Waikato Regional Council Technical Report 2014/12

Flow requirements for fish habitat in the Ohinemuri River, Waihou River and selected tributaries

www.waikatoregion.govt.nz
ISSN 2230-4355 (Print)
ISSN 2230-4363 (Online)

Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato

Prepared by:
I.G. Jowett, National Institute of Water & Atmospheric Research Ltd.

For:
Waikato Regional Council
Private Bag 3038
Waikato Mail Centre
HAMILTON 3240

September 2008

Document #: 2256309

Approved for release by:
Dominique Noiton Date February 2014

Disclaimer

This technical report has been prepared for the use of Waikato Regional Council as a reference document and as such does not constitute Council's policy.

Council requests that if excerpts or inferences are drawn from this document for further use by individuals or organisations, due care should be taken to ensure that the appropriate context has been preserved, and is accurately reflected and referenced in any subsequent spoken or written communication.

While Waikato Regional Council has exercised all reasonable skill and care in controlling the contents of this report, Council accepts no liability in contract, tort or otherwise, for any loss, damage, injury or expense (whether direct, indirect or consequential) arising out of the provision of this information or its use by you or any other party.

Flow requirements for fish habitat in the Ohinemuri River, Waihou River and selected tributaries

NIWA Client Report: HAM2008-159
September 2008

NIWA Project: EVW08216

Flow requirements for fish habitat in the Ohinemuri River, Waihou River and selected tributaries

I.G. Jowett

Prepared for

Environment Waikato

NIWA Client Report: HAM2008-159
September 2008

NIWA Project: EVW08216

National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

© All rights reserved. This publication may not be reproduced or copied in any form without the permission of the client. Such permission is to be given only in accordance with the terms of the client's contract with NIWA. This copyright extends to all forms of copying and any storage of material in any kind of information retrieval system.

Contents

Reviewed by:

P. Franklin

Approved for release by:

D. Rowe

Formatting checked

Executive Summary

The purpose of this study was to investigate the flows required to maintain acceptable habitat for native fish and trout in selected rivers and streams in the Waihou catchment, namely the Ohinemuri River (2 reaches), the Waihou River (5 reaches), Oraka Stream (2 reaches), Mangawhero Stream, Waiomou Stream and Waimakariri Stream.

Instream habitat surveys were carried out in each river and flow requirements for the resident species were assessed by examining the relationships between flow and suitable habitat using instream habitat modelling. Habitat suitability was determined from habitat suitability curves developed from studies in other rivers. The Waihou River and its larger tributaries support rainbow trout fisheries, with relatively high numbers present. The smaller streams contain native fish, with the number of species declining with distance from the sea.

The selection of appropriate minimum flows for fish is a compromise between the contrasting requirements of the different species. For example, upland bullies prefer low velocity water and thus maximum habitat is provided by relatively low flows, whereas trout, especially adult trout, prefer moderate water velocities and require reasonably high flows. Thus, the selection of an appropriate minimum flow depends on the fish species present and flow management objectives that balance the degree of environmental protection against the value of water for other uses. Flow management objectives can also include water quality effects and non-biological objectives. Flow can also affect water temperature and dissolved oxygen and in some circumstances should be taken into account in assessing minimum flow requirements. Usually, changes in water temperature are small and confined to increased daily variation and dissolved oxygen is only problem in slow flowing streams dominated by macrophytes.

Minimum flows based on the flow below which habitat declines sharply are suggested as an appropriate criterion, although for very small streams this flow may be higher than normal low flows. The method used to define a breakpoint is described in Jowett & Biggs (2006) and Jowett et al. (2008). However, the selection of a minimum flow to prevent a sharp decrease in water surface width could also be considered as a criterion in some streams.

The highest flow requirements for most reaches are the flows that provide rainbow trout habitat, and the use of these flows as a minimum flow would be consistent with the high angling usage. Flow requirements for adult rainbow trout were usually similar to food producing requirements.

1. Introduction

1.1 Study brief and background

Environment Waikato (EW) requested NIWA carry out a study to determine flows required to maintain acceptable habitat for the fish species present in the 12 reaches of the Waihou catchment shown in Figure 1.1.

The study brief was to:

- Carry out in-stream habitat surveys in selected reaches of the streams and rivers.

- Carry out a hydraulic analysis of the reaches using RHYHABSIM (Jowett 1989) to determine how weighted usable area (WUA) for rainbow trout and native fish habitat varies with discharge.

- Assess flow requirements for reaches in the rivers based on the habitat requirements of the native and introduced fish species.

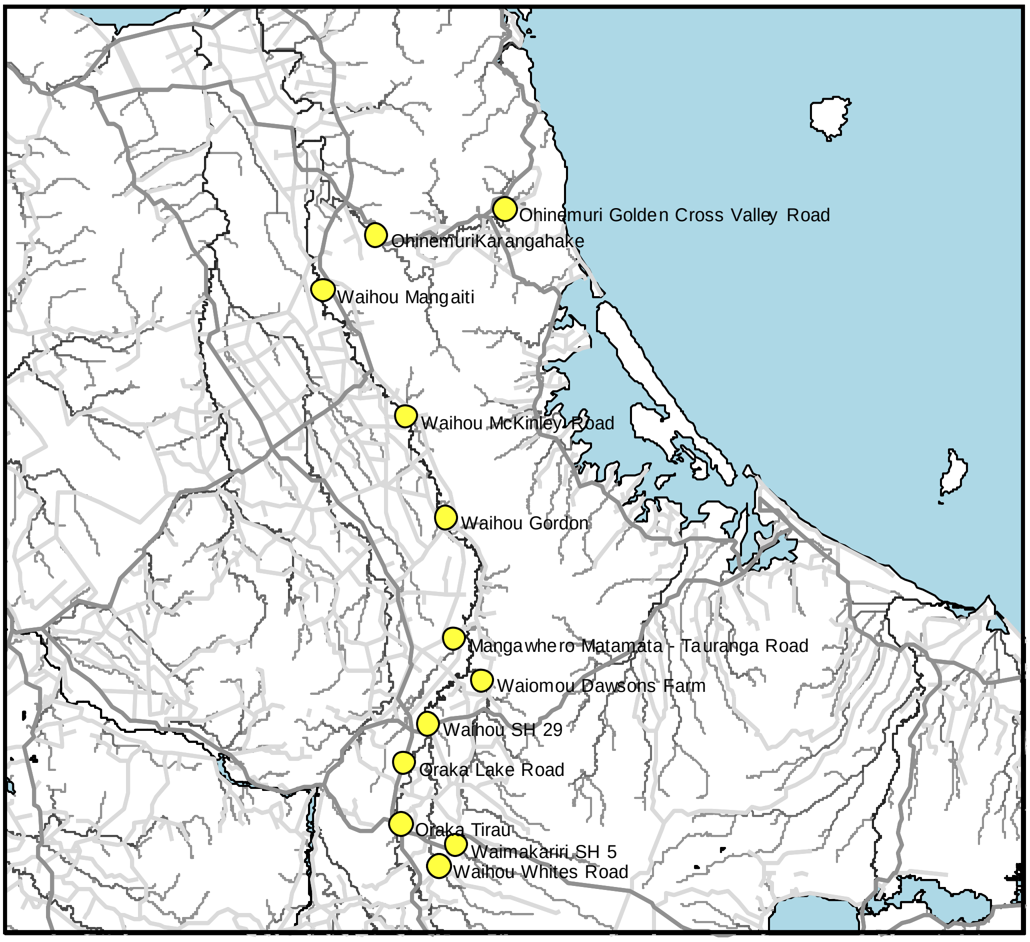


Figure 1.1: Waihou River catchment showing location of survey reaches.

2. Instream flow requirements

Long-term solutions to river flow management need to take a holistic view of the river system, including geology, fluvial morphology, sediment transport, riparian conditions, biological habitat and interactions, and water quality, both in a temporal and spatial sense.

The instream flow incremental methodology (IFIM; Bovee 1982) is an example of an interdisciplinary framework that can be used in a holistic way to determine an appropriate flow regime by considering the effects of flow changes on instream values, such as river morphology, physical habitat, water temperature, water quality, and sediment processes (Fig. 2.1). Its use requires a high degree of knowledge about seasonal and life-stage requirements of species and inter-relationships of the various instream values or uses.

Other flow assessment frameworks are more closely aligned with the “natural flow paradigm” (Poff et al. 1997). The range of variability approach (RVA) and the associated indicators of hydrologic alteration (IHA) allow an appropriate range of variation, usually one standard deviation, in a set of 32 hydrologic parameters derived from the ‘natural’ flow record (Richter et al. 1997). The implicit assumption in this method is that the natural flow regime has intrinsic values or important ecological functions that will be maintained by retaining the key elements of the natural flow regime. Arthington et al. (1992) described an ‘holistic method’ that considers not only the magnitude of low flows, but also the timing, duration and frequency of high flows. This concept was extended to the building block methodology (BBM), which “is essentially a prescriptive approach, designed to construct a flow regime for maintaining a river in a predetermined condition” (King et al. 2000). It is based on the concept that some flows within the complete hydrological regime are more important than others for the maintenance of the river ecosystem, and that these flows can be identified and described in terms of their magnitude, duration, timing, and frequency.

