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NEW ZEALAND FRESHWATER FISHERIES MISCELLANEOUS REPORT NO. 117

FLOW REQUIREMENTS FOR BROWN TROUT IN THE ASHBURTON RIVER

by
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Report to Canterbury Regional Council

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Servicing freshwater fisheries and aquaculture

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INTRODUCTION

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 one (optimum) to zero (unsuitable). Once habitat suitability curves or criteria are defined they can be applied to habitat survey data (Figure 1) 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.

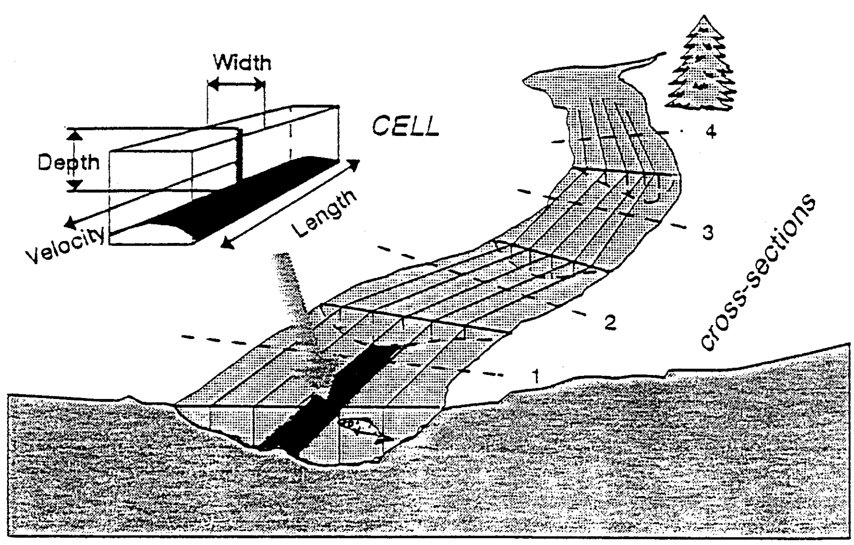
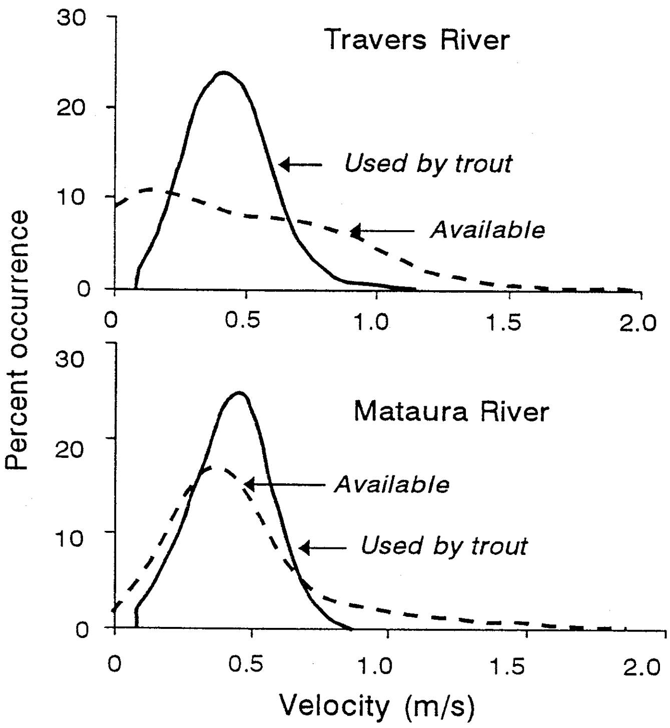


Figure 1. Instream habitat model of river reach showing cross-sections and cells.

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 were different in each river (Figure 2). These data can be formed into habitat preference curves (Figure 3). 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).



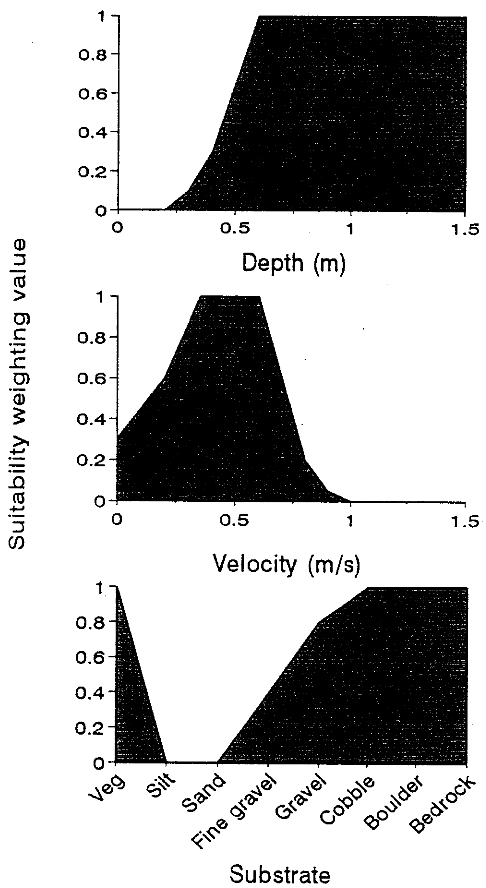


Figure 2 (left). Comparison of water depths and velocities available in two rivers with those used by large brown trout when feeding on drifting invertebrates.

Figure 3 (right). Example of drift-feeding habitat preference curves for adult brown trout [from 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). Over a section of the river the average water velocity is determined by slope, friction, and the hydraulic radius (e.g. Manning equation). For a given flow the longitudinal water surface profile can be calculated using principles of energy conservation. The change in water surface elevation is computed separately and successively between cross-sections. When computing water surface profiles using a uniform flow formula, such as the Manning equation, 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. Calculations begin at the downstream cross-section and progress upstream.

Hydraulic roughness and losses are determined from field data on discharge, cross-section area, hydraulic radius, and slope. Hydraulic roughness (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 (Figure 4) (Mosley and Jowett 1985; Jowett 1989). Cell velocities 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. For every cell in the river 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) (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. This provides useful information on the availability of instream habitat and its variation with flow. The computer programme RHYHABSIM (Jowett 1989) combines hydraulic simulation and evaluation of habitat suitability.

