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REPORT ON MINIMUM FLOW REQUIREMENTS FOR INSTREAM HABITAT IN TARANAKI RIVERS

by
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Report to Taranaki Regional Council

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Servicing freshwater fisheries and aquaculture

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EXECUTIVE SUMMARY

The purpose of this study was to use both the "100 rivers" instream habitat survey data for Taranaki and survey data gathered by the Taranaki Regional Council on five additional rivers to:

1) determine the "habitat quality" of those rivers relative to others in New Zealand

2) determine instream flow requirements for those rivers

3) to establish relationships which would allow instream habitat requirements to be predicted for other Taranaki rivers and streams without the need for habitat surveys.

The 11 Taranaki rivers encompassed a wide range of "habitat quality". Two, the Stony and Patea Rivers, were outstanding, compared to other rivers in the national database, whereas the smaller streams, the Mangaoraka, Kapoaiaia, Waiongana, and Kapuni, were amongst the poorest. This poses a dilemma to water managers. *Should what little habitat exists in the smaller streams be protected and the larger rivers exploited or should those streams of lesser value be exploited and the valuable rivers and fisheries be protected?*

There are many ways in which water management decisions can be made and any single policy will not meet all needs. Conflicting demands on water resources require a balance between conservation and use; a balance that may adjust according to the relative value of the water resource to the community. To assist discussion of policy options and habitat quality standards, this report gives an example of establishing minimum flow requirements based on the following habitat quality guidelines.

> A basic minimum amount of habitat is retained in all rivers but with a limit to the amount of change caused by flow modification to any river. For instance, habitat quality guidelines could require the retention of at least 13% of the water surface width at the minimum flow as habitat suitable for food production and, in trout rivers, at least 6.5% of the area as habitat suitable for adult brown trout. In addition, no flow modification would reduce the existing food producing or brown trout habitat by more than 33%.

The percentages used for these habitat quality guidelines are those which are exceeded by 85% of rivers in the "100 rivers" database. Natural river flows do not necessarily meet these guidelines; 15% of New Zealand rivers fall below the food producing habitat guideline and 15% fall below the trout habitat guideline. If both are applied, between 15% and 30% of rivers in New Zealand fail to meet the guidelines. In the Taranaki region four of the 11 rivers surveyed failed to meet these guidelines.

Multiple regression showed that habitat quality of the rivers surveyed was related to the magnitude of the low flow, the mean depth, width and water velocity. Generally, narrow swift flowing streams or rivers contained better quality habitat. Good trout habitat occurred in deeper rivers and good food producing habitat in swifter rivers. Minimum flows for ungauged catchments can be derived from estimates of slope, width, and mean annual low flow.

INTRODUCTION

The Taranaki Regional Council is currently preparing a working paper on the subject of water allocation for the region which will contribute to the regional policy statement as required by the Resource Management Act 1991. This report on instream flow requirements for rivers in the Taranaki region has been prepared to assist in this discussion.

Historically, the Taranaki Regional Council (and its predecessors) has applied a number of management principles in establishing water allocation policies in its catchment management plans. These have involved the maintenance of biologically sustainable ecosystems; equitable allocation between groups or individuals; efficient use of water; the recognition of multiple and beneficial uses of water; and the recognition of the intrinsic value of water. In some smaller catchments or where consumptive demands were high, a "rule of thumb" of 50% of the 1 day in 10 year low flow has been applied as a basis for a minimum residual flow. In other catchments flows based on higher proportions of the 1 day 10 year low flow have been established or existing "natural flows" maintained to protect regionally important instream values. However, more recently, management issues and the development of instream habitat assessment techniques have highlighted the need to reconsider the use of such "rule of thumb" methods. Recognising the need for a consistent regional approach the Taranaki Regional Council commissioned this assessment of flow requirements.

The report is in two parts. The first part describes the concept of habitat suitability, its application in the instream flow incremental methodology, and the justification for applying these methods to New Zealand rivers. The second part examines instream habitat flow requirements for Taranaki rivers, drawing upon a national database accumulated in the "100 rivers" study and augmented by data collected recently on an additional five Taranaki rivers. Some habitat management guidelines are presented as an illustration of the way in which habitat maintenance can be taken into account when management decisions are made in relation to water allocation.

BACKGROUND TO INSTREAM HABITAT METHODS

Habitat suitability and the instream flow incremental methodology

The concept of habitat suitability is all around us. All life, except perhaps the simplest, has adapted to a particular range of habitats. The concept of "good" habitat is familiar to most people. It is commonly used by anglers and hunters seeking their prey. In the aquatic environment, instream habitat usually refers to the physical habitat - water velocity, depth, substrate, and perhaps cover. Habitat suitability curves provide a means of describing what is considered to be "good" habitat. If the range of suitable habitat for a species or life stage of a species can be determined, it is possible to quantify the area of suitable habitat available within a river. This area is termed the usable area. Habitat suitability can vary from zero (unsuitable) to one (optimum). Figure 1 shows an example of a set of suitability curves for adult brown trout drift feeding habitat derived from measurements at about 400 trout feeding locations.

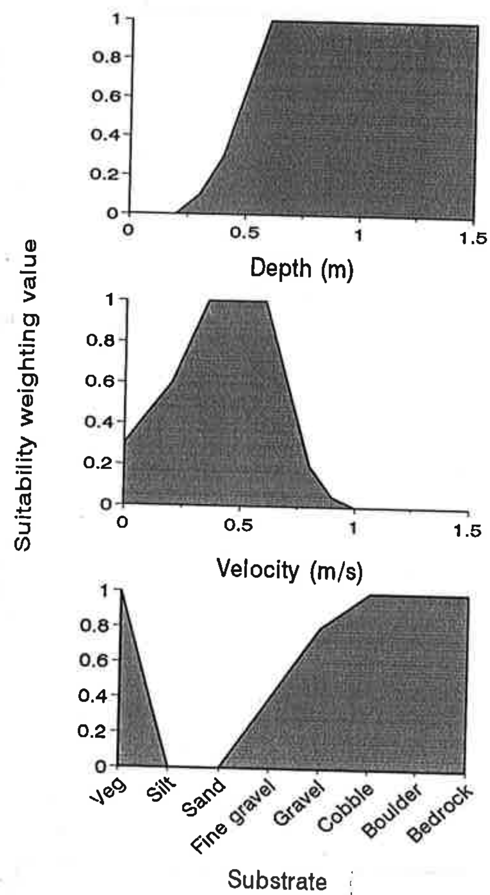

FIGURE 1 Example of drift-feeding habitat suitability curves for adult brown trout [from Jowett (in press)].

Once habitat suitability curves or criteria are defined they can be applied to habitat survey data (Fig. 2) and the amount of suitable habitat calculated. This is the basis of the instream flow incremental methodology (IFIM)(Bovee 1982). The method was recognised as the most "defensible" method of assessing instream flow needs in the U.S. although it has received some criticism (Mathur *et al.* 1985; Scott and Shirvell 1987). The fundamental criticism was that, although it seemed reasonable to assess instream flow needs on the basis of the amount of suitable habitat, there was no evidence that there was any correlation between species abundance and the amount of suitable habitat. This is not an unreasonable criticism - use of inappropriate habitat suitability curves could give misleading results. Some of the early habitat curves for brown trout appeared to describe resting habitat (e.g. Bovee 1978) rather than feeding habitat and even now there are significant differences between the brown trout preference curves derived in New Zealand (Jowett in press) and the curves derived in the U.S. (Raleigh *et al.* 1984). It is also doubtful whether users of IFIM considered all the necessary requirements for a species. For example, the primary requirements for salmonids are both space and food (Chapman 1966). Assessing instream flow needs for a river based on salmonid space requirements and not considering the production of food is like designing a house with no kitchen.

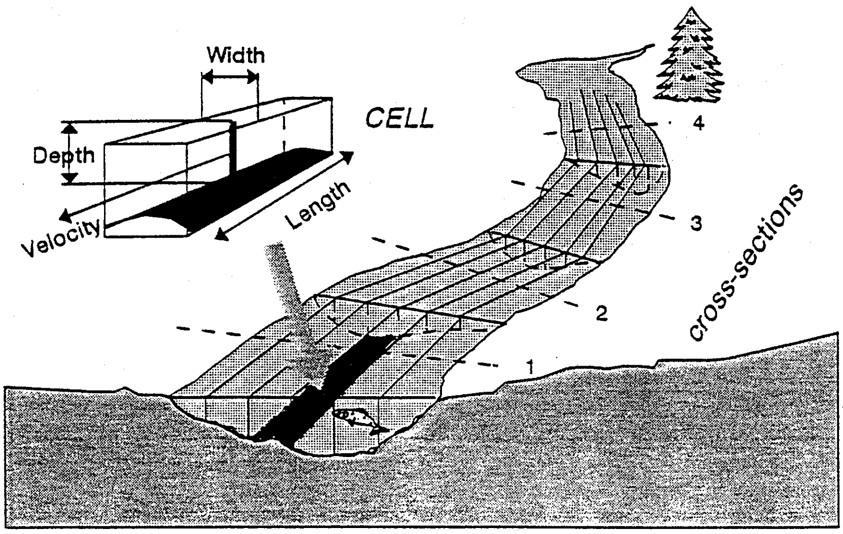

FIGURE 2. Instream habitat model of river reach showing cross-sections and cells.