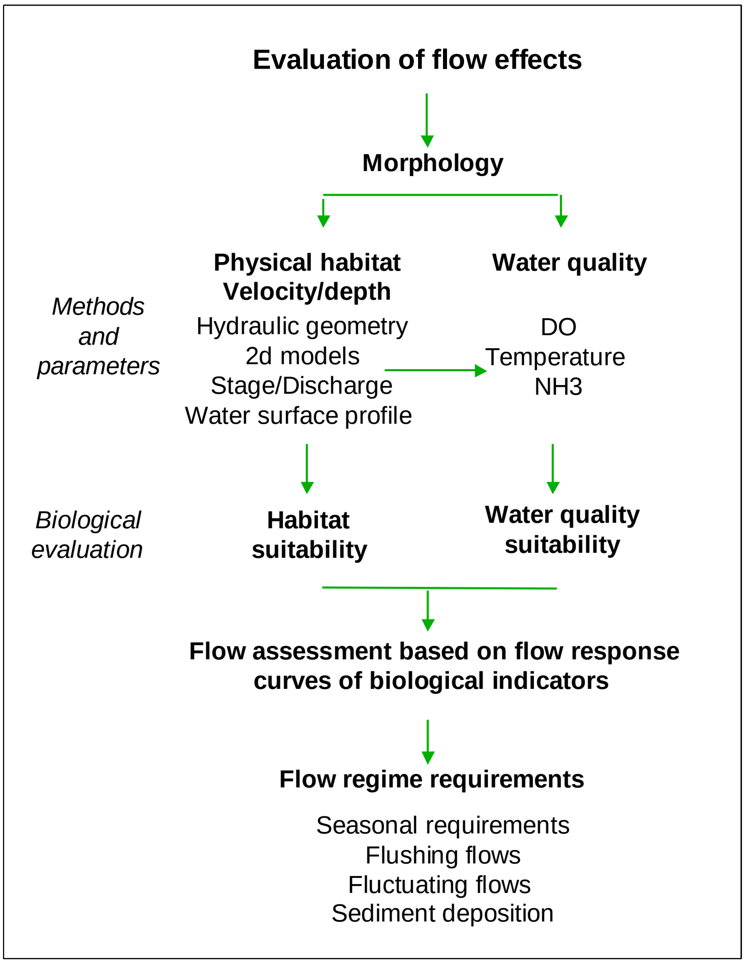


Figure 2.1: A framework for the consideration of flow requirements.

A holistic consideration of every aspect of flow and sediment regime, river and riparian morphology, and their associations with the life cycles of the aquatic biota requires a degree of knowledge about individual rivers that is rarely available. Fortunately, a large proportion of consents considered by regional councils in New Zealand involve changes to the low flows rather than the high flows, and thus there is no significant effect on the sediment transport regime and river morphology. The aim of the minimum flow is to retain adequate water depths and velocities in the stream or river for the maintenance of the critical values. The flow assessment considers habitat at a meso- to macro-habitat level rather than microhabitat. In this way, suitable average depths and velocities can be maintained in the main habitats, with a degree of habitat diversity that is generated by the morphology of the river, and is largely independent of flow. Although the geomorphological and flow related ecological processes that are associated with low to median flows are generally taken into consideration in instream flow methods, special issues, such as fish passage or seasonal flow requirements, may need to be investigated in some situations. Consideration should also be given to downstream effects. The effect of an abstraction is usually greatest immediately below the abstraction site, but diminishes as the river flow is supplemented by contributions from tributaries and the proportion change in flow reduces. However, there may be situations where the critical effect is well downstream. This is most likely where the cumulative effect of abstractions from tributaries may result in unacceptably low flows in downstream reaches.

Methods of assessing instream flow requirements are reviewed in Jowett et al. (2008). Of the three basic types of instream flow methods, historic flow methods are coarse and largely arbitrary. An ecological justification can be argued for the mean annual low flow (MALF), and the concept of a low flow habitat bottleneck for large brown trout has been partly justified by research (e.g., Jowett 1992), but setting flows at lower levels (e.g., the 5 year 7 day low flow $Q_{7,5}$ etc.) is rather arbitrary. Hydraulic methods do not have a direct link with instream habitat, and interpretation of ecological thresholds based on breakpoints or other characteristics of hydraulic parameters, such as wetted perimeter and mean velocity, are arbitrary and depend on rules of thumb and expert experience. On the other hand, habitat based methods have a direct link to habitat use by aquatic species. They predict how habitat (as defined by various habitat suitability models) varies with flow and the shapes of these characteristic curves provide the information that is used to assess flow requirements. Habitat based methods allow more flexibility than historic flow methods, offering the possibility of allocating more flow to out-of-stream uses while still maintaining instream habitat at levels acceptable to other stakeholders (i.e., the method provides the necessary information for instream flow analysis and negotiation).

The ecological goal of habitat methods is to provide or retain a suitable physical environment for aquatic organisms that live in a river. The consequences of loss of habitat are well known; the environmental 'bottom line' is that if there is no suitable habitat for a species it will cease to exist. Habitat methods 'tailor' the flow assessment to the resource needs and can potentially result in improved allocation of resources. However, it is essential to consider all aspects such as food, shelter, and living space and to select appropriate habitat suitability curves (Orth 1987; Jowett 1995). However, appropriate habitat suitability curves are the key to the successful application of habitat based methods.

The procedure in an instream habitat analysis is to select appropriate habitat suitability curves or criteria (e.g., Fig. 2.2), and then to model the effects of a range of flows on the selected habitat variables in relation to these criteria. The area of suitable habitat, or weighted usable area (WUA), is calculated as a joint function of depth, velocity and substrate type for different flows as shown in Fig. 2.2. Instream habitat WUA (m^2/m) is expressed as the total area of suitable habitat per metre of river length. The other measure is the average habitat suitability index HSI, which takes a value of between 0 and 1, and is the area weighted average combined habitat suitability index calculated as in Fig. 2.2. Both WUA (m^2/m) and HSI can be used to assess minimum flow requirements for fish. WUA can be regarded as a measure of the quantity of habitat for a species and HSI as a measure of the average quality of habitat for a species. Habitat is assumed to be generally related to population size. In streams where the flow is confined between defined banks, relationships between flow and WUA (m^2/m) are usually similar to those between flow and HSI.

The area of suitable habitat (WUA) can be calculated for each species of interest. The WUA at each cross-section is multiplied by the proportion of the total river length that each cross-section represents. The total WUA is then the sum WUA of all the cross-sections. Variations in the amount of suitable habitat with flow are then used to assess the effect of different flows for the target organisms. Flows can then be set so that they achieve a particular management goal.

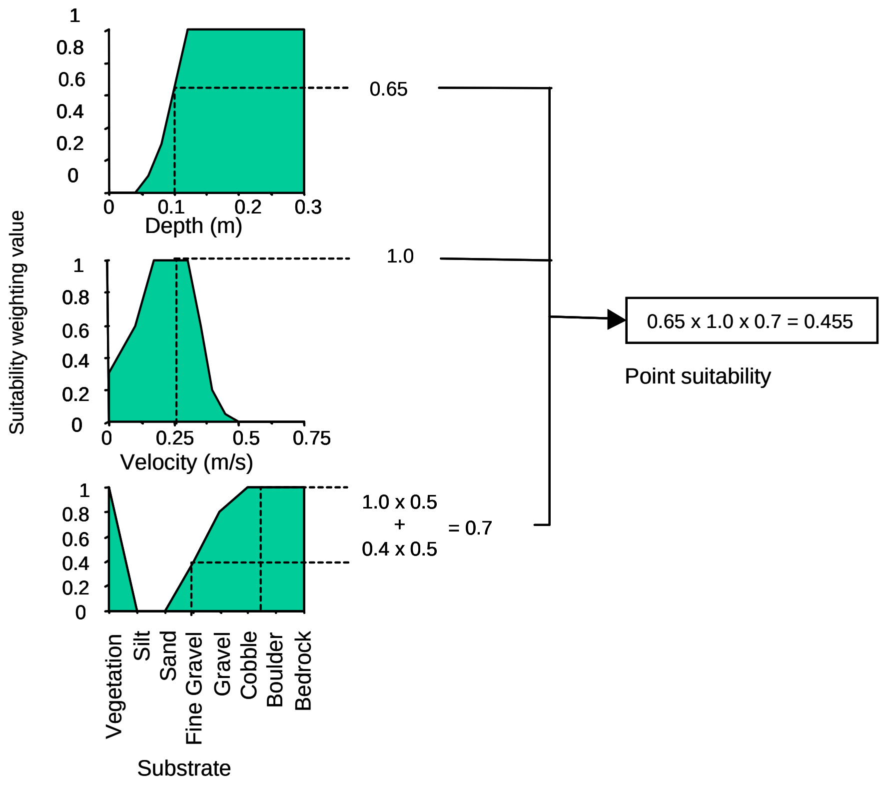


Figure 2.2: Calculation of habitat suitability for a fish species at a point with a depth of 0.1 m, velocity of 0.25 m/s, and substrate comprising 50% fine gravel and 50% cobble. The individual suitability weighting values for depth (0.65), velocity (1.0), and substrate (0.7) are multiplied together to give a combined point suitability of 0.455.