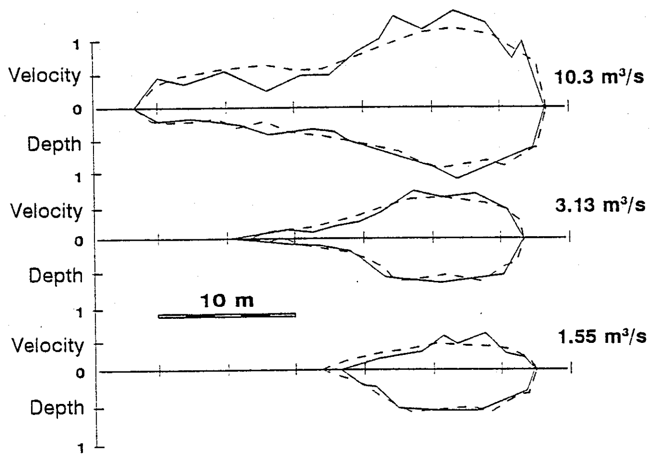


Figure 4. Comparison of measured water velocities and depths across a channel (solid line) with those predicted from measurements (dashed line) taken at a flow of 13.2 m^3/s

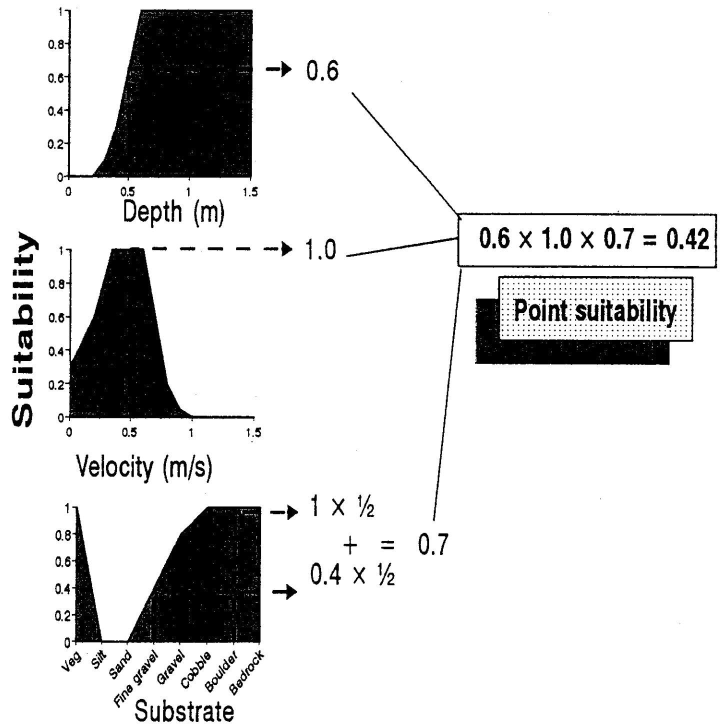


Figure 5. Calculation of point suitability from habitat suitability curves.

Brown trout model

Brown trout are found in most New Zealand rivers from the middle of the North Island to the bottom of the South Island. Brown trout spawn in winter and egg mortality begins to increase when water temperatures exceed 11°C (Scott and Poynter 1991) and this is the most likely reason brown trout do not occur further north. 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. Water temperature is one factor which limits their distribution and abundance. If temperatures are suitable trout may or may not be present depending upon other factors; however, if water temperatures are too high a trout population will not be self-sustaining because of high incubation mortality. This suggests a model of the form:

*trout numbers = temperature suitability *(f1 + f2 + f3+..)*

where temperature suitability takes a value of between 0 and 1 and f1 etc. are other factors influencing trout abundance. If instream habitat (WUA) and the amount of available trout food is incorporated into the model it becomes:

*trout numbers = temperature suitability *(food + space)*

This simple model explained 64.4% of the variation in numbers of large brown trout in 27 rivers where there were data on both trout and invertebrate abundance (Jowett in press). Invertebrate abundance can vary with flow, so by using invertebrate habitat suitability indices in place of measured invertebrate abundance we have a model where the variation of both "food and space" with flow can be predicted. Weighted usable area for trout habitat and WUA for food production plus seven other variables explained 87.7% of the variation in numbers of large brown trout in 59 rivers (Figure 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.

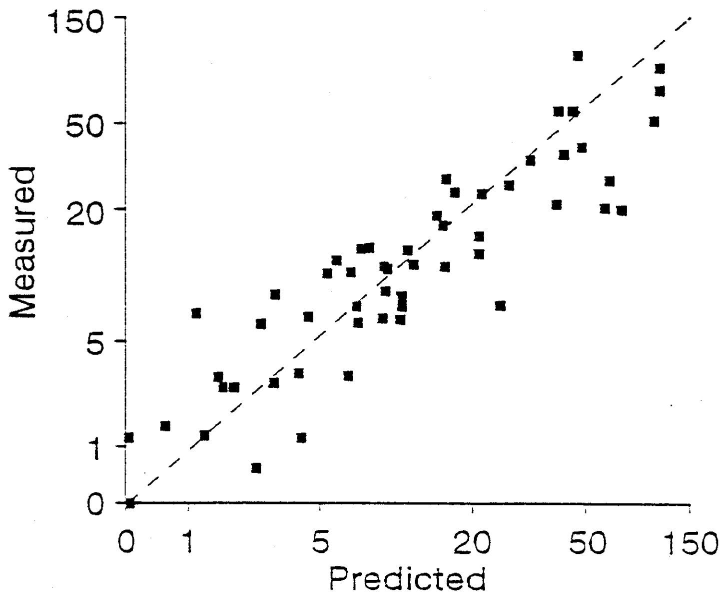


Figure 6. Comparison of measured and predicted numbers of large brown trout per hectare in 59 New Zealand rivers.

However, perhaps the most interesting concept in this model is the flows at which the instream habitat variables (WUA) are calculated. In a natural river, flow and the quality of instream habitat vary with time. The amount of habitat at mean annual low flow, median flow, and mean flow was calculated. Adult trout habitat at mean annual low flow was much more closely related to trout numbers than the habitat available at the higher flows. This suggests that the quality of 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

It is not difficult to predict instream flow requirements for brown trout, 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 alter little with flow. Instream cover can vary with flow, but unless the flow modifications are so severe that stream banks are dewatered, there is usually little change.

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 representive sample of New Zealand rivers, they can be ranked and then divided into groups depending upon the quality of the instream habitat. For instance, 25% of the rivers surveyed had more than 55% of their area providing "food and space" habitat for adult brown trout (Figure 7). This group of rivers represents examples of rivers where naturally occurring flows provide excellent trout habitat. Similarly, 25% of the rivers had less than 38% 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.

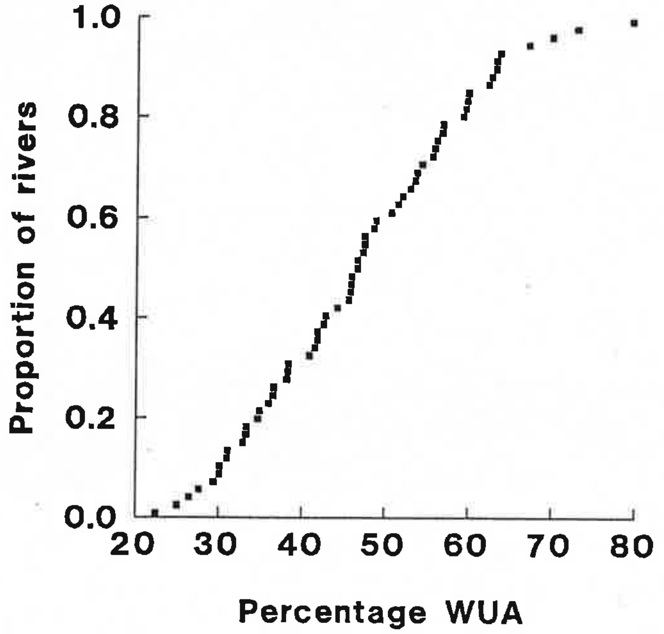


Figure 7. Total "food and space" habitat for adult brown trout in 63 New Zealand rivers.