Trout habitat preferences

Angling texts from the turn of the century describe likely trout streams and more recent books (e.g. Hill and Marshall 1985) accurately describe locations where trout are likely to be found. In New Zealand, the physical characteristics of drift-feeding locations used by large brown trout were measured in two rivers. Similar water velocities were utilised in both rivers although the availability of these was different in each river (Fig. 3). These data can be formed into habitat preference curves (refer to Fig. 1). A significant relationship (r = 0.395, $P<0.001$) between adult brown trout abundance and percentage suitable drift-feeding habitat (WUA) was found in 59 New Zealand rivers (Jowett in press).

Hydraulic modelling and prediction of habitat suitability

The standard step method, used to model non-uniform steady flow in natural rivers, is well established in engineering practice (Chow 1959; Henderson 1966). This method is based on the principle of energy conservation and uses the flow, slope, hydraulic roughness, and the hydraulic properties of the cross-sections to calculate the longitudinal flow profile. An important assumption in the method is that the distance between cross-sections must be short enough that the hydraulic properties of the cross-sections approximate the hydraulic properties and slope between them. This means that cross-sections should be located sufficiently close that the cross-section area increases or decreases uniformly between cross-sections and that the change in slope is kept to a minimum. In practice this means decreasing cross-section spacing at the heads and tails of riffles, where water slopes and cross-section areas change rapidly, and increasing the spacing when the hydraulic conditions are uniform. This sampling procedure is consistent with those used to sample instream physical habitat.

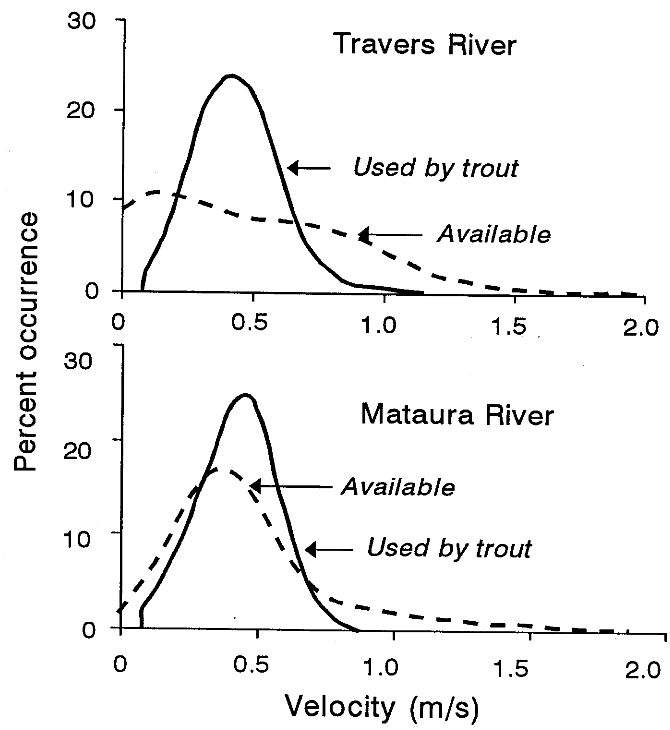

FIGURE 3 Comparison of water depths and velocities available in two rivers with those used by large brown trout when feeding on drifting invertebrates.

The hydraulic roughness (Mannings *N*) is determined from field data on discharge, cross-section area, hydraulic radius, and slope. Mannings *N* can vary with flow in an unpredictable manner (e.g. Hicks and Mason 1991) and this limits the range of flows for which the roughness calibration is valid.

The distribution of water velocities across a cross section can be calculated from its conveyance once the water level and flow are known (Fig. 4) (Mosley and Jowett 1985; Jowett 1989). Each velocity can be adjusted for site specific features such as an upstream obstruction which might cause a reduction in velocity or a current on a bend increasing local velocities. Each measurement point represents a "cell" of the total river area (Fig. 2) for which the suitability of the velocity, depth, and substrate is evaluated on a scale of 0 (unsuitable) to 1 (optimum). The point suitability is multiplied by the plan area of the cell it represents and summed over the reach to give the weighted usable area (WUA). An example of calculating point suitability is shown on Figure 5. Once a hydraulic model of the reach is derived, water velocities and depths can be predicted for any flow and the amount of suitable habitat at that flow evaluated. The computer programme RHYHABSIM (Jowett 1989) combines hydraulic simulation and evaluation of habitat suitability.

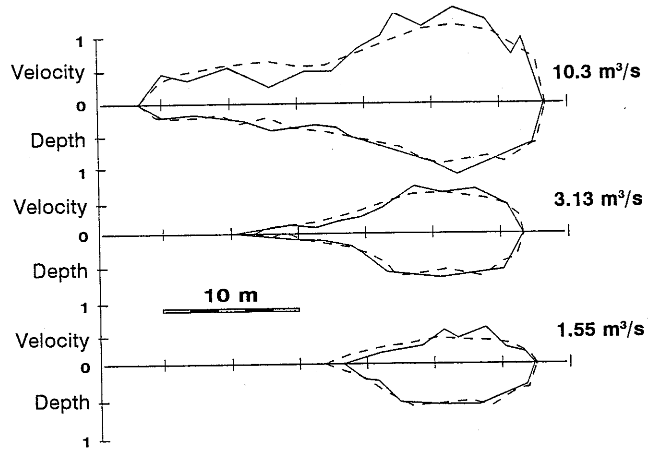

FIGURE 4. Comparison of measured water velocities and depths across a channel (solid line) with those predicted from measurements (dashed line) taken at a flow of 13.2 m³/s

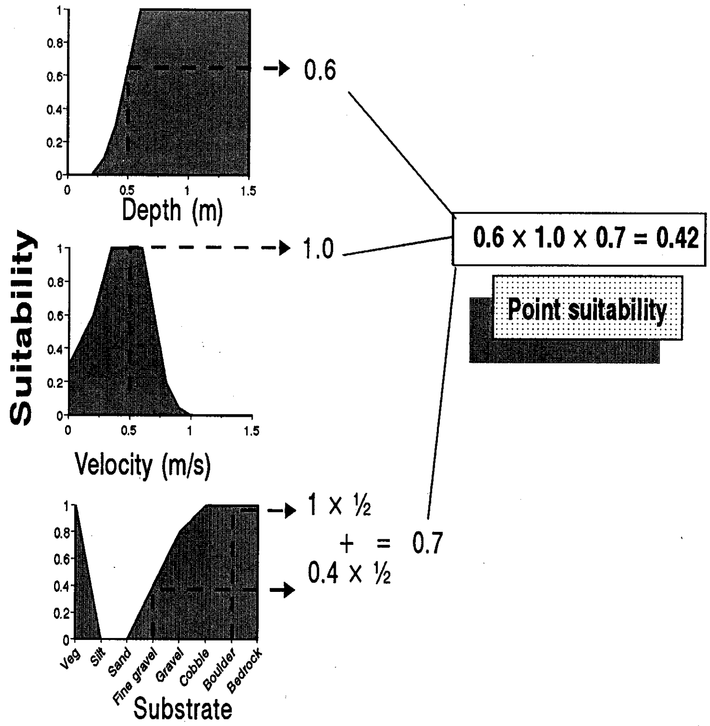

FIGURE 5. Calculation of point suitability for a point with 0.5 m/s velocity, 0.5 m depth, and a substrate of 50% boulders and 50% fine gravel.

Brown trout model

Using data collected for the "100 rivers" survey, Jowett (in press) developed a model of the abundance of large brown trout in New Zealand rivers. This model is based on water temperature, weighted usable areas for "food and space", instream cover, and six other variables which relate to the production of "food".

The water temperature requirements in the model are derived from biological information. Brown trout spawn in winter and egg mortality begins to increase when water temperatures exceed 11°C (Scott and Poynter 1991). A comparison of the distribution of brown trout with respect to river water temperatures shows an absence of trout when winter water temperatures exceed about 10.5°C. Thus, water temperature is one factor which limits their distribution and abundance.

The amount of "food and space" in a river is also known to be important (Chapman 1966). Weighted usable area for trout habitat, "space", and WUA for food production, "food", plus seven other variables explained 87.7% of the variation in numbers of large brown trout in 59 New Zealand rivers (Fig. 6). The most important variables were **WUA for trout habitat, WUA for food production, instream cover,** and **water temperature** as an overriding factor. Of the other variables, **sand substrate** is very poor food producing habitat and it is rare to observe brown trout in areas where the predominant substrate is sand; **lake outlets** are well known for their high trout stocks; **headwaters** usually contain lower trout densities than the lower reaches of a river; trout populations in high **gradient** rivers are severely depleted by floods (Jowett and Richardson 1989); and **pastoral development** appears to have an adverse impact on trout.