Various approaches to setting levels of protection have been used, from maintaining a maximum amount of habitat, a percentage of habitat at median flow, or using an 'inflection point' of the habitat/flow relationship (Jowett 1997). The latter is possibly the most common procedure used for assessing minimum flow requirements using habitat methods. While there is no percentage or absolute value associated with an 'inflection point', it is a point of 'diminishing return', where proportionately more habitat is lost with decreasing the flow than is gained by increasing the flow.

Consideration of water quality is part of IFIM, as described earlier. In some cases, water quality, and particularly dissolved oxygen concentration, can limit fish populations. The dissolved oxygen concentration depends on the re-aeration rate, which depends on the flow, organic content, and channel morphology of the river. Plants produce oxygen during the day by photosynthesis and absorb oxygen during the night, so that there is a diurnal fluctuation in dissolved oxygen. The plant biomass in a stream influences diurnal fluctuations, particularly the minimum dissolved oxygen concentration that occurs just before sunrise. The respiration and production rate parameters that control dissolved oxygen concentration in a stream are difficult to estimate, and are best derived from continuous measurement of water temperature and dissolved oxygen (McBride & Chapra 2005) carried out during the summer when plant biomass and water temperature are highest.

3. Survey reaches, flow characteristics, and fish species

3.1 Reach selection

The objective of an instream habitat survey is to get the best possible representation of the characteristics of a segment of river. This encompasses the range of water velocities and depths that occur in a river, along with the co-occurrence of stationary stream elements (such as substrate, bank formations, and cover) with the hydraulic conditions. It is important that the selection of reaches and cross-section locations should be unbiased and a stratified process of selection is one means of achieving this. In habitat analyses, we use the term "section of river" to denote a long length of river (usually several kilometres or more). A reach is shorter and is usually a kilometre or less. A cross-section or transect is a point within a reach.

The morphology of a river is determined by the strength of banks and bed (riparian vegetation, bank material, and substrate), gradient, and magnitude of flood flows. If any of these factors change, the morphological and hydraulic characteristics of the river will change.

Survey reaches were selected to represent the average conditions in a longer section of morphologically similar river. The location of cross-sections in a reach reflected the variation in morphology with cross-sections being located in a variety of pool, run, and riffle habitats where they existed. In some cases, the rivers were too uniform to select specific habitats and cross-sections were uniformly spaced throughout the reach. Jowett et al. (2008) discuss reach and cross-section selection in some detail and show that 15 or so cross-sections will adequately represent average conditions in a long section of river and that a representative reach will also represent a long section of river.

Instream habitat surveys were carried out in selected rivers and streams in the Waihou catchment, namely the Ohinemuri River (2 reaches), the Waihou River (5 reaches), Oraka Stream (2 reaches), Mangawhero Stream, Waiomou Stream and Waimakariri Stream. (Fig. 1.1, Table 3.1). The Waimakariri Stream and Waihou River at Whites Road were surveyed in 1986 as part of the "100 Rivers" survey, and the remaining 10 reaches were surveyed between January and April 2008.

Table 3.1: Reach locations including grid references (NZMS260 east and north). Shallow cross-sections were surveyed by wading; deeper cross-sections were surveyed with a acoustic current Doppler profiler (ADCP).

River	Reach	Survey date	East	North	Number of cross-sections	Reach length*	Survey method
Ohinemuri	Golden Cross Valley Road	21/2/08	2764301	6420062	15	na	Wading
Ohinemuri	Karangahake	13/2/08	2750582	6417251	15	na	Wading and ADCP
Oraka	Lake Road	30/1/08	2753639	6360768	15	na	ADCP
Oraka	Tirau	29/1/08	2753193	6354410	15	na	ADCP
Mangawhero	Matamata - Tauranga Road	23/1/08	2758853	6374081	15	na	Wading
Waiomou	Dawsons farm	1/2/08	2761957	6369648	15	na	Wading and ADCP
Waimakariri	SH 5	1986	2759100	6352200	30	269	Wading
Waihou	Whites Road	1986	2757200	6350000	31	183	Wading
Waihou	SH 29	11/2/08	2756157	6365147	14	na	ADCP
Waihou	Gordon	2/4/08	2758429	6395489	15	na	ADCP
Waihou	McKinley Road	2/4/08	2753793	6397879	15	na	ADCP
Waihou	Mangaiti	4/4/08	2744925	6411325	15	na	ADCP

*Reach lengths are only applicable to representative reaches. Other surveys were representative of habitat mapped over 1 km or longer reaches.

The Ohinemuri River is shown above and below the Golden Cross Valley Road bridge on 21 February 2008 in Figure 3.1. The river was incised over the majority of the length surveyed with bed material ranging from silt and macrophytes to bedrock. Bank vegetation consisted of a wide variety of plants ranging from willows through gorse and blackberry to grasses. This channel form was maintained for some distance downstream, at least as far as the Waihi township.

The channel comprised pool, run and riffle habitat, with the runs varying between fast and slow, deep and shallow and wide and narrow.

Figure 3.1: Survey reach: Ohinemuri River at high flow above and below the Golden Cross Valley Road bridge.

The second reach on the Ohinemuri River was at Karangahake, where the stream was considerably larger (Fig. 3.2). The stream was surveyed above (5 cross-sections) and below (10 cross-sections) the old railway/road bridge crossing State Highway 2 on 13 February 2008. Above the bridge, the river was contained by banks about one to one and a half metres in height, but below the bridge the channel widened with gradually sloping banks. The bed material ranged from bedrock and very large boulders (in excess of 2 metre diameter) down to silt in the edge of pools. Banks are either made up of bedrock, exposed bed materials or vegetation predominantly root-mats, grasses and willows. The channel comprised pool, run and riffle habitat, and at low flows there were long reaches of low velocity water.

Figure 3.2: Survey reach: Ohinemuri River at Karangahake. Left: boulder run at cross-section 12 above bridge. Right: slow flowing run at cross-section 1 below bridge.

The Oraka Stream is a left bank tributary of the Waihou River draining a mainly pasture catchment (Fig. 3.3). Two reaches of the stream were surveyed, one at Lake Road on 30 January 2008 and the other at Tirau on 21 January 2008. At Lake Road, the river is confined between stream banks about one metre in height with any flood flows spreading out over adjacent paddocks. The bed material is mainly gravels with sand and silt in low velocity areas. There were small patches of aquatic macrophytes growing in the sandy bed areas where there were low velocities and sun light. There were also small amounts of green filamentous periphyton along the channel. Exposed banks are made up of mainly sandy material but most of the banks are covered in grasses and/or willows. The river has a uniform gradient and the habitat types in the survey reach were run, with short sections of pools. Willows overhang the river up the full length of survey reach on the true left bank and at a number of points completely cover the channel. In places, the willows grow into the flow causing partial damming.

The Oraka Stream at Tirau was surveyed below SH1 Road Bridge on 29 January 2008 (Fig. 3.3). The river is generally confined by stream banks about half to one metre in height. The bed material is mainly gravels, with sand and silt in low velocity areas. This section of stream contained more aquatic macrophytes than Lake Road, especially in some of the deep slow runs, but at the most, cover was only about 20-30% of the bed. Banks with exposed soils are made up of mainly sandy material with some clay outcrops, but most banks were covered in grasses and/or willows. The reach was made up of mostly run, with short sections of pools. Willows overhang sections of the river mainly on the left bank with a few points completely covered by overhanging growth.

Figure 3.3: Uniform run in the willow lined channel of Oraka Stream at Lake Road (Section 9 top left Section 1 top right). Oraka Stream at Tirau open cross-section 2 (bottom left) and the more enclosed cross-section 14 (bottom right).

The Mangawhero Stream is another left bank tributary of the Waihou that drains mainly pasture catchment (Fig. 3.4). The stream was surveyed below the Matamata-Tauranga Road on the 23 January 2008. The river is confined by stream banks about half a metre in height with any flood flows spreading out over adjacent paddocks. The bed material is mainly sand and vegetation with small amounts of silt and gravels. The macrophyte growth in this stream was more extensive than in any of the other streams surveyed, with more than 70% of the bed covered in most places. The banks were all covered in weeds or grasses with some trees on the left bank. Where the banks had small exposed patches of soils they were made up of fine gravels and sand. Like the Oraka Stream, the gradient of the stream is uniform and the habitat type is predominantly run with one short section of pool. For this reason, cross-sections were selected every 30 m.

Figure 3.4: Survey reach: The Mangawhero Stream. Cross-section 3 showing macrophytes and aquatic vegetation (left) and upstream end of reach (right).