THE ASHBURTON RIVER

Habitat surveys

Habitat surveys of the Ashburton River were carried out at three locations between 11 and 13 February 1992. Fifty-nine cross-sections were surveyed over 693 m of river. The most downstream reach was at Wakanui below the SH1 bridge (map reference L37:118903), the middle reach at Olivers Road (map reference K37:019089) between the Valetta and SH1 Bridges, and the most upstream reach was just upstream of the Valetta Bridge (map reference K36:915173). Each reach sampled a variety of habitat. The Wakanui reach split into three braids, the Olivers Road reach into two, whereas the Valetta reach was a single channel with a small backwater. The river flowed against a dense bank of willows on the true left of the Wakanui reach, whereas the other two reaches, especially the Olivers Road reach, were more central in the gravel river bed. Each reach contained at least two areas of riffle and a mixture of pool and run habitat (Figures 8-10, Table 1). Substrate generally increased in size with distance upstream. Table 1 lists the number of cross-sections, reach length, average gradient, substrate composition, and flow at the time of survey for each of the reaches.

Table 1. Characteristics of the habitat survey reaches

	Wakanui	Olivers	Valetta
No. of cross-sections	16	23	20
Reach length (m)	260.05	245.35	188.20
Gradient	0.00320	0.00563	0.00657
Survey discharge (m^3/s)	3.39	1.90	2.20
Mean flow*	23	14	9.2
Median flow*	16	8	5.0
Mean annual low flow*	2.5	1.3	0.7
Substrate composition			
% boulder	0.0	0.0	8.9
% cobble	5.2	27.3	54.0
% gravel	62.7	53.6	25.0
% fine gravel	22.3	18.8	9.2
% sand	3.0	0.1	1.6
% silt + vegetation	6.8	0.1	1.3
Habitat type			
% riffle	8	14	10
% run	70	64	75
% pool	22	22	15

* estimated

Hydraulic simulation and habitat evaluation

Hydraulic models were developed for each reach. The Valetta and Wakanui reaches were difficult to model through their riffle sections which were both rather steep. Flow profiles were calculated for flows in the range of 0.5 to 6 m^3/s, using starting levels at the downstream cross-sections which were read from rating curves developed from gaugings made at each of the downstream sections. Higher flows were not simulated because of the complexity of the braied channels and amount of overbank flow which would occur. The measured and simulated water level profiles are shown on Figures 8-10. The amount of adult brown trout habitat and food producing habitat was calculated for each reach and flow simulation.

At the most downstream reach, Wakanui Road, adult trout habitat increased with flow from 1.5 to 6 m^3/s (Figure 11), with a reduction in the rate of increase at between 2 and 3 m^3/s. This reduction combined with the manner in which river width was increasing with flow created a peak in percentage WUA at 2 m^3/s. The habitat available for food production also increased with flow (Figure 12) and the slight changes in the rate of increase, combined with the steady increase in river width (Figure 13), caused a peak in percentage WUA at 2.5 m^3/s.

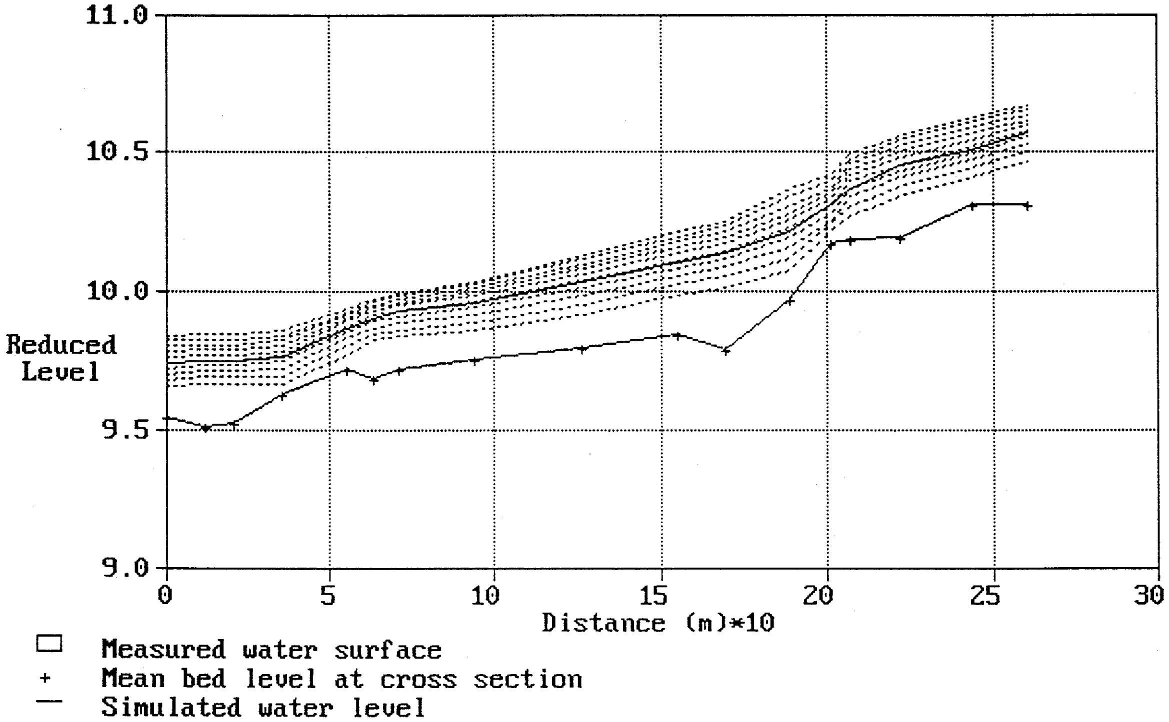


Figure 8. Measured (solid line) and simulated (dashed lines) water level profiles for flows of 1.5 to 6 m^3/s at the Wakanui Road reach of the Ashburton River.