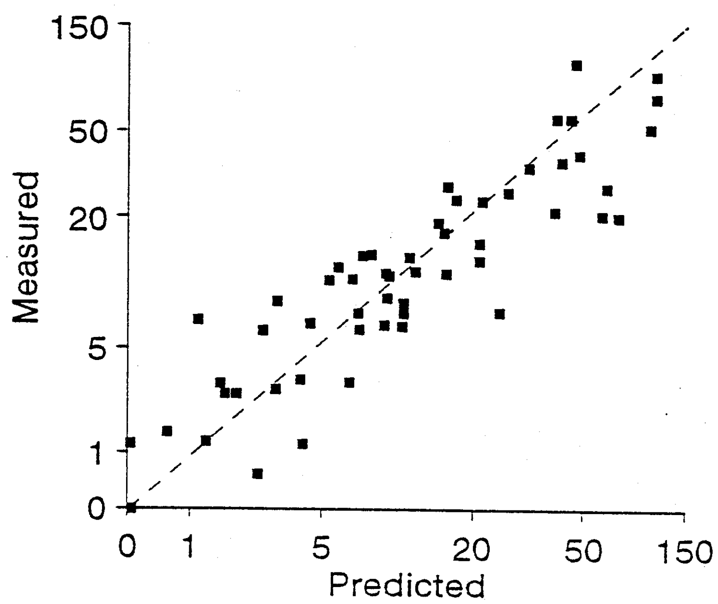

FIGURE 6. Comparison of measured numbers of large brown trout per hectare in 59 New Zealand rivers with numbers predicted by the brown trout model (Jowett in press).

Perhaps the most interesting concept in the brown trout model is the flows at which the instream habitat variables (WUA) are calculated. In a natural river, flow and the amount of suitable instream habitat vary with time. The amount of habitat was calculated at mean annual low flow, median flow, and mean flow. (The mean annual low flow is the average of the instantaneous minimum flows for each year of recorded flow, the median flow the instantaneous flow which is exceeded 50% of the time, and the mean flow is the average of instantaneous flow for the whole period of record.) The amount of adult trout habitat at mean annual low flow was more closely related to trout numbers than the habitat available at the higher flows. This suggests that the amount of suitable trout habitat at low flow is one of the limiting factors in the system. The amount of habitat for food production at median flow was more closely related to trout numbers than the amount at either low or mean flow. Thus, even if there is adequate habitat at low flows, a trout population is controlled by the average food producing capacity of the river rather than the capacity during more extreme events.

Management of instream habitat and river ecology

Instream flow requirements for brown trout can be predicted using the model just described. Winter water temperatures must be maintained at less than 10.5°C and summer temperatures should not exceed the lethal limit of 25 to 27°C. Adult trout habitat at low flow and food production under normal flow must be maintained at adequate levels. The other factors which influence trout abundance usually alter little with flow.

In the "100 rivers study" (Biggs *et al.* 1990) the habitat quality in 63 rivers around New Zealand was evaluated. Assuming that the 63 rivers are a representative sample of New Zealand rivers, they can be ranked and then divided into groups depending upon the quality of the instream habitat. For instance, 15% of the rivers surveyed had more than 60% of their area providing "food and space" habitat for adult brown trout (Fig. 7). This group of rivers represents examples of rivers where naturally occurring flows provide excellent trout habitat. Similarly, 15% of the rivers had less than 32% of their area as trout "food and space" habitat. Rivers in this group are examples of poor quality rivers when it comes to trout habitat.

Proposals to modify river flows can be assessed against this background - showing both the extent of the impact and the relative value of the resource.

This concept can be extended to other habitat types which are appropriate to the river, region, and management objectives. However, before this is done, relationships between the habitat suitability curves, WUA, and the aquatic biota to which they apply should be established. At present such relationships have been established for brown trout, a number of benthic invertebrate species, and for total benthic invertebrate biomass. Weighted usable area for food production was significantly correlated with total benthic invertebrate biomass in the 40 rivers of the "100 rivers" survey where there were data (unpublished data) and WUA for brown trout habitat was significantly correlated with brown trout numbers in 59 rivers (Jowett in press).

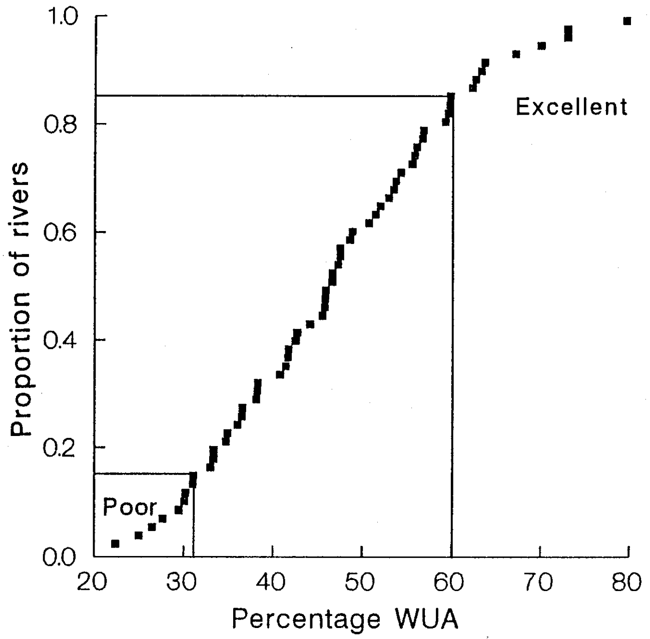

FIGURE 7. Total "food and space" habitat for adult brown trout in 63 New Zealand rivers.

APPLICATION TO RIVER MANAGEMENT IN TARANAKI

Introduction to regional study

The water resources (Taranaki Catchment Commission 1984a) and biology (Taranaki Catchment Commission 1984b) of the Taranaki ring plain rivers were extensively studied by the Taranaki Catchment Commission between 1980 and 1984. These reports provide a valuable source of data which should be considered along with the results of the habitat analyses in this study.

This study examines the habitat quality of 11 Taranaki streams and rivers (Fig. 8) with the intention of deriving a consistent estimate of instream flow requirements. These estimates were then compared to the natural flows and physical structure of the river to determine whether a satisfactory method of setting instream flow requirements for ungauged or other areas of gauged catchments could be derived.

Survey rivers and selection of reaches

Instream habitat surveys were made of 11 Taranaki rivers. Ten of the rivers were Taranaki ring plain rivers which could be described as "typical Taranaki rivers". They were generally well-confined boulder rivers with well-defined pools and steep riffles or rapids. The smaller streams tended to contain fewer boulders than the larger rivers. This was particularly evident in the Kapuni Stream where the survey reach was in the lower part of the river. The Tawhiti Stream was the only stream surveyed which was not on the ring plain. It was a meandering stream with the characteristics of a stable "spring-fed" stream. Its channel was almost rectangular with steep banks and a large amount of aquatic macrophytes growing on the stream bed - suggesting a stable flow regime with little movement of coarse sediment.

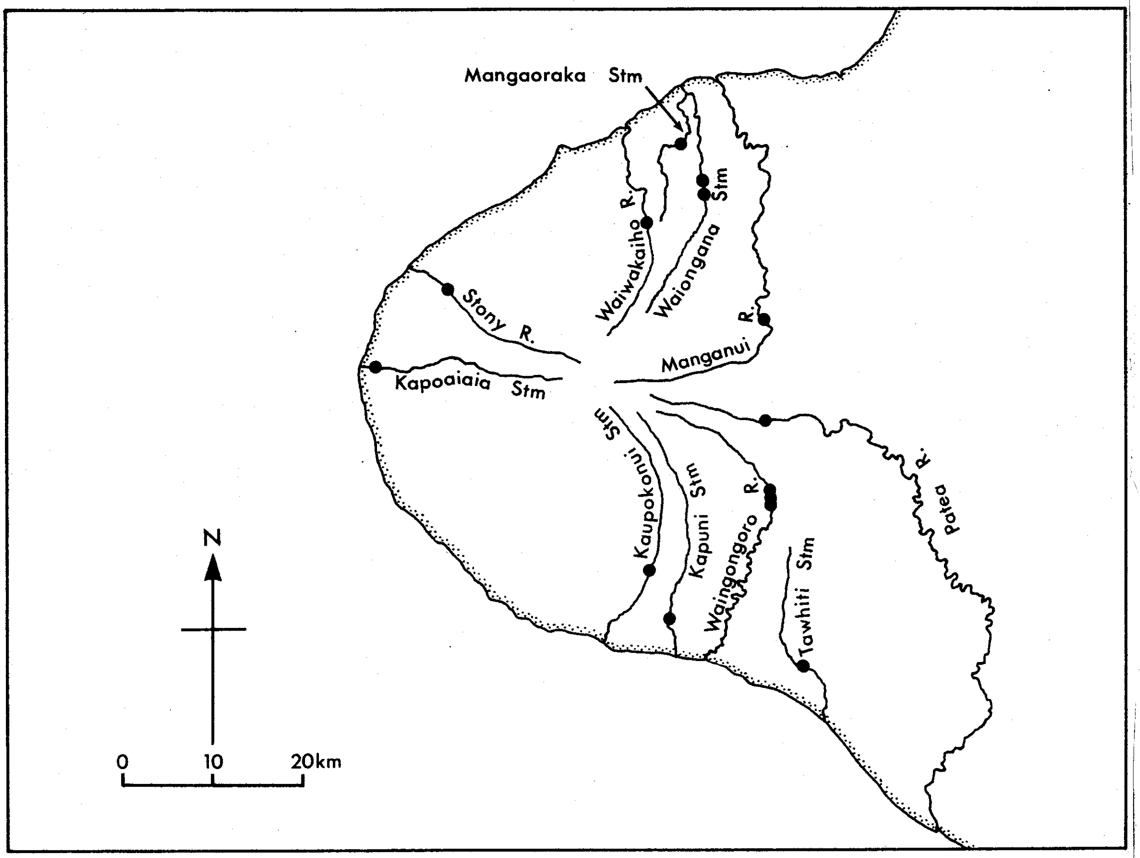

FIGURE 8. Location of the instream habitat survey reaches in 11 Taranaki rivers and streams.

