreciate if you could also indicate the potential effects of abstraction on the river by weighting the potential effects, on a scale of 1 (low) to 8 (high), for each of the sub-categories of terrestial ecology.

4. For Water-borne recreation, three activities were identified to be taking place in the river accordingly. From a low of 0 and a high of 3, kindly indicate the potential effects of abstraction to each of the activity.

To assist you in providing answers, I have also attached a brief backgrounder on the environmental weighting scheme on which your comments would be appreciated.

I realise that your time is limited but any contribution to this exercise would be highly appreciated.

Thank you.

Rufino C. Guinto

BACKGROUNDER ON ENVIRONMENTAL WEIGHTING SYSTEM:

Granting abstraction licences based on daily low-flow statistics in North Yorkshire, England became a problem primarily because of the inability of distinguishing between frequency and duration of repeated abstractions. To remedy the situation a change in approach was adopted whereby limitations were imposed on the frequency and magnitude of abstraction, at the same time protecting very low flows. This was accomplished by setting a maximum permitted volume of abstraction during the dry months and the prescription of a minimum flow below which no abstraction would be permitted.
To achieve this operational objective, a numerical weighting system was developed to measure the sensitivity of the environment to a reduction of river flow, particularly during naturally occurring low flow periods. People who developed the methodology, after consultations with appropriate bodies and individuals, came to the conclusion that it would not be possible to develop a numerical system based on rigorous scientific principles. It was decided to develop a system using a subjective approach embodying the experience and opinions of those individuals and organisations connected with water abstraction and environment.

The system which was developed considered the environment under the following six environmental categories:

a. fisheries
b. angling
c. aquatic ecology
d. terrestial ecology
e. amenity, and
f. recreation.

For a given location in the river system, a points score was assigned to each category. The individual scores were added to give the environmental weighting (EW) which then became the overall expression of the relative sensitivity of that location to abstractions during periods of low flow.

It was recognized that each category was not independent of the others. For example, a good quality water may be likely to contain good fisheries, to be high in amenity values and to offer recreational opportunities. For this reason, consideration was given to the use of a mutually exclusive system where the highest scoring category was used as a measure of of the environmental sensitivity of the location. However, it was decided that an additive system would be preferable since it could demonstrate that specific account had been taken of all environmental factors.

Prior to development of the EW scheme, 39 organisations were consulted for their views. These organisations represented a wide range of interests relating to water abstraction and river environment, and included both local and national bodies.
In general, the responses which were obtained from the consultations reflected a general appreciation of and concern for the inter-relationships between water abstraction and river environment. Using the results of the consultation as a starting point, an EW scheme was formulated which reflected, as far as possible, the views and opinions which were expressed.

Fisheries:
It was apparent that the tolerance of fish species to changes in river flow, depth and quality, which result from river abstractions, varies from one species to another. The approximate scale of tolerance increases from salmonid (or game fish) to coarse fish, ie. salmonid species being most sensitive. Therefore the score assigned to fisheries was related to the species of fish which were present at a particular location.

Angling:
The effects of abstraction upon angling have been measured in terms of the intensity of angling activity rather than the species involved. Although some measure of quality of angling would have been desirable, no adequate measure could be found. Angling intensity was split into subjective groupings of heavy, moderate and lightly fished, and separate scores were assigned to each grouping.

Aquatic Ecology:
Aquatic ecology was considered to be related to the quality of river water, and therefore the existing classification system for biological water quality index was adopted as a measure of sensitivity of aquatic ecology to water abstraction. However, an aquatic Site of Special Scientific Interest (SSSI) was given a fixed score regardless of its water quality.

Terrestrial Ecology:
Terrestial ecology was scored according to the existence of designated sites. The scores were related to the type of the site, such as the national nature reserves, SSSIs, sites for protection of flora and fauna and green form sites.

Amenity:
Amenity was divided into groupings of high, medium or low amenity value. Although it was recognized that it would be difficult to determine the appropriate grouping for a particular catchment, an attempt had to be made. Hence, for example, a catchment with national park was

assigned a high amenity value, whereas a non-designated amenity, eg. riverside walk was assigned a low amenity value.

Recreation:
Recreational amenity was related to water-borne activities and was sub-divided into two main groupings, canoeing and sub-aqua, and other water-borne activities.
Recognizing that environmental factors could occur which had not been specifically included (like Maori values) a further miscellaneous category was added to permit the user to score additional issues up to a defined maximum score.

The scores for each environmental category were selected initially according to the perceived sensitivity of each category to artificial reductions in low flow.

Multidisciplinary consultations and discussions were carried out to arrive at the assignment of appropriate scores for each category and sub-categories.

To use the system, any officer (similar to DOC-experts) with considerable knowledge and presently involved with the studies on the river may be asked to perform the rating. The resulting framework and scoring system is exhibited in table form (Table I). The maximum possible score is 63.

Maximum Permitted Volume of Abstraction (MPV):
The determination of allowable abstraction volume sets the amount of water that can be diverted from the river during the driest periods of the year. This method recommends the granting of abstraction only if such volume is not exceeded.