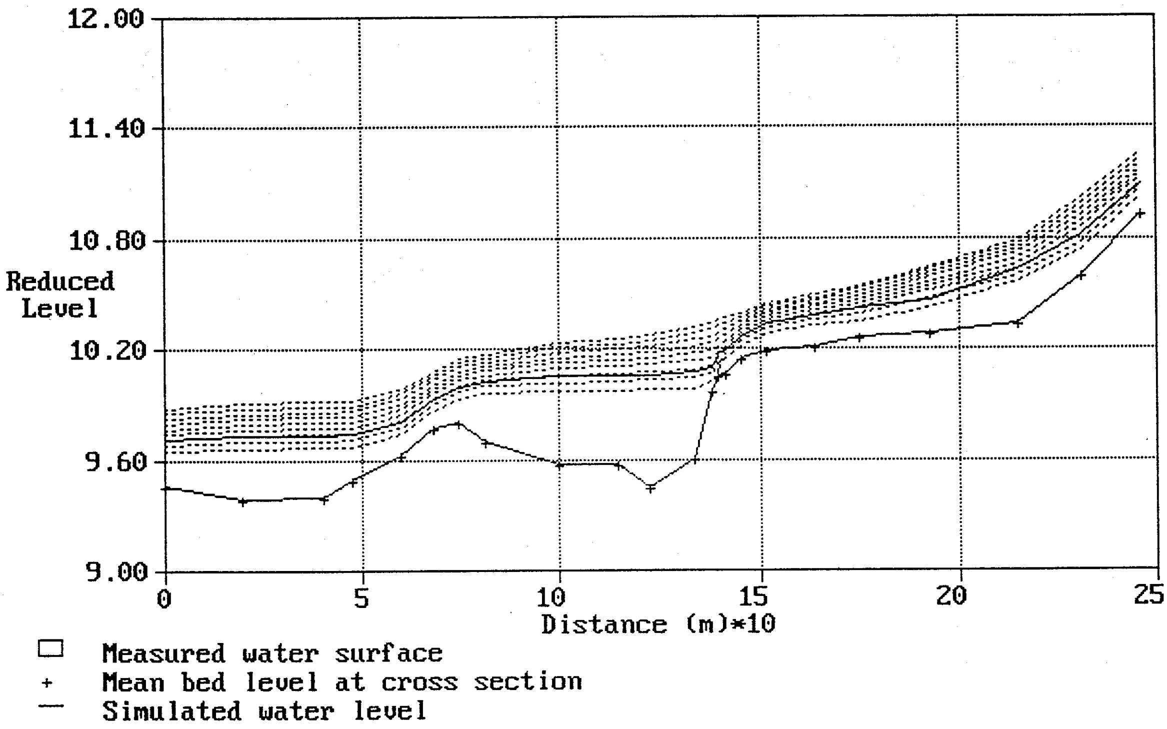


Figure 9. Measured (solid line) and simulated (dashed lines) water level profiles for flows of 1 to 5 m^3/s at the Olivers Road reach of the Ashburton River.

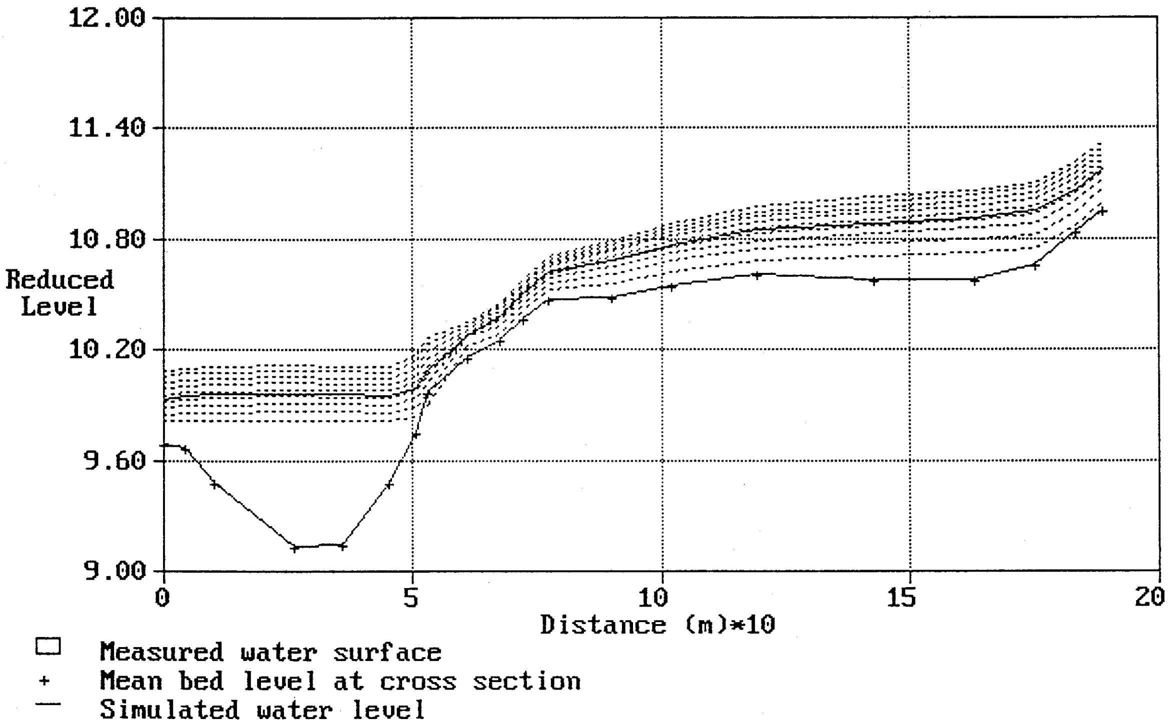


Figure 10. Measured (solid line) and simulated (dashed lines) water level profiles for flows of 0.5 to 4.5 m^3/s at the Valetta Bridge reach of the Ashburton River.

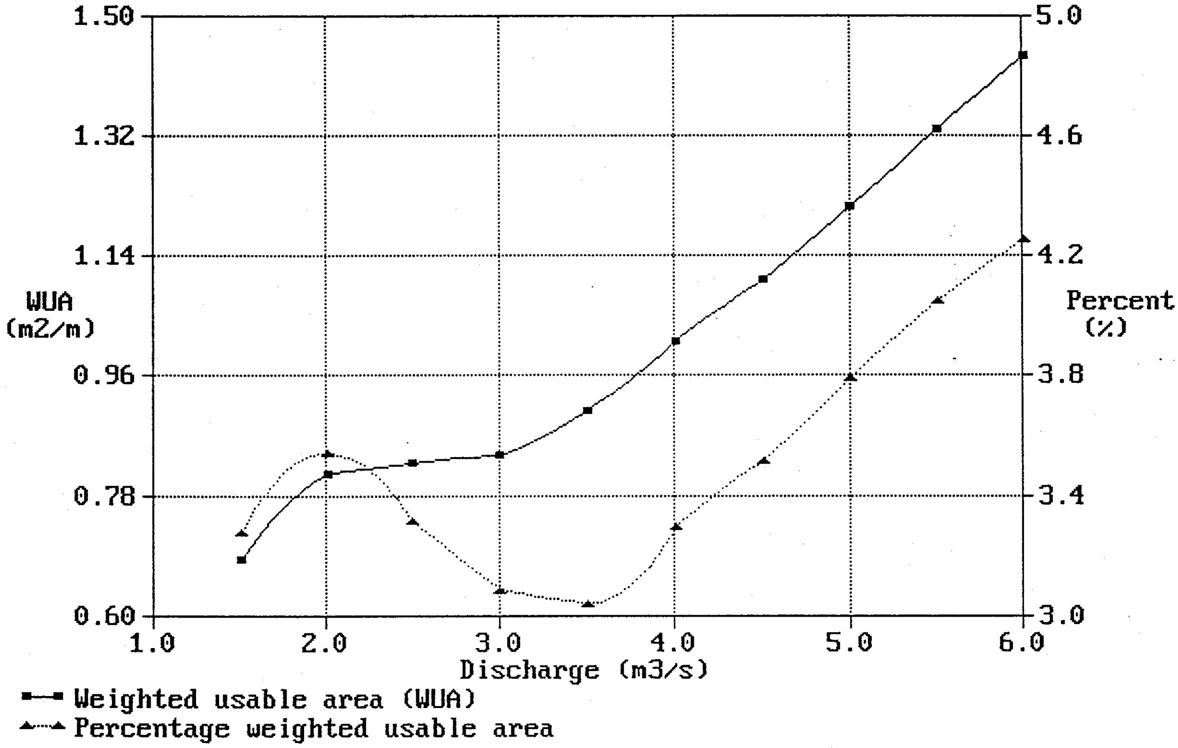


Figure 11. Variation in adult brown trout habitat with flow in the Wakanui Road reach of the Ashburton River.