The Waiomou Stream is a right bank tributary of the Waihou River that flows through pastoral land from the Kaimai Ranges (Fig. 3.5). The stream was surveyed below the Tauranga Road on 1 February 2008. The river was generally confined by stream banks about one to one and a half metres in height. The bed material was mainly cobbles and gravels with small amounts of sand and silt in low velocity areas. Banks with exposed soils were fine gravel and sand with small areas of gravels but most banks were covered by grasses and willows. The reach contained pool, run and riffle habitats, but was dominated by runs of varying velocity and width.

Figure 3.5: Waiomou Stream riffle at cross-section 11 (left) and run at cross-section 8.

The Waimakariri Stream is a left bank tributary of the Waihou river flowing from the Kaimai Ranges (Fig. 3.6). The flow is more stable than the Waiomou Stream and its substrate is finer with mostly gravel. A representative reach was surveyed in this stream in 1986 with 30 cross-sections at an average spacing of 9.3 m. A hydraulic model of the reach was calibrated by adjusting values of Manning N so that the predicted water surface profile matched the measured profile. A rating was fitted to the downstream cross-section, which was located on a riffle, and water surface levels were predicted at upstream cross-sections. It is assumed that these profiles have not changed greatly since 1986.

A similar representative survey was carried out of the Waihou River at Whites Road. At this point, the flow in the Waihou River derives mainly from springs and there is very little variation in flow. The stream contains fine substrate, mainly fine gravel. A total of 31 cross-sections were surveyed along the representative reach at an average spacing of 6.1 m.

The Waihou River at SH 29 (Fig. 3.6), Gordon (Fig. 3.7), McKinley Road (Fig. 3.8) and Mangaiti (Fig. 3.9) were all uniform runs with occasional places that were slightly deeper. All of these reaches were surveyed by boat using the acoustic Doppler current profiler (ADCP). The banks were usually relatively steep and lined with trees or grass.

Figure 3.6: Survey reach: Waihou at SH 29. Section 3 (left) and section 12 (right).

Figure 3.7: Waihou River at Gordon. View along river at cross-section 14 (left) and cross-section 10 showing steep banks that are characteristic of the river (right).

Figure 3.8: Waihou River at McKinley Road. Section 3 (left) and section 12 showing steep banks (right).

Figure 3.9: Survey reach: Waihou at Mangaiti. Section 1 looking upstream (left) and looking upstream at section 10 (right).

3.2 Flows

Flow estimates were taken from nearby EW and NIWA water level recorders with adjustments for differences in catchment area made using specific discharges at the recorder sites.

Table 3.2: Estimated flow statistics (m^3/s) from EW and NIWA water level recorders.

River	Reach	Catchment area (km^2)	7-day mean annual low flow EW	5 year 7-day low flow	Median flow	Source (flow recorder)
Ohinemuri	Golden Cross Valley Road	46	0.32	0.26	1.0	Frendrups
Ohinemuri	Karangahake	284	2.0	1.6	6.2	Karangahake
Oraka	Lake Road	252	4.2	3.6	4.9	Pinedale
Oraka	Tirau	223	3.7	3.2	4.31	Pinedale
Mangawhero	Matamata - Tauranga Road	61	0.7	0.6	0.8	Pinedale and concurrent gaugings
Waiomou	Dawsons farm	201	3.7	3.1	5.9	2008 flows
Waimakariri	SH 5	88	3.0	2.5	3.4	Waimakariri Road
Waihou	Whites Road	108	4.8	4.2	5.0	Whites Road
Waihou	SH 29	466	13.5	12.6	14.1	SH29
Waihou	Gordon	913	23.1	21.3	25.8	Shaftsbury
Waihou	McKinley Road	1047	24.8	23.1	29.8	
Waihou	Mangaiti	1182	26.2	24.6	33.9	Tirohia/Te Aroha

3.3 Fish species

New Zealand native fish can be classified as either diadromous (migrating to and from the sea as a necessary part of their life cycle) or non-diadromous (spending their whole life in fresh water). Diadromy has a strong influence on fish distribution in the Waihou catchment, with the low river gradient allowing diadromous native fish to move long distances inland, until further passage is restricted by waterfalls. The records in the New Zealand Freshwater Fish Database (NZFFD) were examined to determine the fish species present in each of the rivers (Table 3.3).

The lower Waihou and Ohinemuri rivers probably contain a diverse community of native fish, although species such as torrentfish and redfin bullies may only be present occasionally. All rivers contain rainbow trout (*Oncorhynchus mykiss*) and possibly small numbers of brown trout (*Salmo trutta*). Some angling use (Table 3.4) is recorded on all of the study rivers, with the Waihou and Ohinemuri the 2nd and 3rd most popular rivers in the Waikato region, after the Waikato River (Unwin & Image 2003).

Table 3.3: Number of fish species recorded in the study streams. Introduced fish, other than trout, not listed. M found in main stem, P present in tributaries and probably present in main stem.

Fish species		**Ohinemuri (**Golden Cross Valley Road**)**	**Ohinemuri (**Karangahake**)**	**Waimakariri**	**Waiomou**
Shortfin eel	*Anguilla australis*	M	M		
Longfin eel	*Anguilla dieffenbachii*	M	M		M
Common bully	*Gobiomorphus cotidianus*	M	M		
Crans bully	*Gobiomorphus basalis*	M	M	M	
Brown trout	*Salmo trutta*	M	M		
Rainbow trout	*Oncorhynchus mykiss*	M	M	M	M
Common smelt	*Retropinna retropinna*		M		
Inanga	*Galaxias maculatus*		M		M
Dwarf galaxias	*Galaxias divergens*				
Redfin bully	*Gobiomorphus huttoni*	P	P		
Torrentfish	*Cheimarrichthys fosteri*	P	P		

Fish species		**Oraka**	**Mangawhero**	**Waihou < 100 km from sea**	**Waihou > 150 km from sea**
Shortfin eel	*Anguilla australis*	M	M	M	
Longfin eel	*Anguilla dieffenbachii*			M	
Common bully	*Gobiomorphus cotidianus*		M	M	
Crans bully	*Gobiomorphus basalis*			P	M
Brown trout	*Salmo trutta*			P	M
Rainbow trout	*Oncorhynchus mykiss*	M	M	P	M
Common smelt	*Retropinna retropinna*			P	
Inanga	*Galaxias maculatus*	M		M	
Dwarf galaxias	*Galaxias divergens*				M
Redfin bully	*Gobiomorphus huttoni*			P	
Torrentfish	*Cheimarrichthys fosteri*			P	

Table 3.4: Estimated 2001/02 angler use on the study rivers (Unwin & Image 2003).

River	**Angler days**
Waihou River	2955
Ohinemuri River	2635
Waimakariri Stream	767
Waiomou Stream	495
Oraka Stream	95
Mangawhero Stream	52

3.4 Habitat suitability curves

The habitat suitability curves chosen for a study must be appropriate for the species known to occur, or likely to occur, in the study river. Habitat suitability curves for native fish were derived from data collected in 32 New Zealand rivers. (Jowett & Richardson 1995). Many of the native fish species are benthic and are most commonly found in riffles. Many of the survey reaches were deep with steep banks and did not provide riffle habitat for native fish, although some of the riffle dwelling species were present in shallow gravel tributaries. Jowett & Richardson (2008) describe the habitat used by native fish measured at over 5000 locations in 124 rivers. Sampling in these rivers demonstrated that some native species are most abundant in runs and riffles, whereas other species are most abundant in pool habitat. The habitat suitability curves for torrentfish, common bullies, redfin bullies, Crans bully, and dwarf galaxias all describe shallow water habitats and it was not considered useful to apply habitat suitability curves for torrentfish, common bullies, redfin bullies, Crans bully, and dwarf galaxias to reaches where there was no riffle habitat. This was because the flow that would be necessary to create the optimal shallow water habitat preferred by these species would be very low in the deep rivers and much less than flow requirements for trout, as is shown later (e.g., Fig. 4.4 and Fig 4.8). Although brown trout are reported from these rivers, the fisheries are primarily for rainbow trout and rainbow trout curves for spawning (Jowett et al. 1996) and adult and juvenile habitat (Thomas & Bovee 1993) were used in the analysis. All habitat suitability curves used are shown in Appendix I.

Wilding (2006) used Froude number as an indicator of invertebrate habitat for a study of Coromandel streams and showed that it increased with flow and essentially mirrored the way in which velocity increased. Jowett et al. (1991) examined the use of Froude number and depth and velocity as predictors of invertebrate density and found that depth and velocity was a better predictor than Froude number. In this report, the variation of depth and velocity with flow in each reach is shown as an indicator of habitat suitability for benthic invertebrates. The preferred depths and velocities of benthic invertebrates in small streams and medium-sized rivers are given in Jowett (2000). Jowett (2000) showed that velocity use and preference varied with species, with some species, such as *Aoteapsyche* sp. and *Austrosimulium* sp. being found in the high velocity areas in streams and others such as *Olinga feredayi* and *Potamopyrgus antipodarum* being found in low velocity areas. Thus, any reduction in flow will tend to increase the abundance of those species that prefer low velocities and decrease the abundance of species preferring swift water. The information on the physical habitat used by benthic invertebrates is derived from gravel bed rivers and it is not known how applicable it would be to rivers with fine substrate and macrophytes, although generally one would expect the community composition to change with velocity.