Six of the rivers were surveyed in 1988 by DSIR Water Resources staff and the remaining 5 were surveyed in 1992 by Taranaki Regional Council staff (Table 1 and Fig. 8). All surveys were made in sections of the rivers and streams with known flows and often reaches were close to water level recorders. The survey reaches were intended to represent a sample of the habitat available in a longer section of river, the length depending primarily on river gradient and flow. A change in either gradient of flow may alter the morphological characteristics of the river and thus instream habitat. Thus, the survey reaches in the Kapuni and Kapoaiaia Streams were representative of their lower catchments, whereas the Patea and Waingongoro reaches were typical of their headwater areas. Each survey contained a sample of pool, riffle, and run habitat in the proportion generally present in a longer section of the river. In some cases more than one reach was sampled to get a better representation of the available habitat. Reaches were surveyed when flows were generally between the mean annual minimum (the average of the annual instantaneous flows) and median, although the Stony, Kaupokonui, and Waiongana Rivers were surveyed at just over the median and the Manganui River at just under the mean annual low flow (Table 2).

TABLE 1. Location and physical characteristics of the instream habitat survey reaches.

River/stream	Map reference	No. of sections	Gradient	Average roughness coef.(N)	Substrate* % boul	% cobb	% grav	% fineg	% sand	% vege
Kapoaiaia Stream (Lighthouse)	P20:755143	13	0.0180	0.118	30	34	20	6	8	1
Kapuni Stream (SH 45)	P21:084833	19	0.0081	0.053	1	45	28	13	11	2
Kaupokonui Stream (Skeet Road)	P20:073905	15	0.0099	0.069	23	40	25	5	0	3
Manganui River (Tariki Road)	Q20:207178	23	0.0072	0.108	48	16	15	10	10	2
Mangaoraka Stream (Corbett Road)	Q19:127381	13	0.0043	0.086	33	22	11	28	3	1
Patea River (Stratford)	Q20:206061	16	0.0093	0.088	58	22	14	4	1	1
Stony River (Okato)	P19:852229	30	0.0118	0.064	51	27	12	1	6	0
Tawhiti Stream (Duffys Farm)	Q21:242776	13	0.0015	0.087	1	7	10	0	14	58
Waingongoro River (Eltham)	Q20:207986	28	0.0078	0.081	37	22	17	10	5	3
Waiongana Stream (SH 3A)	Q19:145340	17	0.0117	0.098	61	131	5	3	11	0
Waiwakaiho River (SH 3)	P19:083288	17	0.0158	0.110	71	22	3	1	1	0

* = bedrock and silt present in small amounts in some reaches.

TABLE 2. Discharge characteristics of the rivers and streams surveyed (DSIR Water Resources survey and Taranaki Regional Council data).

River/stream	Flow (l/s) Mean annual minimum	Median	Mean	Survey
Kapoaiaia Stream	284	714	1128	535
Kapuni Stream	346	1300	1748	1220
Kaupokonui Stream	760	2040	3110	2450
Manganui River	1160	3600	6500	1170
Mangaoraka Stream	251	1240	2000	974
Patea River	770	3110	4880	2860
Stony River	2300	3630	6270	4910
Tawhiti Stream	172	425	570	273
Waingongoro River	420	1760	2650	1500
Waiongana Stream	379	1420	2617	1480
Waiwakaiho River	1970	3640	7140	2390

Survey method and habitat prediction

The number of cross-sections surveyed in each river varied with river characteristics. Larger rivers were generally more variable and complex and required more cross-sections (Table 1). Cross-sections were located so that they represented the average hydraulic properties of the river as well as the available habitat. Each cross-section profile was surveyed, water velocities measured, and visual estimates of substrate composition made. Substrates were classified as bedrock, boulder (>264 mm), cobble (264-64 mm), gravel (64-10 mm), fine gravel (10-2 mm), silt (<2 mm), and vegetation (terrestrial or aquatic vegetable matter).

Hydraulic models of each reach were developed by fitting roughness coefficients (Manning's *N*) between adjacent cross-sections for the flow and elevation differences recorded during the survey. At later dates, water level and flow measurements were made at the downstream cross-section for a range of flows so that a relationship between water level and flow could be established. This relationship was used to predict water surface profiles for flows of just less than the mean annual minimum to the mean. The hydraulic methods are described in more detail on page 4 and in Jowett (1989). Water depths and velocities at all measurement points were predicted over a range of flows. The suitability of each point as food producing or brown trout habitat was assessed and summed over the reach. A full listing of the results is given in Table 2 of the Appendix.

Substrate composition was not taken into account in evaluating instream habitat in the Tawhiti Stream. The "spring-fed" characteristics of the Tawhiti Stream were different from any other river in either the national or Taranaki surveys. Aquatic macrophytes were the predominant substrate and although they rate highly as trout habitat, they rate poorly as food producing habitat. It is well known that spring-fed streams can support high numbers of trout, both brown and rainbow, and it illustrates the potential danger of using a model of drift-feeding trout rivers (i.e. the brown trout model described earlier) on river types where the food sources may be different.

Habitat units are units of area (e.g. square metres), therefore larger rivers usually contain more habitat. Thus, weighted usable area is expressed as a percentage of the river width or area for comparisons between rivers of different size. Five metres of usable width in a 20 metre wide river (i.e. 5 m) is equivalent to 5 square metres per metre length of river (i.e. 5 m^2/m) and both can be expressed as 25% WUA. These are the units used in this report.

Ranking rivers in terms of habitat quality

The quality of the instream habitat of the Taranaki rivers surveyed can be compared with the larger group of New Zealand rivers as described on page 8. This allows us to assess the relative quality of habitat in Taranaki rivers, which can be expressed as the percentage of the rivers in the national database that contain "better" habitat (i.e. the weighted usable area (WUA) is greater). Table 3 lists the flows and the sum of the food producing and adult brown trout habitat (WUA as a percentage of water surface area) of the "top ten" rivers in the existing national database. On this basis two the Taranaki rivers are outstanding, being among the "top ten" - in terms of food producing and brown trout habitat - surveyed in the country. Seven of the 11 Taranaki rivers surveyed were of better than average (Table 4).

TABLE 3. Total weighted usable area (adult trout habitat at mean annual low flow (MALF) + food producing habitat at median flow) for the "top ten" of the 63 rivers surveyed as part of the "100 rivers" study.

Ranking	River	Flow (m^3/s) MALF	Flow (m^3/s) Median	Total WUA (%)	Ratio trout: food-producing habitat
1	Hurunui	8.2	19.4	79.6	0.69
2	Gowan	8.7	22.0	72.9	0.92
3	Inangahua	2.0	7.6	70.0	0.47
4	Motueka	7.7	32.8	67.1	0.68
5	Patea	0.8	3.1	63.3	0.24
6	Rangitikei	4.6	13.1	63.2	0.32
7	Buller	3.9	10.0	63.2	0.32
8	Wanganui	5.0	15.8	62.3	0.30
9	Stony	2.3	3.6	61.9	0.59
10	Ahuriri	8.0	18.0	59.8	0.43

TABLE 4. Relative quality of instream habitat in Taranaki rivers. Relative quality is the percentage of rivers in the national database that have higher values of WUA.

	Brown trout habitat		Food producing habitat		Sum of food and trout	
River/stream	WUA at MALF (%)	Relative quality	WUA at median flow (%)	Relative quality	Total WUA (%)	Relative quality
Kapoaiaia Stream	2.5	(99)	36.3	(39)	38.8	(66)
Kapuni Stream	4.9	(92)	33.8	(50)	38.7	(67)
Kaupokonui Stream	10.8	(62)	46.0	(12)	56.7	(22)
Manganui River	16.4	(35)	29.6	(64)	46.0	(49)
Mangaoraka Stream	3.6	(97)	24.5	(78)	28.1	(92)
Patea River	12.4	(56)	50.9	(1)	63.3)	(8)
Stony River	22.9	(13)	39.0	(28)	61.9	(13)
Tawhiti Stream	11.8	(58)	38.6	(28)	50.4	(38)
Waingongoro River	10.0	(67)	37.3	(34)	47.3	(44)
Waiongana Stream	15.5	(39)	20.8	(84)	36.3	(75)
Waiwakaiho River	19.0	(16)	33.6	(53)	52.6	(35)

The smaller streams (Kapoaiaia, Kapuni, Mangaoraka, and Tawhiti) have little suitable habitat for adult brown trout (Table 4). There is a significant correlation ($P < 0.001$) between the weighted usable area for adult brown trout (at mean annual low flow) and mean annual minimum flow.