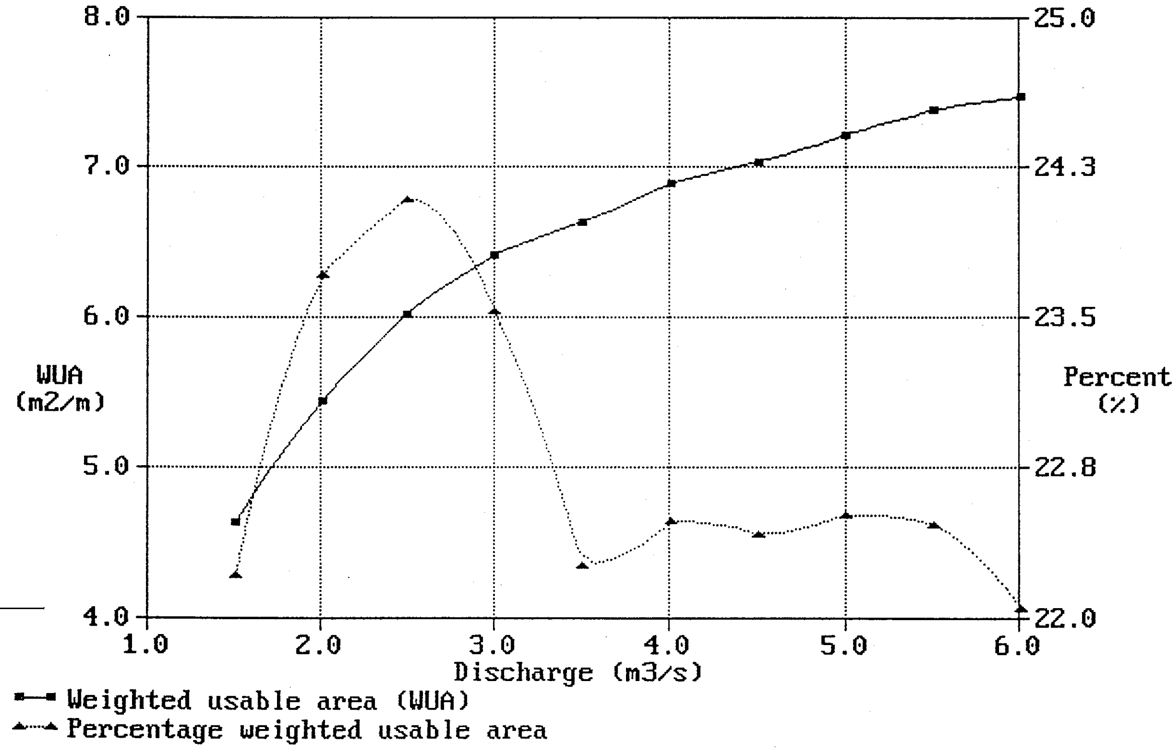


Figure 12. Variation in food producing habitat with flow in the Wakanui Road reach of the Ashburton River.

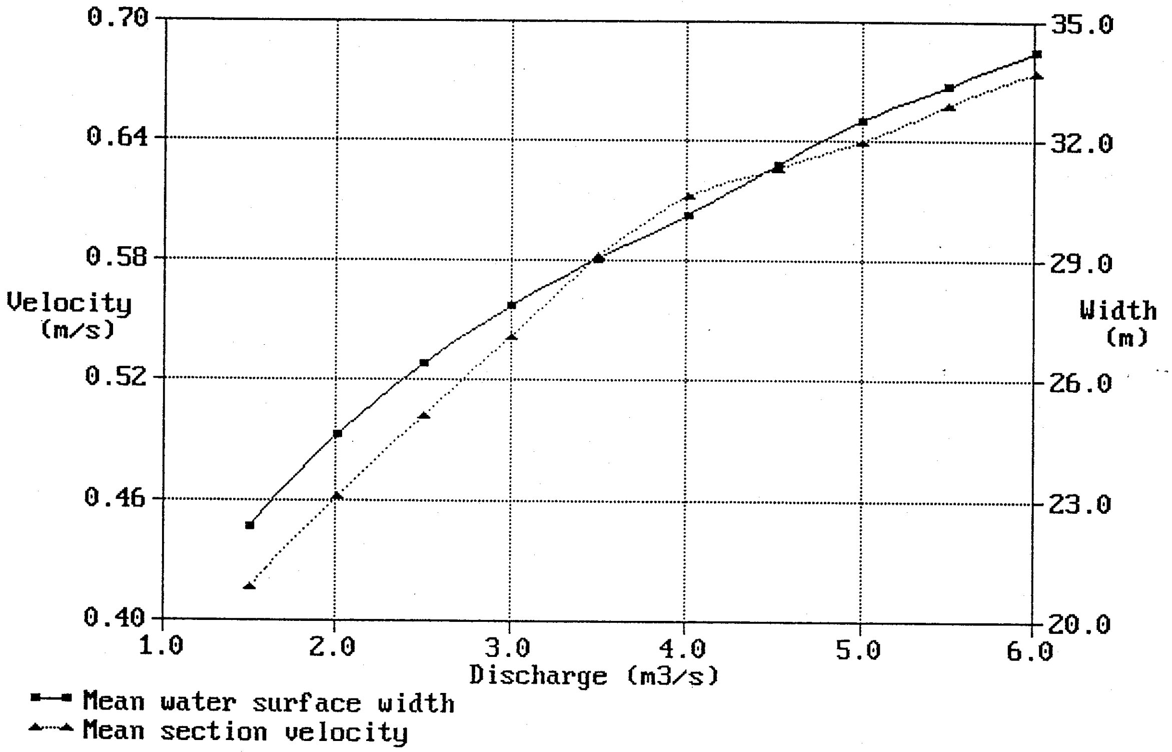


Figure 13. Variation in river width and average velocity with flow in the Wakanui Road reach of the Ashburton River.