3.5 Habitat mapping and cross-section selection

Habitat mapping was carried out over 1-2 km sections of river in each reach surveyed and the percentage of each habitat type present was recorded. Cross-section locations were then selected in each habitat type, ensuring that they sampled the range of width, depth, and velocity characteristics that were apparent in each habitat type. For example, riffle cross-sections included both steep and narrow, and wide and shallow riffles. Pool cross-sections were alternately located at heads, middles, and tails of pools. Where the reaches were uniform, such as in the Waihou and Mangawhero, sections were selected at regular intervals through the reach.

3.6 Instream habitat survey and analysis

At each cross-section, water level was measured and referenced against a temporary staff gauge. In order to establish the relationship between water level and flow at each cross-section, water level was measured on the temporary gauge at two or three other flows.

The habitat analysis proceeded as follows:

1. Flows were computed from depth and velocity measurements for each cross-section.

2. A stage-discharge relationship was developed for each cross-section using a least squares fit to the logarithms of the measured flows and stages (water levels) including an estimated stage at zero flow.

3. Water depths and velocities were computed at each measurement point across each cross-section for a range of simulated flows, and habitat suitability was evaluated (see Fig 2.2) from habitat suitability curves for each fish species.

4. The weighted usable area (WUA) for each simulated flow was calculated as the sum of the habitat suitability scores across each cross-section, weighted by the proportion of the habitat type which each cross-section represented in the river.

5. Weighted usable area was plotted against flow and the resulting curves examined to determine the flow that provided maximum habitat and the flow at which habitat (WUA) began to reduce sharply (inflection points).

4. Results

4.1 Physical characteristics

The instream habitat surveys were carried out during a period of very low flows and stage/discharge calibration gaugings were usually carried out when flows had increased (Table 4.1). Survey flows in 2008 were close to the estimated 5-year low flows.

Table 4.1: Survey flows, calibration flows, and average physical characteristics of reaches at the survey flow.

River	Reach	Survey flow (m^3/s)	Calibration flow 1 (m^3/s)	Calibration flow 2 (m^3/s)	Calibration flow 3 (m^3/s)	Width (m)	Depth (m)	Velocity (m/s)
Ohinemuri	Golden Cross Valley Road	0.175	1.856	0.957		7.3	0.26	0.14
Ohinemuri	Karangahake	1.639	6.822	4.109		25.8	0.76	0.12
Oraka	Lake Road	2.85	2.871	3.195	4.099	8.1	0.66	0.54
Oraka	Tirau	2.85	2.73	3.17	3.79	8.8	0.52	0.60
Mangawhero	Matamata - Tauranga Road	0.66	0.67	2.92		9.1	0.79	0.08
Waiomou	Dawsons farm	3.23	3.05	4.53	8.46	12.5	0.50	0.56
Waimakariri	SH 5	4.053	4.14	3.90		11.5	0.50	0.62
Waihou	Whites Road	4.695	4.975	4.830		10.5	0.76	0.62
Waihou	SH 29	13.17	28.26	16.57		16.1	1.47	0.58
Waihou	Gordon	19.16	24.59	31.15		20.4	1.63	0.51
Waihou	McKinley Road	17.33	30.41	27.32		23.1	1.45	0.47
Waihou	Mangaiti	20.96	33.02	52.78		26.3	1.57	0.50

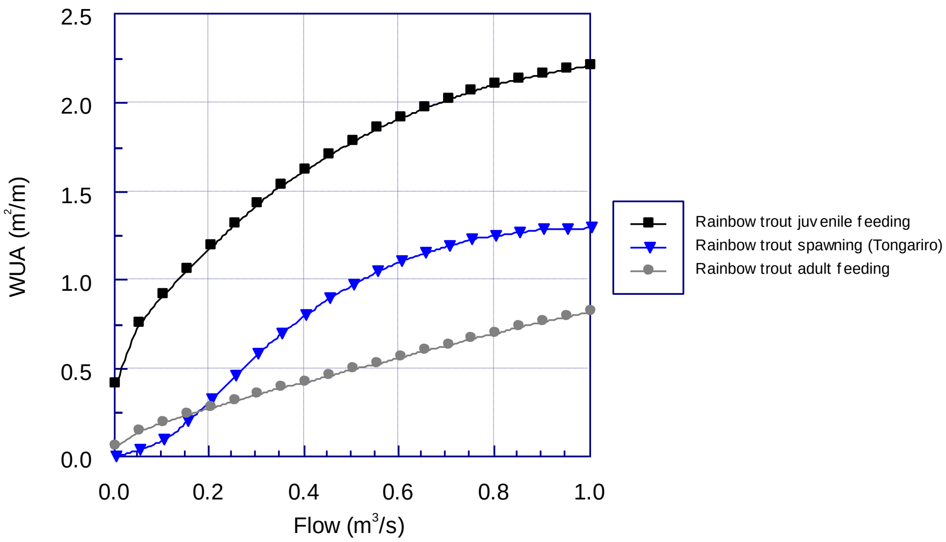
4.2 Instream habitat

Table 4.3: Instream habitat in study stream reaches as classified by Froude number (Fr < 0.18 pool, Fr > 0.41 riffle and intermediate values run) at the survey flow.

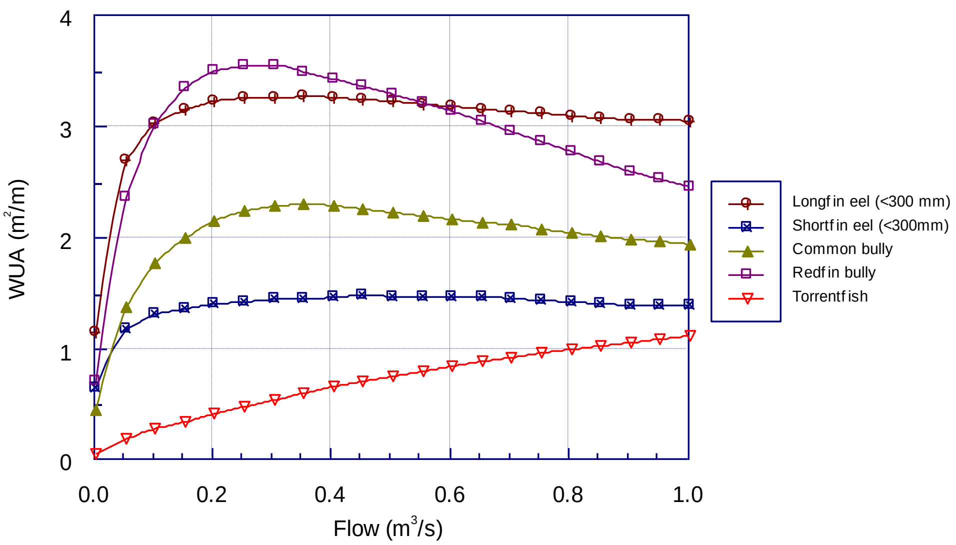
River	Reach	Pool (%)	Run (%)	Riffle (%)
Ohinemuri	Golden Cross Valley Road	79	16	5
Ohinemuri	Karangahake	90	7	2
Oraka	Lake Road	43	45	12
Oraka	Tirau	28	55	17
Mangawhero	Matamata - Tauranga Road	100	0	0
Waiomou	Dawsons farm	35	40	25
Waimakariri	SH 5	35	33	32
Waihou	Whites Road	43	43	15
Waihou	SH 29	58	42	0
Waihou	Gordon	78	22	0
Waihou	McKinley Road	77	23	0
Waihou	Mangaiti	82	18	0

In terms of habitat composition classified by Froude number at each point in the reaches, most of the reaches contained relatively high proportions of pool habitat, moderate amounts of run, with little riffle habitat (Table 4.3). Pool habitat was mostly relatively deep water with moderate velocities, with few distinct pools separated by shallow riffles.

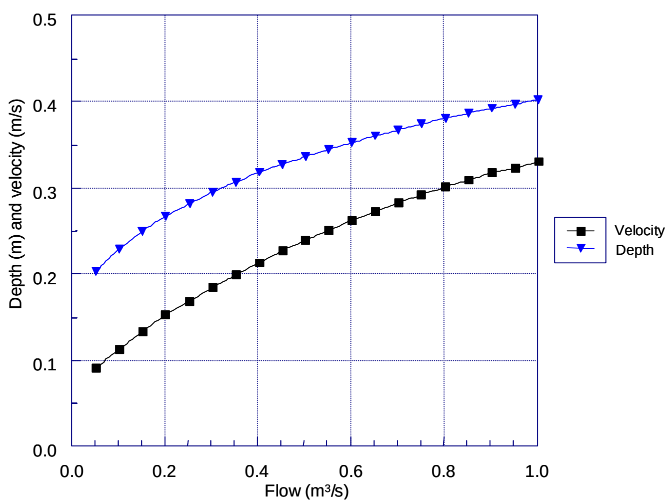
The Ohinemuri River at Golden Cross Valley Road was a relatively small shallow stream that provided good habitat for native fish at flows of 0.2-0.3 m^3/s, and reasonable trout spawning habitat at near median flow (Fig. 4.1). However, it was generally too shallow to provide a large amount of adult or juvenile rainbow trout habitat at low flows.