The quality of the food producing habitat in these rivers varies considerably (Table 4) - from the best in country in the Patea River to some of the worst in the Mangaoraka and Waiongana Streams. There was no significant correlation between the amount of food producing habitat and median flow. Overall, there was little difference between the assessments of habitat quality based on the sum of the food producing habitat at median flow and the brown trout habitat at low flow and the assessment based on an average of the national ratings for each habitat type independently (Table 4).

Habitat changes with flow

Food producing habitat shows optimum or near optimum values between median and mean flow for the Stony, Patea, Waiwakaiho, Kaupokonui, Waingongoro, and Manganui Rivers (Fig. 9). The Stony River differs from the others in that optimum food producing habitat is at or just below median flow - a characteristic of some of the "best" trout rivers. In the five other rivers (Kapoaiaia, Kapuni, Mangaoraka, Tawhiti, and Waiongana), food producing habitat increases with flow from mean annual low flow to mean flow, suggesting that the natural flows in these rivers are less than optimum for their channel characteristics. In all rivers except the Stony and Waiwakaiho, food producing habitat declines towards zero as flows fall below mean annual low flow (Fig. 10).

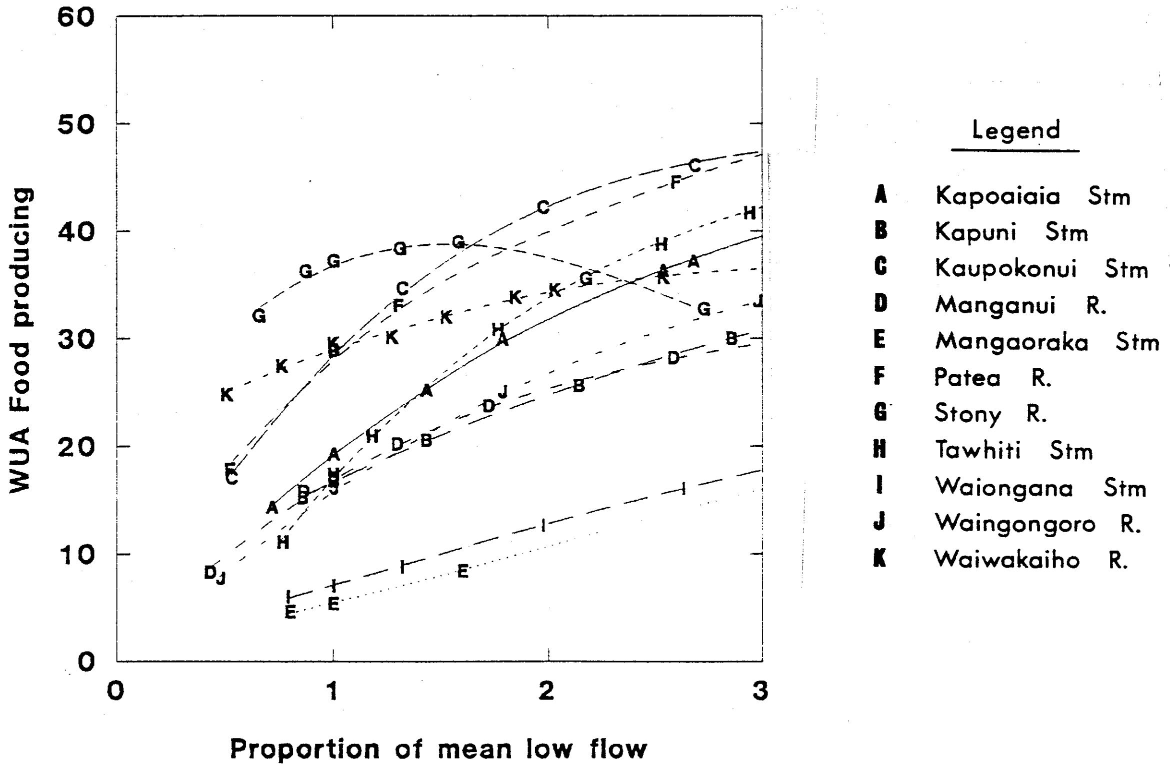

FIGURE 9. Variation in the weighted usable area of food-producing habitat with flow (as a proportion of the mean annual low flow) in 11 Taranaki streams and rivers.

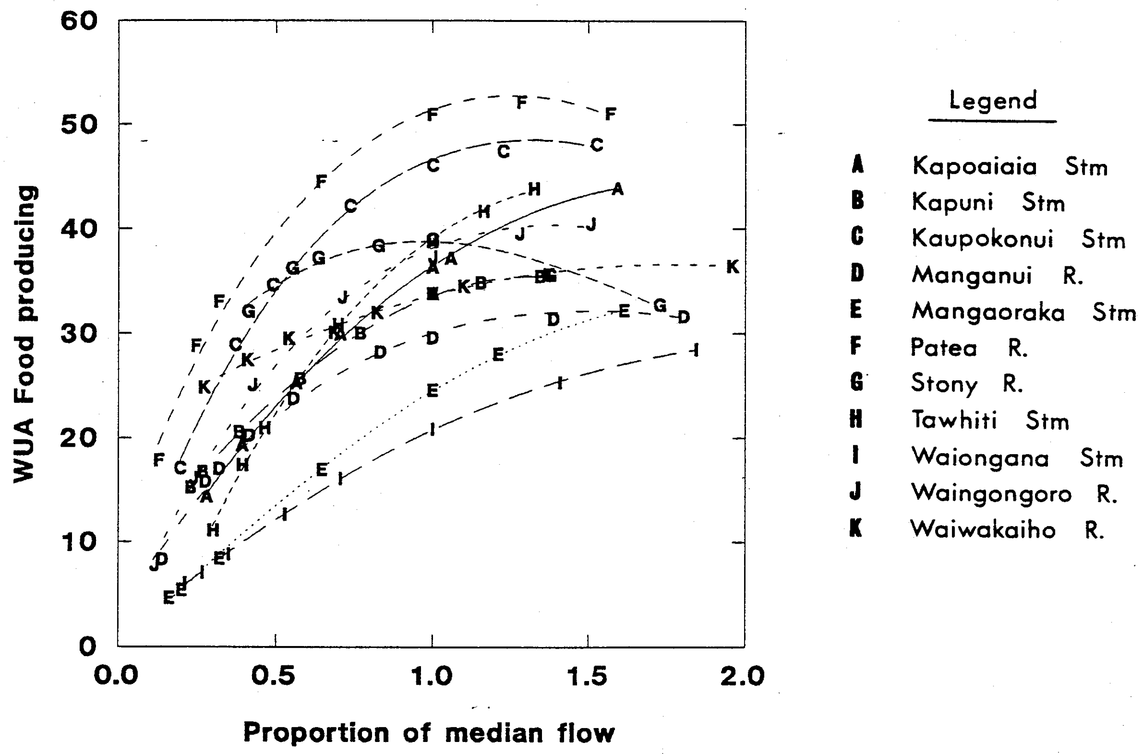

FIGURE 10. Variation in the weighted usable area of food-producing habitat with flow (as a proportion of the median flow) in 11 Taranaki streams and rivers.

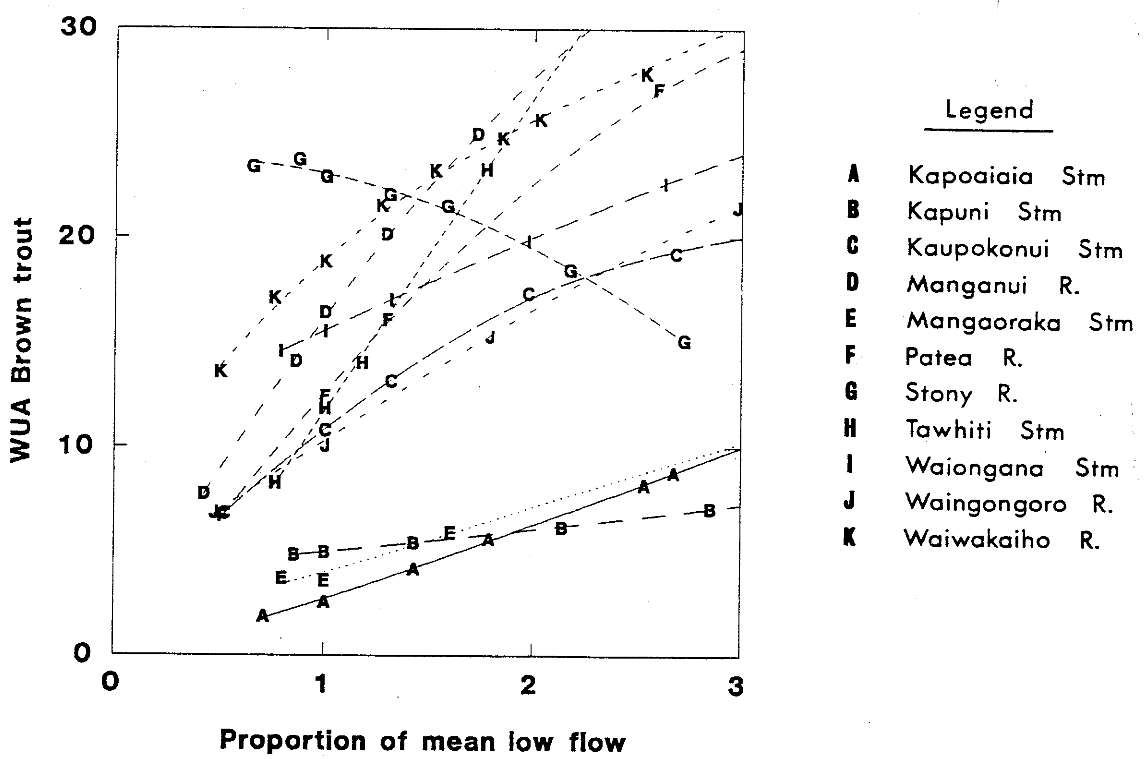

FIGURE 11. Variation in the weighted usable area of adult brown trout habitat with flow (as a proportion of the mean annual low flow) in 11 Taranaki streams and rivers.