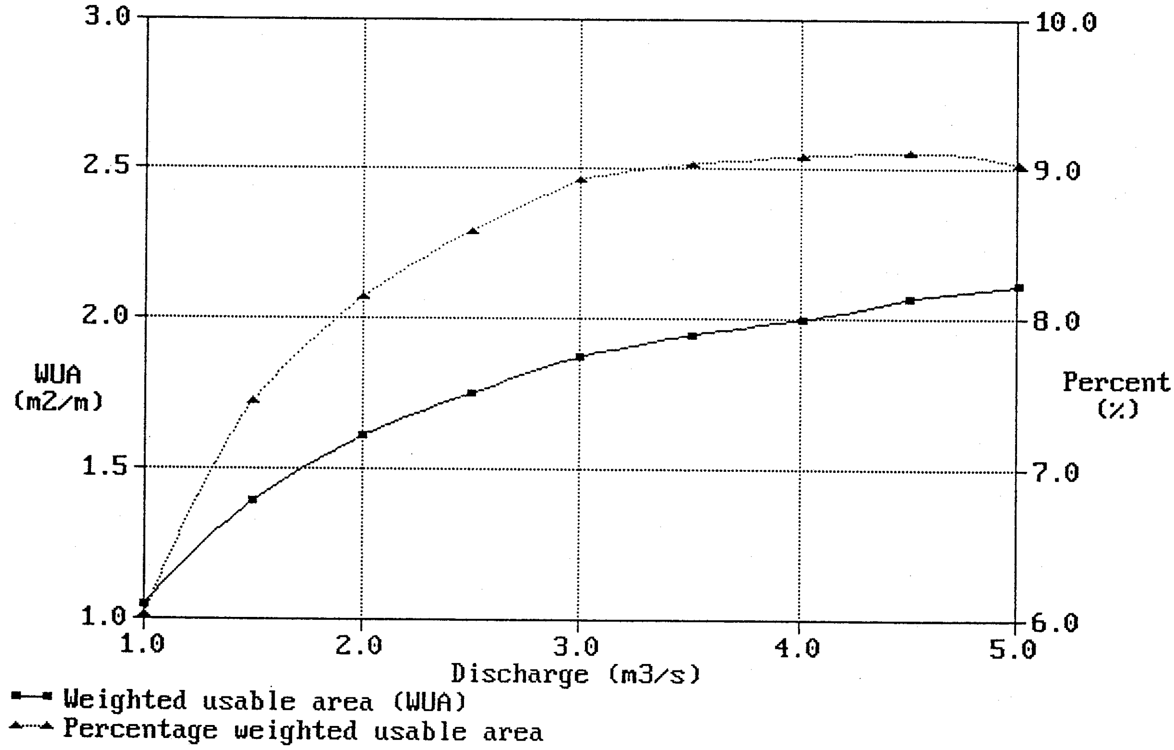


Figure 14. Variation in adult brown trout habitat with flow in the Olivers Road reach of the Ashburton River.

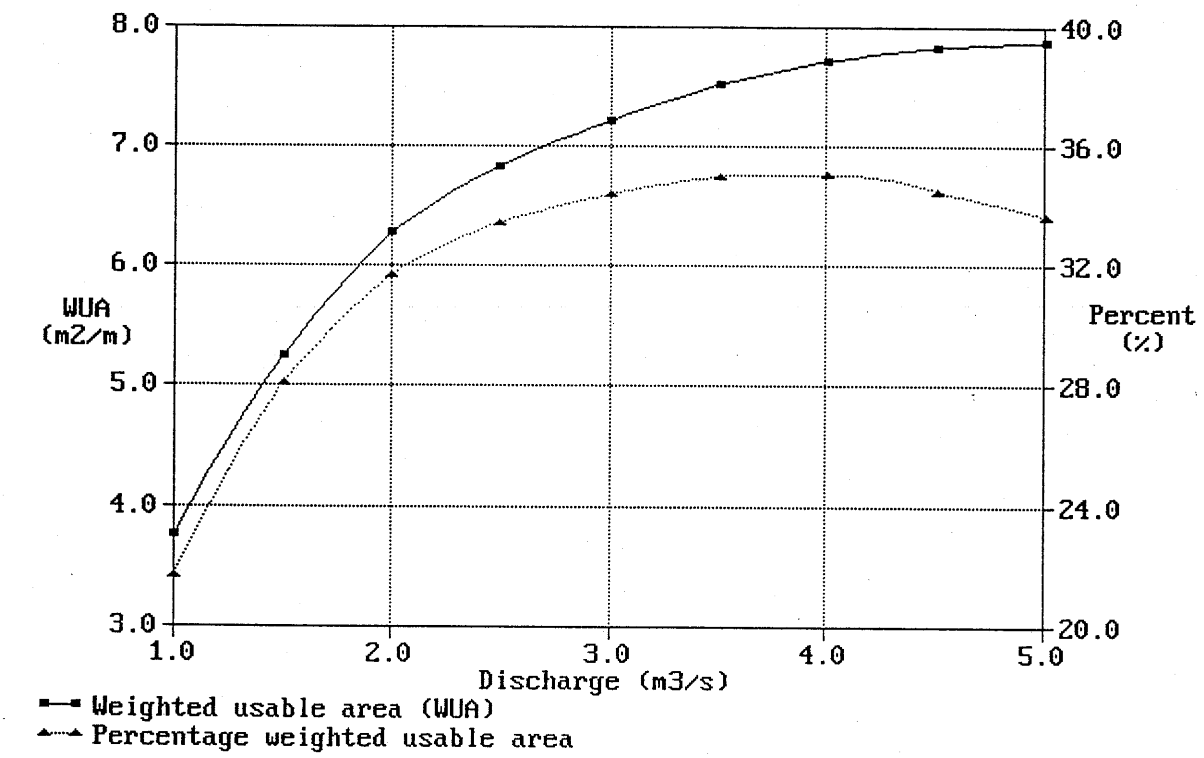


Figure 15. Variation in food producing habitat with flow in the Olivers Road reach of the Ashburton River.