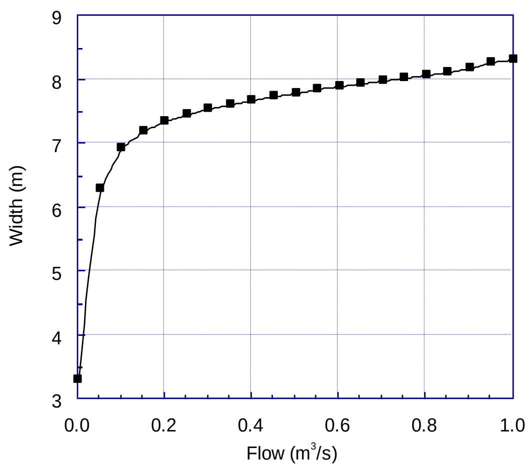
WUA (m²/m)
Flow (m³/s)
Rainbow trout juvenile feeding
Rainbow trout spawning (Tongariro)
Rainbow trout adult feeding



WUA (m²/m)
Flow (m³/s)
Longfin eel (<300 mm)
Shortfin eel (<300mm)
Common bully
Redfin bully
Torrentfish



Depth (m) and velocity (m/s)
Flow (m³/s)
Velocity
Depth

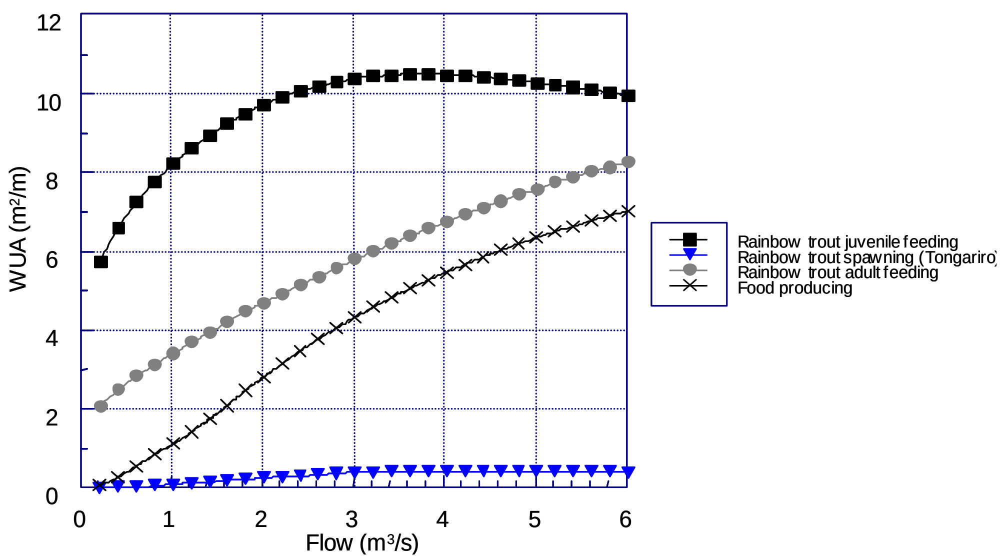


Width (m)
Flow (m³/s)

Figure 4.1: Variation of instream habitat for rainbow trout (weighted usable area WUA) with flow in Ohinemuri River at Golden Cross Valley Road (top), for native fish (middle), and variation in depth, velocity and width (below).

The water surface width of the Ohinemuri River at Golden Cross Valley Road begins to reduce sharply when the flow falls below 0.15 m^3/s (Fig. 4.1 lower) and at this flow the average depth and velocity is about 0.25m and 0.13 m/s, respectively. A point velocity of about 0.4 m/s and a mean velocity of about 0.3 m/s in a stream of this size would provide good habitat for benthic invertebrates (from Jowett 2000 Figure 12.5).

The Ohinemuri River at Karangahake was a relatively wide and deep, but velocities were low at low flows. Good native fish habitat in the riffles was provided by a flow of about 1 m^3/s, and maximum juvenile rainbow trout habitat occurred at 3 m^3/s (Fig. 4.2). However, velocities were generally too low to provide a large amount of adult rainbow trout habitat and there was little suitable habitat for trout spawning. The amount of adult rainbow trout habitat and food producing habitat (Waters 1976) increased with flow up to 6 m^3/s, with maximum habitat for both provided by a flow of about 12.5 m^3/s. The water surface width began to reduce sharply when flows fell below 1.2 m^3/s.