MPV is related to EW on the basis that catchments with high EW should have a relatively low volume of permitted abstractions (MPV). In determining the relationship between volume and EW, the value of MPV was expressed in terms of normalized units which would account for rivers of different sizes. Dry-weather flow (DWF), defined as the mean of the series of annual minimum 7-day flows, was adopted as the river flow statistic for the method. Normalization was obtained by dividing the abstraction volume by the value of DWF. With volume expressed in megalitres, and DWF in megalitres per day (Ml/d), the unit of normalized volume is days, ie. 1 unit = the volume of water obtained during 1 day at flow rate of 1 DWF. Hence actual MPV = Normalized MPV * DWF.

The next step was to make an assessment of the effect of the annual volume of licensed abstraction upon the duration of a given low flow.

If it is assumed that 100 percent of the license abstraction takes place over a 60-day period, with an abstraction volume of 4 units, the average abstraction during the period would be 1/15 DWF. If this rate of abstraction was deducted from the natural flow duration curve, the resulting net flow duration curve would be shifted along the time axis. The amount of the shift would then represent the increase in the number of days on average that low flows would occur as a result of the abstraction.

Flow duration curves for a number of stations were made in the study and the average shift in the number of days of low flow for a volume of 4 abstraction units was about 7 days, although rivers with high base flow rates and particularly flashy rivers gave extreme shifts of 19 days and 2 days, respectively.

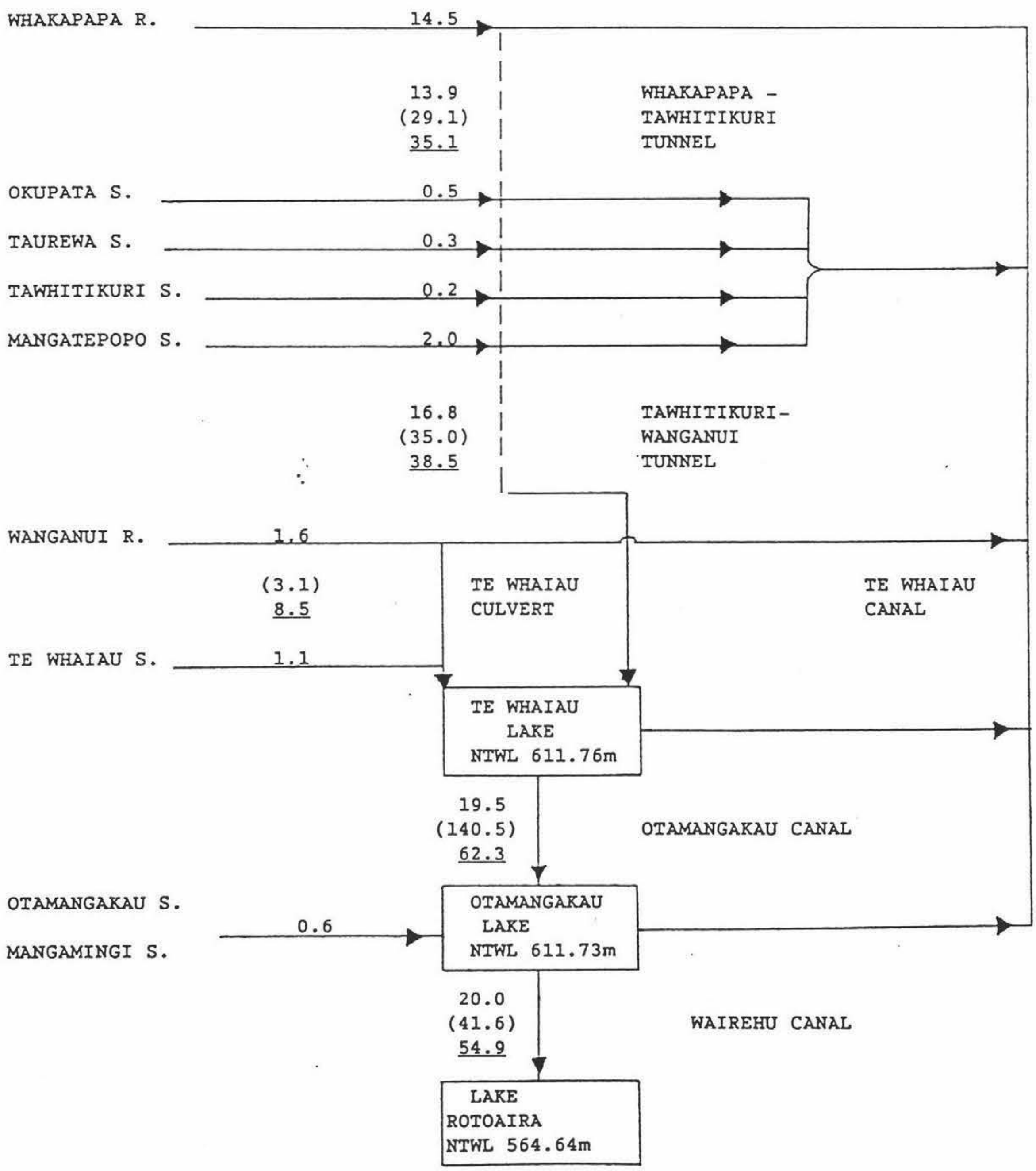
Relating the shift in days to the individual river types, it was considered that a normalized MPV of 4 units should be the maximum applied to the majority of environmentally sensitive rivers.