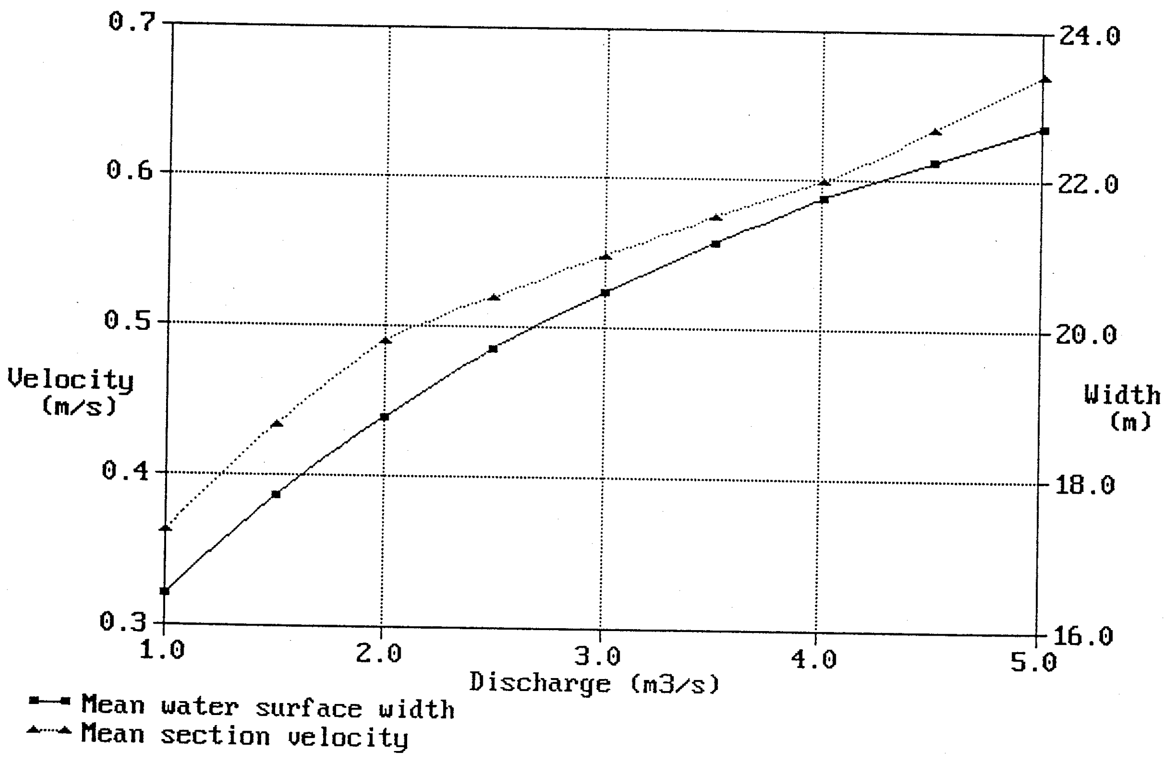


Figure 16. Variation in river width and average velocity with flow in the Olivers Road reach of the Ashburton River.

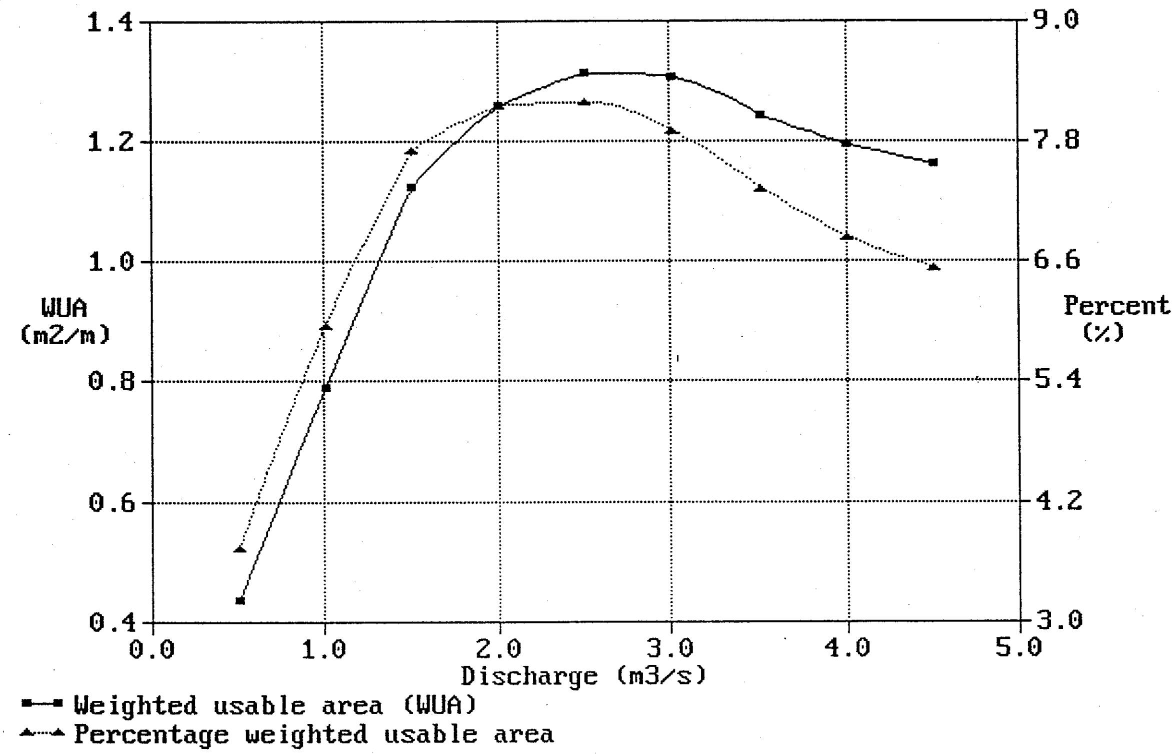


Figure 17. Variation in adult brown trout habitat with flow in the Valetta Bridge reach of the Ashburton River.

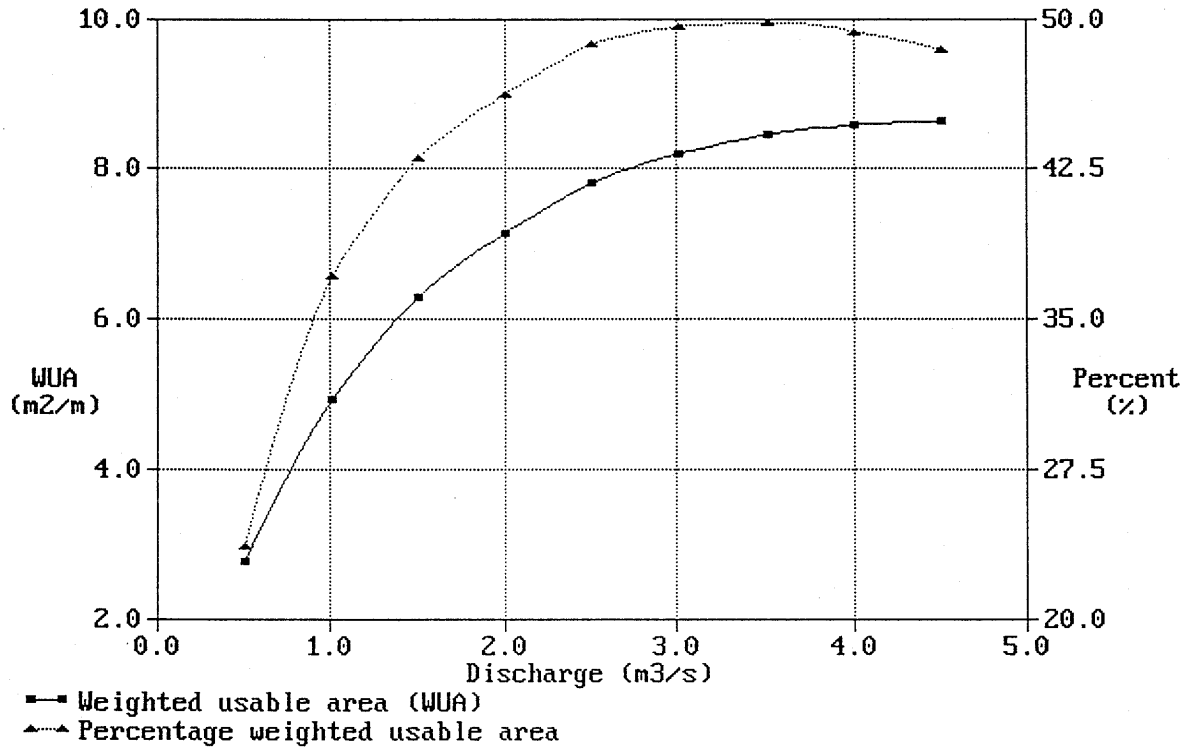


Figure 18. Variation in food producing habitat with flow in the Valetta Bridge reach of the Ashburton River.