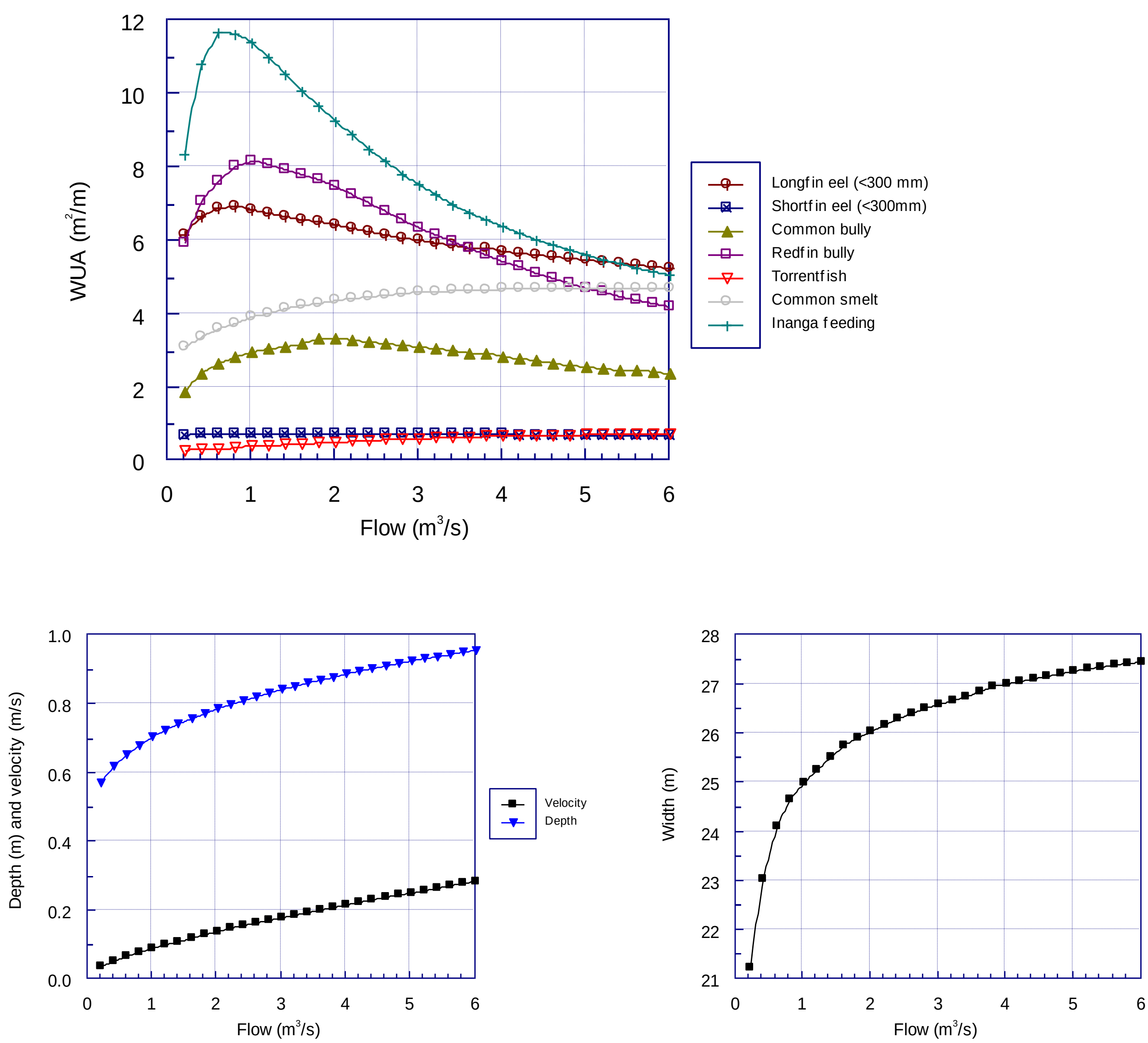
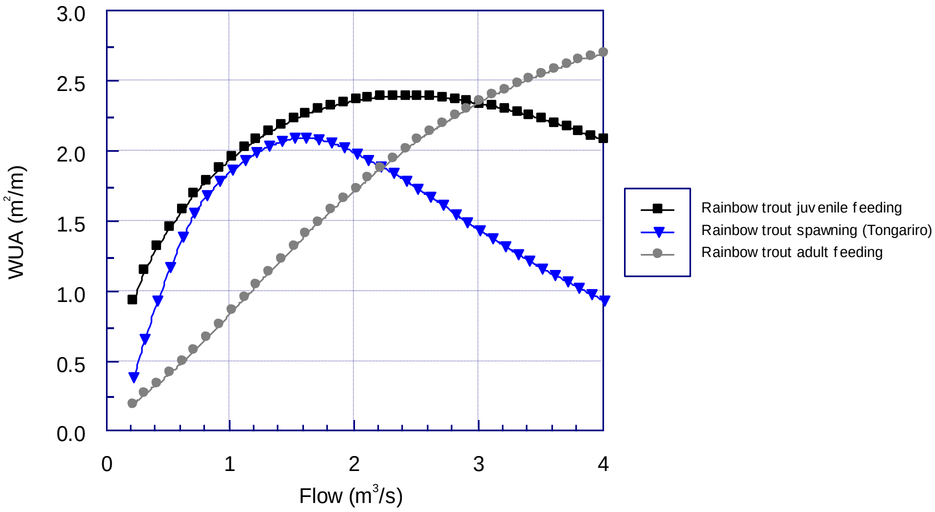
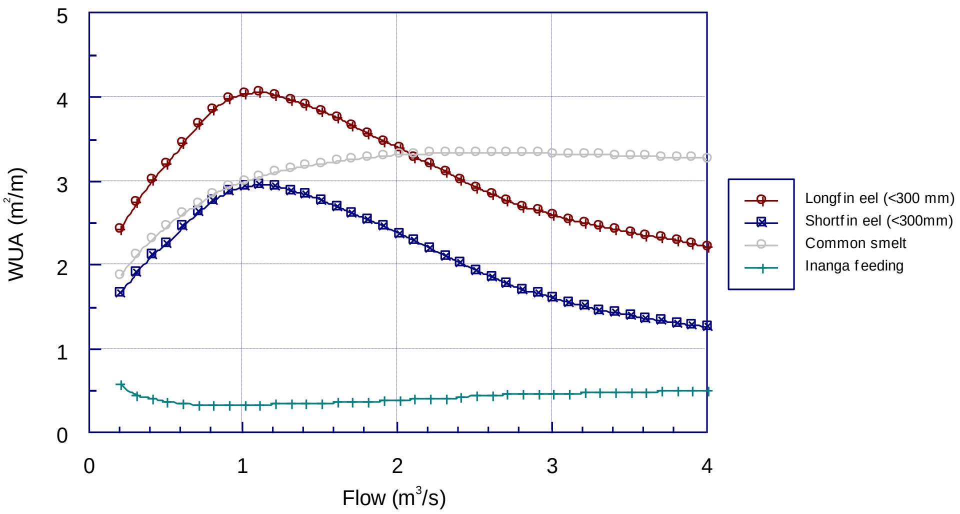
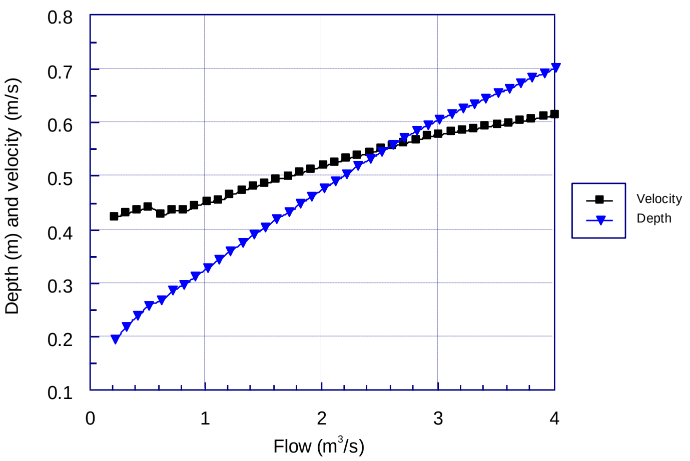


Figure 4.2: Variation of instream habitat for rainbow trout (weighted usable area WUA) with flow in the Ohinemuri River at Karangahake (top), for native fish (middle), and variation in depth, velocity and width (below).

The Oraka Stream at Tirau and Lake Road was a surprisingly swift deep stream and provided good spawning and juvenile rainbow trout habitat at flows of 1.5 to 2.5 m^3/s (Fig. 4.3). Flows of 5-6 m^3/s provided maximum habitat for adult rainbow trout. Velocities appeared to be too high for inanga and more suited to smelt. However, there would be suitable habitat for both of these species along the margins. The water surface width decreased sharply at flows less than about 1.2 m^3/s and velocities were relatively high over the range of flows modelled. A mean velocity of 0.45 m/s would provide good benthic invertebrate habitat in this stream.


3.0
2.5
2.0
1.5
1.0
0.5
0.0
WUA (m²/m)
0
1
2
3
4
Flow (m³/s)
Rainbow trout juvenile feeding
Rainbow trout spawning (Tongariro)
Rainbow trout adult feeding


5
4
3
2
1
0
WUA (m²/m)
0
1
2
3
4
Flow (m³/s)
Longfin eel (<300 mm)
Shortfin eel (<300mm)
Common smelt
Inanga feeding


0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Depth (m) and velocity (m/s)
0
1
2
3
4
Flow (m³/s)
Velocity
Depth

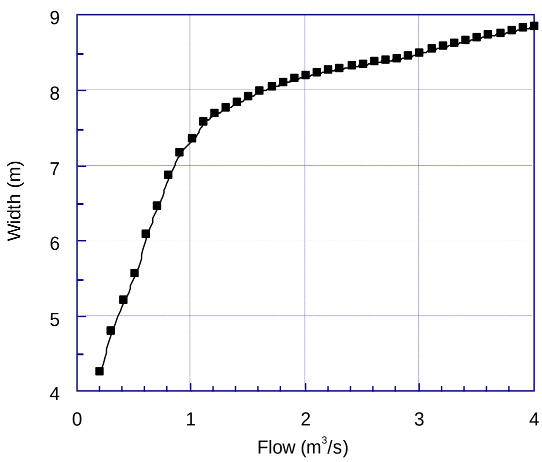
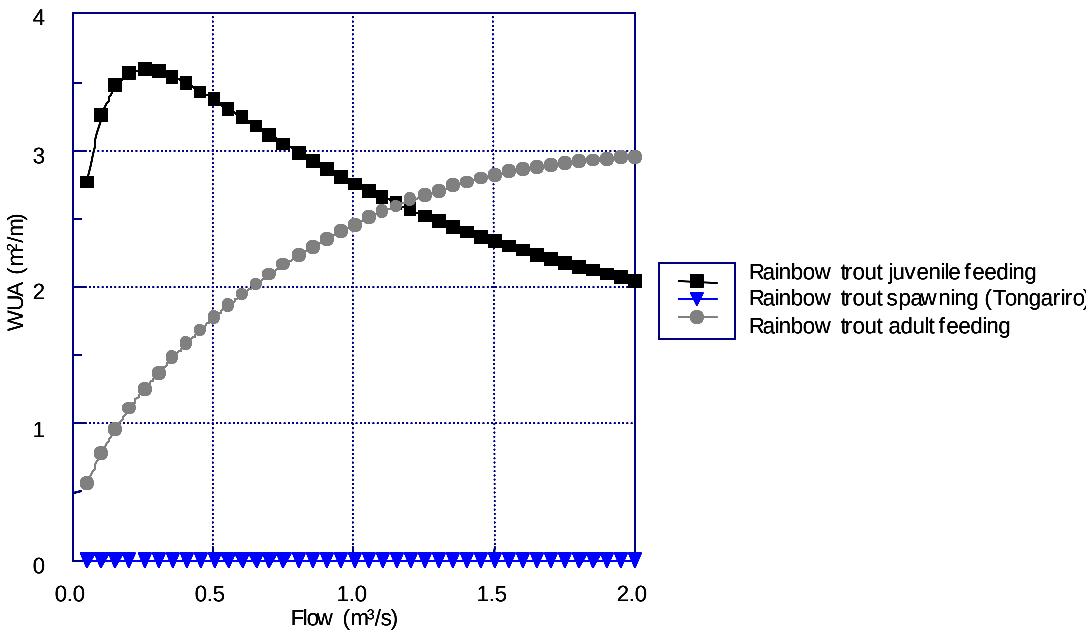

9
8
7
6
5
4
Width (m)
0
1
2
3
4
Flow (m³/s)

Figure 4.3: Variation of instream habitat (weighted usable area WUA) with flow in the Oraka Stream at Tirau and Lake Road (top), for native fish (middle), and variation in depth, velocity and width (below).