Brown trout habitat decreases with flow below about three times the mean annual low flow in all rivers except the Stony (Fig. 11). The Stony River is steep (>0.01) with higher water velocities than in the other rivers surveyed so that a reduction in flow actually increases the amount of suitable habitat (the preferred velocities are in the range of 0.3 to 0.6 m/s (Fig.3)). The high average water velocity of the Stony River (0.45 m/s) at mean annual low flow may be one of the factors that make the river suitable for rainbow trout as well as brown trout.

The amount of change in instream habitat as a result of modifying the flow regime of a river is directly proportional to the slope of the flow/habitat relationship. If the slope is flat, there will be little change in habitat, whereas a steep slope declining towards zero habitat means that any reduction of flow will rapidly decrease the amount of suitable habitat.

Habitat management guidelines

Regional water allocation decisions can be made with minimal impact in a number of ways. In the past, "best" rivers have been protected by conservation orders and abstractions to a common guideline, usually hydrological, have been allowed in other rivers. In practice there have been difficulties; minimum acceptable guidelines have proven difficult to define to the satisfaction of all interested parties and local demands for water-use and the cost of obtaining water from other sources can often outweigh environmental concerns.

If habitat-based methods of flow allocation are adopted, the appropriate type of habitat must be considered as well as the objective or target of habitat management. Some Taranaki rivers support good brown trout fisheries and consideration of both adult brown trout habitat and the habitat which generates food for them is appropriate. Other streams, mainly smaller, contain poor or no trout fisheries but will contain native fish which feed on benthic invertebrates and make consideration of food producing habitat a valid concern. Thus, consideration of food producing habitat is or should be common to all rivers, whether it is to maintain native fish, brown or rainbow trout, or to maintain a "healthy" stream environment. Habitat management objectives are more difficult to define. The three objectives discussed here are:

1) preservation of regionally important or "best" rivers

2) accepting a percentage reduction in habitat

3) retaining a minimum amount of habitat.

The first objective is well known. Water use has been restricted on rivers considered to be nationally or regionally outstanding. In the Taranaki region, the Stony River has been considered regionally outstanding - a view supported by the instream habitat analysis in this study.

A percentage reduction in the amount of existing or "natural" habitat would allow a degree of water use in all rivers of the region. The percentage could vary between rivers depending on the relative value of competing water demands. For the purposes of this study a constant percentage has been assumed.

The third objective, retaining a minimum amount of habitat, could be applied by setting minimum habitat quality guidelines in terms of habitat units (percentage weighted usable area). This allows regionally consistent guidelines to be applied.

Management requirements and consultative processes could consider and, if necessary, vary the percentage reduction or minimum habitat in order to obtain desired outcomes.

In many rivers available habitat, both food producing and adult trout, declines towards zero as the flow falls below the mean annual low flow. Any decision on minimum flows is thus one of "how much habitat loss is acceptable", rather than one of selecting a minimum flow that results in little or no habitat loss. Selection of habitat quality guidelines is an important issue and one for which there is no precise formula. In this study, guidelines are established for two objectives - a percentage reduction in habitat and retention of a minimum amount of habitat - to illustrate the application of habitat-based methods of flow allocation.

No guideline or biological justification exists for the percentage loss of "natural" habitat which would be considered acceptable. The guideline of one-third loss (i.e., retention of two-thirds) existing habitat has been assumed for this study.

Guidelines for minimum amounts of habitat can be derived from the 63 rivers of the "100 rivers" database. These rivers define the range and variation of habitat quality in rivers over much of New Zealand, and, in as much as they were selected without reference to habitat or biological quality, form an unbiased sample which can be used to define habitat guidelines. The selection criteria for these rivers were that there were good flow records and that the water clarity was suitable for underwater observation. About 10% of the rivers were in the Taranaki region. The presence of a water level recorder may have biased the selection towards larger rivers because many smaller New Zealand streams are not monitored for flow. Only two of the rivers in the national database had mean flows of less than 2 m^3/s and 12 had flows less than 5 m^3/s. Weighted usable areas were calculated for the 63 rivers and the values ranked so that they could be used to define habitat guidelines (e.g. Fig. 7). The rivers with the lowest amounts of habitat represent "poor" quality and those with the highest amounts represent "high" quality rivers. The "guideline" is the percentage of rivers of either higher or lower quality. Examples of habitat guidelines derived from the national database are: for food producing habitat, 85% of the rivers contain more than 20% WUA at median flow (15% contain less than 20% WUA), and at mean annual low flow 85% contain more than 13% WUA; for adult brown trout habitat, 85% contain more than 6.5% WUA at mean annual low flow.

Minimum flow assessments

Relationships between flow and WUA (Figs. 9-11) were used to estimate the proportion of each river's mean annual low flow which retains:

a) a minimum amount of habitat equivalent to that exceeded by 85% of the rivers in the national survey, and

b) two thirds of the amount of habitat at existing or "natural" mean annual low flow.

Although retaining a minimum amount of usable habitat has a certain biological justification, it could result in very severe changes in the larger rivers such as the Stony and Waiwakaiho. To prevent this, the second guideline, that of retaining two-thirds of existing habitat is applied. Thus minimum flow assessments (Table 5) are based on the highest of the two guidelines in order to maintain either a minimum amount or prevent excessive habitat loss.

TABLE 5. Minimum flows to maintain food producing and adult brown trout habitat (WUA) at habitat guidelines of either retaining a percentage of the water surface area as usable habitat or retaining two thirds of the habitat available under "natural" flows.

River/stream	Mean annual low flow MALF (l/s)	Food producing habitat Minimum as proportion of MALF: 13% WUA	2/3 WUA	Adult brown trout habitat Minimum as proportion of MALF: 6.5% WUA	2/3 WUA	Minimum flow assessment (l/s)
Waiongana Stream	379	2.09	0.67	0.10	0.25	792
Mangaoraka Stream	251	2.47	0.67	1.84	0.40	620
Tawhiti Stream	172	0.85	0.79	0.64	0.72	146
Manganui River	1160	0.74	0.67	0.34	0.67	858
Kapoaiaia Stream	284	0.65	0.67	2.07	0.67	588
Kapuni Stream	346	0.71	0.67	2.73	0.35	945
Waingongoro River	420	0.84	0.67	0.45	0.48	353
Kaupokonui Stream	760	0.38	0.67	0.50	0.56	509
Patea River	770	0.32	0.67	0.50	0.67	516
Stony River	2300	0.09	0.29	0.04	0.24	667
Waiwakaiho River	1970	0.09	0.20	0.12	0.44	867

In the four rivers of highest habitat quality (the Patea, Stony, Kaupokonui, and Waiwakaiho Rivers (Table 4)) the two-thirds guideline is the one which determines the minimum flow. Of the seven remaining rivers, the minimum food producing habitat guideline determines minimum flows in five and trout habitat in two. The two streams where trout habitat is critical are the Kapuni and Kapoaiaia Streams - streams in which surveyed trout habitat was of very poor quality (Table 4). For such streams it may not be appropriate to attempt to maintain minimum trout habitat, either because the reach may not be representative of the stream or because the overall quality of the stream is unsuitable for trout. In most of the Taranaki rivers surveyed, retaining two thirds (i.e. reducing habitat by one third) is tantamount to selecting a minimum flow which is one third less than the mean annual low flow because in most cases habitat declines uniformly to zero as the flow falls below the low flow.

The minimum flow assessments in Table 5 apply to the sections of the river that the surveys represent. Usually this means sections with similar flow and gradient to the survey reaches. Some reaches like that of the Kapuni Stream are in the lower reaches where substrate is finer. Others like the Patea are in the headwaters of the river and flow requirements for this section of the river would differ markedly from the flow requirements of the lower Patea River.

If consistent habitat guidelines, either as a percentage reduction or retaining a set amount, are applied, minimum flows are higher, relative to the mean annual low flow, in smaller Taranaki rivers and streams than the larger ones. Small streams appear to contain less food producing habitat than larger streams and the consequences of reducing flows in small streams are therefore more severe. This hypothesis is not unreasonable hydraulically. The main criteria for food production are a suitable substrate and water velocity. In most small streams at low flows, depths tend to be shallow, and with coarse substrate, hydraulic friction losses increase and water velocities fall below those suitable for good invertebrate habitat. Ideally, further research into the hydraulic and biological characteristics of small streams and a comparison with larger streams is required to establish whether small streams are more "fragile" than large streams or whether the same criteria should apply.