In the middle reach, Olivers Road, adult trout habitat increased steadily with flow from 1 to 5 m^3/s (Figure 14). This, combined with the increase in river width, gave maximum percentage

WUA at 4-4.5 m^3/s. The habitat available for food production also increased steadily with flow (Figure 15) which, combined with the steady increase in river width (Figure 16), gave maximum percentage WUA at 3.5-4 m^3/s.
At the upstream reach, Valetta Bridge, adult trout habitat increased to a maximum at 2.5 m^3/s, with percentage WUA reaching its maximum at 2-2.5 m^3/s (Figure 17). The habitat available for food production increased with flow to a maximum at about 4.5 m^3/s (Figure 18), with maximum percentage WUA at 3.5 m^3/s.

Comparison of Ashburton River instream habitat with other rivers

The brown trout model, described in the introduction, demonstrated that the abundance of large brown trout was related to the sum of the weighted usable areas for adult brown trout at mean annual low flow and food producing habitat at median flow. The estimated values of mean annual low flow and median flow for the three reaches of the Ashburton River (Table 2) can be compared to the values in 63 other New Zealand rivers (Figure 7), and with the 10 highest identified in Table 2. This shows that the quality of the trout habitat below the State Highway Bridge, as represented by the Wakanui Road reach, is not very high and falls within the bottom 10% of rivers sampled. However, trout habitat quality increases with distance upstream, so that the quality at the Valetta Bridge is just above average, although the amount of drift-feeding adult habitat is relatively low. This agrees generally with comments by Graynoth and Skrzynski (1973) that the "Ashburton has many deficiencies as a trout river" and comments by Hobbs (1948) that the trout stock is principally governed by physical conditions in the river. Anglers generally prefer the reaches below the State Highway bridge (B. Strange, South Canterbury Fish and Game, pers. comm.).

Table 2 Total weighted usable area (adult trout habitat at mean annual low flow (MALF) + food producing habitat at median flow) for the Ashburton River reaches compared to the "top ten" in New Zealand.

Habitat ranking	River	Flow (m^3/s) MALF	Median	Total WUA (%)	Ratio of trout to 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	63.7	0.25
6	Rangitikei	4.6	13.1	63.2	0.32
7	Buller	3.9	10.0	63.2	0.32
8	Stony	2.3	3.6	62.7	0.59
9	Wanganui	5.0	15.8	62.3	0.30
10	Ahuriri	8.0	18.0	59.8	0.43
Ashburton					
	Wakanui	2.5	16	21.7	0.17
	Olivers	1.3	8	35.3	0.25
	Valetta	0.7	5	52.1	0.10

Table 3 Weighted usable area (%) for adult brown trout drift-feeding habitat and food-producing habitat for flows of between 1.5 and 4 m^3/s.

	Flow (l/s)					
	1500	2000	2500	3000	3500	4000
Wakanui						
WUA adult trout	3.2	3.5	3.1	3.1	3.0	3.2
WUA food producing habitat	22.2	23.7	24.5	23.5	22.2	22.2
Total at minimum flow	25.4	27.2	27.6	26.6	25.2	25.4
Olivers						
WUA adult trout	7.5	8.1	8.7	9.0	9.1	9.4
WUA food producing habitat	27.9	31.6	33.5	34.6	35.2	35.2
Total at minimum flow	35.4	39.7	42.2	43.6	44.3	44.6
Valetta						
WUA adult trout	7.5	8.2	8.3	7.9	7.4	7.0
WUA food producing habitat	42.7	46.7	49.2	49.9	50.0	49.3
Total at minimum flow	50.2	54.9	57.5	57.8	57.4	56.3

The quantity of flow in the Ashburton River at any one time is complicated by the amount and timing of water abstractions. The present water management plan restricts abstractions when the flow at the State Highway bridge falls below 3.5 $m^3/3$. Even with this restriction flows at the bridge commonly fall below 3.5 m^3/s and the estimated average annual low flow is about 2.5 m^3/s. This is a relatively small flow compared to the estimated mean of 23 m^3/s and median of 16 m^3/s and the character of the river reflects this, with its wide open gravel river bed and numerous channels. The mobile nature of the bed means that channels are not well-defined and at low flows water depths and the amount of trout cover are generally inadequate. Increasing flow, increases the channel width rather than depth so that there appears to be little benefit (at least to trout) in increasing minimum flows. However it should be noted that while the WUA expressed as a percentage of the water surface area changes little the actual WUA in the river does increase with flow.

The brown trout model (Jowett in press) suggests that trout numbers are limited by the adult habitat at mean annual low flow and the food producing habitat at median flow. If the mean annual low flow in the Ashburton River is less than the flow at which abstractions are ceased - a "cut-off" flow, the model suggests that the magnitude of that flow is likely to have little effect on trout numbers. Similarly, the food producing capacity at median flow is unlikely to alter. Conversely, increasing the mean annual minimum low flow, rather than the "cut-off" flow, should improve trout habitat and increase trout numbers.

The amount of drift-feeding habitat for adult trout and food-producing habitat at low flows can be examined to determine whether a different "cut-off" flow might increase the amonut of habitat available at that flow. Table 3 shows that there was little variation in the amount of habitat at flows of between 2 and 4 $m^3/3$. Two reaches showed maxima at 2.5 and 3 m^3/s whereas the third (Olivers Road) was at a maximum at about 4 m^3/s. All reaches show that the amount of habitat declines rapidly at flows lower than 1.5-2 m^3/s. The present "cut-off" flow of 3.5 m^3/s is slightly above that which maintains maximum WUA at the Wakanui Road reach but results in flows of 1.5 to 2.5 m^3/s at the Olivers and Valetta reaches. Reducing the "cut-off" flow at the State Highway bridge would tend to reduce significantly the amount of habitat upstream whereas increasing the "cut-off" flow would tend to increase upstream habitat at the expense of the habitat below the State Highway bridge (although only in terms of percentage WUA).

In conclusion, these results show that reducing the flow at which abstractions cease to less than 3.5 m^3/s at the State Highway bridge will significantly reduce the trout and food-producing habitat quality of areas further upstream because of the way in which habitat begins to decline at flows of less than 1.5-2 m^3/s. Conversely, increasing the flow at which abstractions cease will reduce the habitat quality below the State Highway bridge but increase the quality further upstream. Results of modelling brown trout abundance in a number of New Zealand rivers suggest that trout numbers in the Ashburton River are limited by the amount of cover and suitable habitat available at low flow. The nature of the river channel, its steep gradient, relatively fine bed material, and the large variation between low and median flows mean that there is poor habitat and very little cover available for adult trout either in the way of bank cover or deep pools for flows in the range of 2 to 5 m^3/s. Thus, flow changes are unlikely to affect trout numbers significantly.

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