Appendix VI - Hydraulic Diagram

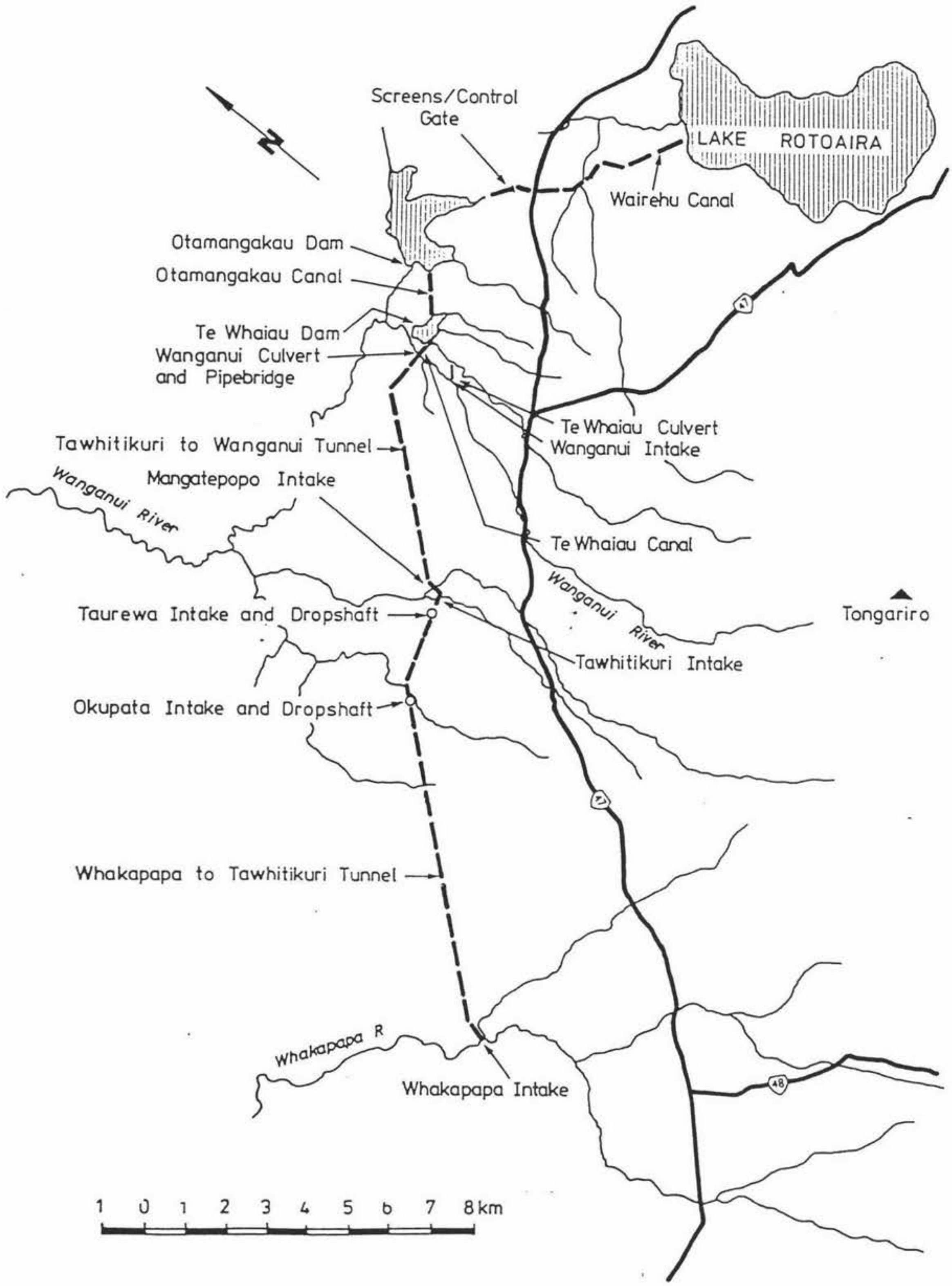
HYDRAULIC DIAGRAM

NOTES:

1. ALL FLOWS ARE IN m^3/s
2. FLOWS THUS 14.5 ARE DESIGN MEAN FLOWS
3. FLOWS THUS (29.0) ARE DESIGN CAPACITIES
4. FLOWS THUS 35.1 ARE MAXIMUM CAPACITIES
5. MINIMUM FLOW BEFORE COMPENSATION IS PAYABLE = 9.9
   ABSOLUTE MINIMUM ALLOWABLE FLOW = 7.1



Appendix VII - Plan of Western Diversion



Appendix VIII - Location Map of Catchment Area.