Calculation of flow requirements for other Taranaki rivers

Instream flow requirements for food producing and brown trout habitat depend primarily on the depth and velocity of the flowing water. These physical characteristics are in turn controlled by the morphological characteristics of the river (i.e. its width, mean depth, and slope and/or mean velocity). Thus, the amount of suitable instream habitat should be related to the river width, mean depth, slope, and mean velocity. Stepwise interactive regression was used to investigate the relationships between river and catchment characteristics (mean annual minimum flow, median flow, reach water surface slope, average substrate size, average water depth, velocity and width at median flow, roughness coefficient, river slope, and catchment area), and weighted usable areas (as percentage of river area). A number of significant relationships were derived which describe ways in which general morphological characteristics are related to habitat quality.

Weighted usable area for food production at mean annual low flow (WUA_FP_LF) was positively related to the magnitude of the low flow (MALF) and mean water velocity (VEL) and negatively related to river width (WID).

$$\text{WUA\_FP\_LF} = 1.88 + 0.01\ \text{MALF} + 57.6\ \text{VEL} - 0.94\ \text{WID}$$
$$R^2 = 0.83 \quad P = 0.001$$

Food producing WUA at median flow (WUA_FP_M) was positively related to the mean velocity and negatively related to width.

$$\text{WUA\_FP\_M} = 16.32 + 79.44\ \text{VEL} - 0.92\ \text{WID}$$
$$R^2 = 0.707 \quad P = 0.007$$

These relationships suggest that narrow, fast streams contain the highest proportion of food producing habitat and that the larger streams or rivers contain better habitat at low flows.

Weighted usable area for adult brown trout habitat at mean annual low flow (WUA_BT_LF) was positively related to mean annual low flow (MALF) and depth (DEP) and negatively related to width (WID).

$$\text{WUA\_BT\_LF} = -3.38 + 0.006\ \text{MALF} + 32.79\ \text{DEP} - 0.36\ \text{WID}$$
$$R^2 = 0.947 \quad P < 0.001$$

This suggests that good brown trout streams are narrow and deep with a higher proportion of habitat at low flow in larger streams.

The measurement of "overall" relative quality, the sum of food producing habitat at median flow and trout habitat at low flow (Table 4) was positively related to median flow and velocity and negatively related to width.

$$\text{WUA\_SUM} = 42.25 + 0.011\ \text{MEDIAN} + 38.39\ \text{VEL} - 2.66\ \text{WID}$$
$$R^2 = 0.81 \quad P = 0.004$$

This combines both the trout and food producing characteristics, suggesting that the best overall quality is found in larger rivers which are fast and relatively narrow.

These relationships could be used to establish the relative habitat quality of ungauged streams or rivers or for different sections of rivers with existing habitat data. Simple and efficient procedures for the determination of mean depths, widths, and velocities could be established. For instance, ten measurements of width through two pool/run/riffle sequences, 10-20 depth measurements along the line of mean current flow, and dye time-of-travel measurements could be used to establish mean widths, line of main current flow depths and velocities. The mean line of main current flow depth could be related empirically to mean river depth as obtained from surveys.

These relationships establish the habitat "quality" of an existing river or section of river. They do not provide any information about the variation of WUA with discharge - information which is necessary before minimum flows can be assessed according to habitat guidelines. Stepwise multiple regression was used to determine relationships between the minimum flow assessments in Table 5 and river and catchment characteristics. Minimum flows, as a proportion of mean annual low flow, were most closely related to mean annual low flow (Fig. 12), with smaller streams requiring a higher proportion of the mean annual low flow to maintain minimum habitat guidelines. The best relationships was with slope, river width at median flow, and mean annual low flow.

$$\text{Minimum flow} = 721\ \text{MALF}^{-0.226}\ \text{WID}^{1.172}\ \text{SLOPE}^{0.349}$$
$$R^2 = 0.91 \quad P < 0.001$$

where the width is in metres, slope is dimensionless, and MALF the mean annual low flow in litres/sec.

Minimum flow for a river, or more precisely for a section of the river, can be derived either from recorded mean annual minimum flows or flows estimated by conventional hydrological techniques (e.g. Taranaki Catchment Commission 1984a), river width at median flow, and average water surface slope for that section of the river. The easiest procedure for estimation of width at median flow is to measure the river width at near median flow at 10 locations - 5 at the widest sections and 5 at the narrowest sections. The average of the values will give an estimate of mean width. Water surface slope can be measured from a 1:50000 map. Any derived minimum flows should be checked against the proportions of mean annual low flow shown in Fig. 12. Extrapolation of Fig. 12 beyond about 2500 ℓ/s cannot be linear, otherwise the extrapolated flow would be zero or less for rivers with mean annual low flows greater than about 3500 ℓ/s.

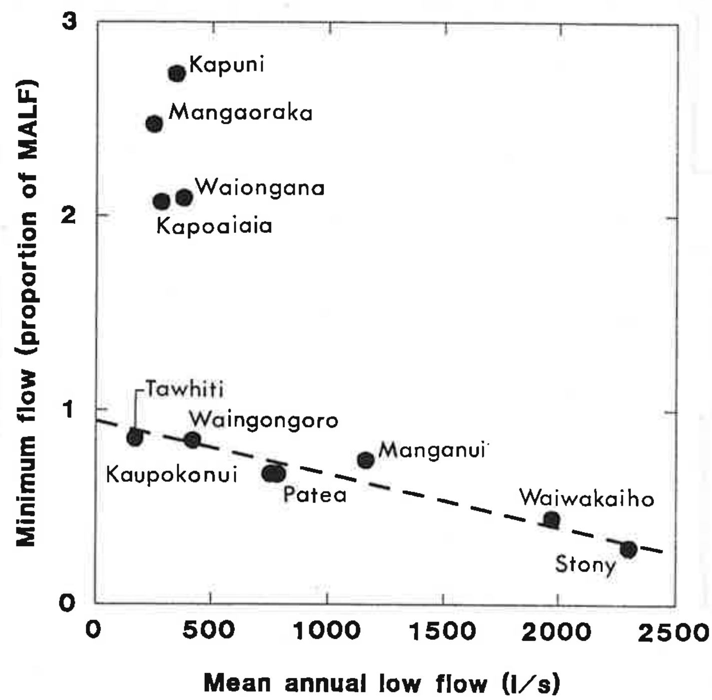

FIGURE 12. Relationship between mean annual low flow and minimum flow, expressed as a proportion of the mean annual low flow, set using habitat guidelines for 11 Taranaki streams and rivers.

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APPENDIX

Minimum Flow Assessment for Streams where the Flow Regime is Severely Modified

The habitat guidelines and assessments of minimum flow are based on the assumption that the flow regime will remain "natural", that is the minimum flow will occur relatively infrequently and that the most commonly occurring flow, the median, is two to five times higher. If natural river flows are modified to such an extent that the minimum and median flows are equal or similar (such as a residual flow below a storage dam), then instream habitat guidelines should be based on that available at median rather than minimum flow. For example, 85% of the rivers in the national database have more than 20% WUA for food production and a residual minimum (and median) flow should provide that amount of habitat if the guideline is to be met. Table 1 lists the proportion of median flow which is required to retain either a) a minimum of 20% food producing WUA, or b) two thirds of the habitat available at existing or "natural" median flow as a guide to assessing the amount of change in food production resulting from significant changes to the flow regime. Similar calculations can be made for brown trout habitat if required.

The selection of guidelines is arbitrary and similar tables can be calculated from Figs 9-11 for other habitat guidelines.

TABLE 1. Proportion of median flow which retains either 20% of the water surface area as food producing habitat or two thirds of the habitat available at existing or "natural" median flow.

	Food producing habitat Proportion of median flow to retain:	
River/stream	20% WUA	2/3 WUA
Waiongana Stream	0.93	0.58
Mangaoraka Stream	0.78	0.61
Tawhiti Stream	0.55	0.44
Manganui River	0.57	0.43
Kapoaiaia Stream	0.41	0.53
Kapuni Stream	0.37	0.45
Waingongoro River	0.33	0.46
Kaupokonui Stream	0.23	0.43
Patea River	0.12	0.38
Stony River	0.11	0.23
Waiwakaiho River	0.10	0.17

TABLE 2. Predicted hydraulic characteristics and instream habitat for up to mean flow.

Flow (m^3/s)	Section area (m^2)	Width (m)	Wetted perimeter (m)	Depth Mean (m)	Depth Maximum (m)	Velocity Mean (m/s)	Velocity Maximum (m/s)	Weighted usable area Food (m)	Food (%)	Brown trout (m)	Brown trout (%)
Kapoaiaia Stream											
.20	1.04	6.47	7.01	.16	.88	.206	.99	.93	14.4	.12	1.9
.28	1.23	7.10	7.70	.17	.89	.237	.99	1.37	19.3	.18	2.5
.40	1.52	7.50	8.16	.21	.92	.262	1.03	1.89	25.2	.31	4.1
.50	1.73	7.73	8.43	.23	.95	.287	1.14	2.31	29.9	.43	5.6
.71	2.06	8.18	8.93	.26	.98	.343	1.32	2.97	36.3	.67	8.2
.75	2.12	8.21	8.98	.26	.99	.350	1.35	3.05	37.1	.72	8.8
1.13	2.66	8.40	9.25	.32	1.05	.421	1.70	3.69	43.9	1.19	14.2
Kapuni Stream											
.30	1.97	8.54	8.83	.23	1.89	.268	.80	1.30	15.2	.41	4.8
.35	2.07	8.91	9.21	.24	1.90	.277	.86	1.49	16.7	.44	4.9
.50	2.33	9.83	10.15	.25	1.93	.313	.98	2.02	20.5	.53	5.4
.75	2.63	10.57	10.92	.27	1.95	.377	1.66	2.71	25.6	.65	6.1
1.00	2.98	11.17	11.53	.30	1.98	.415	1.59	3.35	30.0	.79	7.1
1.30	3.32	11.60	11.99	.32	2.00	.458	1.83	3.92	33.8	.94	8.1
1.50	3.54	11.97	12.36	.33	2.01	.476	2.12	4.17	34.8	1.02	8.5
1.75	3.81	12.39	12.80	.34	2.03	.493	2.38	4.39	35.4	1.13	9.1
Kaupokonui Stream											
.40	1.96	8.97	9.40	.22	.64	.220	1.00	1.53	17.1	.61	6.8
.76	2.59	10.48	11.03	.25	.73	.297	1.13	3.03	28.9	1.13	10.8
1.00	2.93	11.03	11.64	.27	.78	.335	1.25	3.82	34.6	1.45	13.1
1.50	3.60	11.78	12.48	.32	.85	.401	1.43	4.97	42.2	2.04	17.3
2.04	4.18	12.52	13.29	.35	.91	.464	1.62	5.77	46.1	2.41	19.2
2.50	4.66	13.07	13.89	.38	.96	.508	1.73	6.20	47.4	2.65	20.3
3.11	5.16	13.31	14.18	.41	1.01	.571	1.96	6.40	48.1	2.80	21.0
Manganui River											
.50	3.26	12.43	13.71	.26	.81	.148	.87	1.03	8.3	.96	7.7
1.00	4.67	14.19	15.87	.33	.90	.200	1.13	2.24	15.8	2.00	14.1
1.16	5.21	14.81	16.61	.35	.93	.207	1.15	2.52	17.0	2.43	16.4
1.50	5.94	15.44	17.36	.39	.98	.236	1.27	3.12	20.2	3.11	20.1
2.00	6.97	16.18	18.25	.43	1.04	.266	1.51	3.84	23.7	4.04	25.0
3.00	8.71	16.91	19.17	.52	1.14	.317	1.88	4.77	28.2	5.53	32.7
3.60	9.64	17.25	19.60	.56	1.20	.341	2.09	5.10	29.6	6.14	35.6
5.00	11.57	17.80	20.30	.65	1.30	.393	2.47	5.58	31.3	6.98	39.2
6.50	13.43	18.29	20.93	.74	1.40	.436	2.78	5.78	31.6	7.57	41.4
Mangaoraka Stream											
.20	2.34	10.85	11.40	.20	.60	.115	.73	.5	4.6	.4	3.7
.25	2.57	11.21	11.80	.22	.62	.123	.70	.6	5.4	.4	3.6
.40	3.03	11.91	12.59	.25	.66	.154	.76	1.0	8.4	.7	5.9
.80	4.06	12.98	13.81	.31	.74	.215	.86	2.2	16.9	1.4	10.8
1.24	4.91	13.45	14.42	.37	.81	.272	.92	3.3	24.5	2.1	15.6
1.50	5.31	13.57	14.61	.40	.84	.302	1.01	3.8	28.0	2.5	18.4
2.00	6.00	13.67	14.82	.44	.90	.353	1.34	4.4	32.2	3.1	22.7
Patea River											
.40	1.93	8.08	8.73	.25	1.18	.202	.84	1.44	17.8	.54	6.7
.77	2.72	9.57	10.43	.30	1.29	.263	1.03	2.76	28.8	1.19	12.4
1.00	3.15	10.20	11.18	.33	1.35	.293	1.07	3.37	33.0	1.64	16.1
2.00	4.60	11.79	13.08	.42	1.51	.401	1.17	5.25	44.5	3.20	27.1
3.11	5.87	12.46	13.96	.51	1.62	.503	1.47	6.35	51.0	3.97	31.9
4.00	6.77	12.79	14.40	.56	1.70	.566	1.95	6.67	52.2	4.19	32.8
4.88	7.59	13.01	14.72	.62	1.77	.620	2.33	6.64	51.0	4.34	33.4
Stony River											
1.50	3.84	9.75	10.51	.45	2.04	.371	1.74	3.13	32.1	2.28	23.4
2.00	4.27	10.54	11.36	.46	2.10	.423	2.04	3.82	36.2	2.50	23.7
2.30	4.55	11.13	11.98	.47	2.13	.449	2.17	4.14	37.2	2.55	22.9
3.00	5.17	12.02	12.94	.50	2.20	.505	2.47	4.61	38.4	2.65	22.0
3.63	5.68	12.60	13.55	.52	2.25	.546	2.51	4.91	39.0	2.71	21.5
5.00	6.74	14.09	15.14	.54	2.35	.610	3.20	5.01	35.6	2.60	18.5
6.27	7.67	15.43	16.55	.56	2.44	.661	3.94	5.05	32.7	2.33	15.1

TABLE 2. (Contd.)

Flow (m^3/s)	Section area (m^2)	Width (m)	Wetted perimeter (m)	Depth Mean (m)	Depth Maximum (m)	Velocity Mean (m/s)	Velocity Maximum (m/s)	Weighted usable area Food (m)	Food (%)	Brown trout (m)	Brown trout (%)
Tawhiti Stream											
.13	1.17	4.23	4.59	.28	.75	.139	.57	.47	11.1	.35	8.3
.17	1.31	4.31	4.71	.31	.79	.168	.58	.75	17.4	.51	11.8
.20	1.39	4.35	4.77	.33	.81	.183	.59	.91	20.9	.61	14.0
.30	1.67	4.51	4.99	.38	.87	.228	.62	1.39	30.8	1.05	23.3
.43	1.97	4.67	5.22	.43	.93	.270	.70	1.81	38.8	1.59	34.0
.50	2.15	4.75	5.33	.46	.97	.289	.74	1.98	41.7	1.88	39.6
.57	2.31	4.81	5.43	.49	1.00	.306	.79	2.11	43.9	2.09	43.5
Waingongoro River											
.20	1.55	6.59	7.17	.23	1.28	.153	.77	.51	7.7	.45	6.8
.42	2.03	7.76	8.48	.27	1.34	.216	.90	1.25	16.1	.78	10.1
.75	2.65	8.90	9.76	.31	1.41	.278	1.07	2.23	25.1	1.36	15.3
1.25	3.36	9.68	10.66	.36	1.48	.356	1.27	3.24	33.5	2.08	21.5
1.76	4.03	10.35	11.42	.40	1.54	.414	1.59	3.86	37.3	2.53	24.4
2.25	4.59	10.70	11.85	.44	1.59	.458	1.71	4.23	39.5	2.77	25.9
2.65	4.99	10.92	12.12	.47	1.62	.492	1.88	4.42	40.5	2.85	26.1
Waiongana Stream											
.30	4.50	8.17	9.34	.51	2.31	.111	1.00	.49	6.0	1.19	14.6
.38	4.69	8.56	9.78	.52	2.33	.122	1.18	.60	7.0	1.33	15.5
.50	5.02	8.99	10.30	.54	2.37	.143	1.13	.79	8.8	1.53	17.0
.75	5.48	9.73	11.19	.56	2.40	.175	1.29	1.23	12.6	1.93	19.8
1.00	5.92	10.26	11.85	.58	2.44	.203	1.34	1.65	16.1	2.32	22.6
1.42	6.60	11.05	12.82	.62	2.49	.244	1.69	2.30	20.8	2.94	26.6
2.00	7.36	11.96	13.85	.65	2.56	.306	1.91	3.02	25.3	3.57	29.8
2.62	8.00	12.26	14.24	.68	2.61	.360	2.15	3.49	28.5	3.99	32.5
Waiwakaiho River											
1.00	4.41	12.82	14.01	.30	1.49	.285	1.13	3.18	24.8	1.74	13.6
1.50	5.43	14.69	16.17	.34	1.56	.317	1.32	4.03	27.4	2.51	17.1
1.97	6.29	16.05	17.75	.37	1.62	.345	1.49	4.74	29.5	3.12	18.8
2.50	7.49	18.11	20.05	.40	1.71	.358	1.70	5.45	30.1	3.90	21.5
3.00	8.16	18.57	20.66	.42	1.74	.384	1.81	5.94	32.0	4.31	23.2
3.64	8.98	19.14	21.40	.46	1.78	.411	1.93	6.47	33.8	4.74	24.8
4.00	9.46	19.51	21.87	.47	1.81	.422	2.05	6.73	34.5	5.01	25.7
5.00	10.60	20.09	22.64	.52	1.86	.459	2.40	7.16	35.6	5.60	27.9
7.14	12.75	20.70	23.53	.61	1.97	.529	2.91	7.54	36.4	6.77	32.7