The Mangawhero Stream at the Matamata-Tauranga Road had the lowest velocity and the densest macrophyte growth of any of the rivers surveyed. In the area surveyed, there was little riparian vegetation and this would encourage macrophyte growth. The stream has a relatively stable flow. The stream contains rainbow trout as well as Crans bully and common bully and probably also has inanga and smelt. A flow 0.25 m^3/s of provided maximum habitat for juvenile rainbow trout and a flow of 2.0 m^3/s provided maximum adult rainbow trout habitat (Fig. 4.4). A flow of about 0.1 m^3/s provided maximum habitat for inanga. The velocity in this stream was low and well below preferred velocities of benthic invertebrates found in gravel bed rivers.



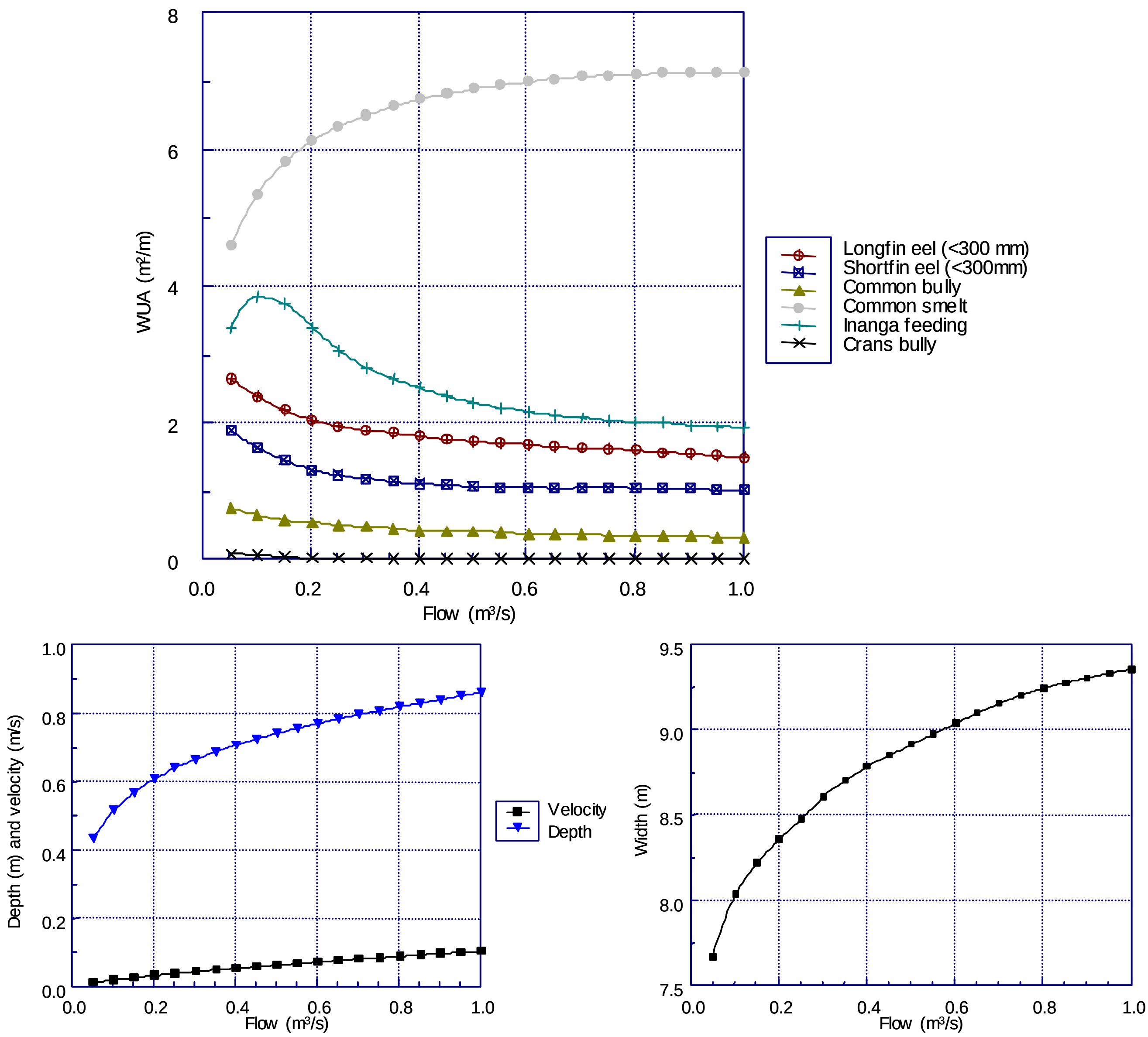
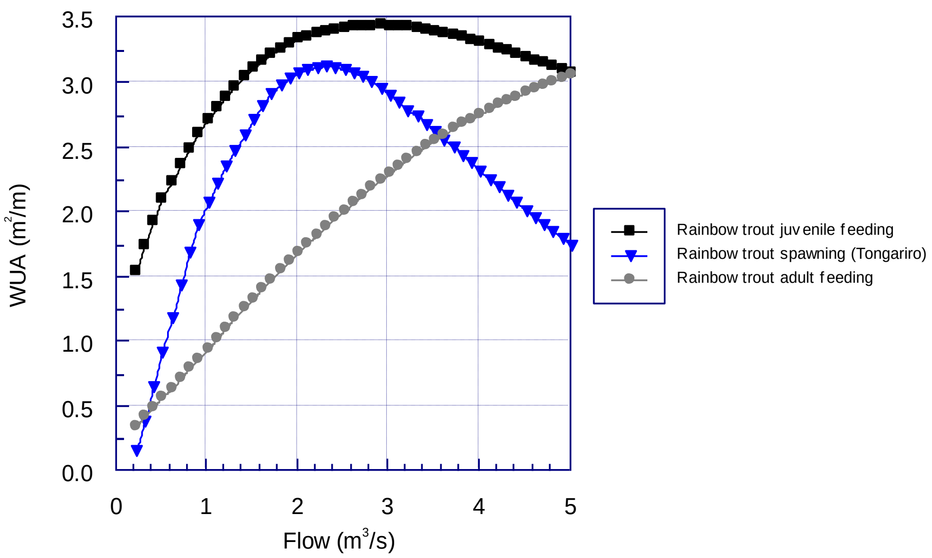
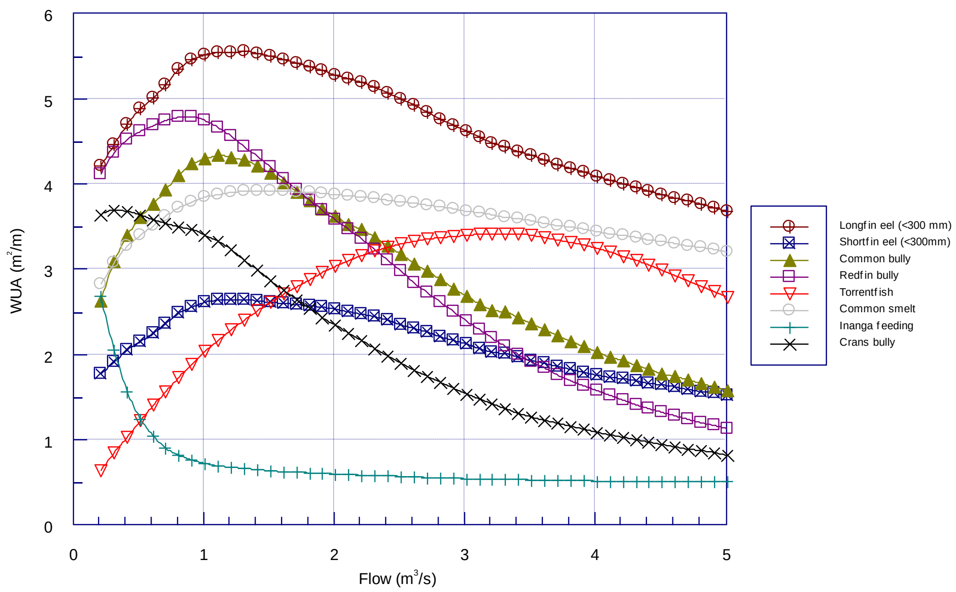


Figure 4.4: Variation of instream habitat for rainbow trout (weighted usable area WUA) with flow in the Mangawhero Stream (top), for native fish (middle), and variation in depth, velocity and width (below).

The Waiomou Stream is a gravel bed stream with pools, runs, and riffles and potentially provides habitat for a variety of native fish species as well as rainbow trout. Maximum native fish habitat was provided by flows of 0.9-3 m^3/s, and maximum rainbow trout spawning and juvenile habitat by flows of 2.4-3 m^3/s (Fig. 4.5). Flow in the order of 8 m^3/s provided maximum adult rainbow trout habitat. The width of the Waiomou Stream begins to decrease at a flow of about 2 m^3/s and decreases more sharply when flows fall below 1 m^3/s. The velocities are relatively high and mean velocities of 0.45 m/s would provide good benthic invertebrate habitat in a stream of this size.





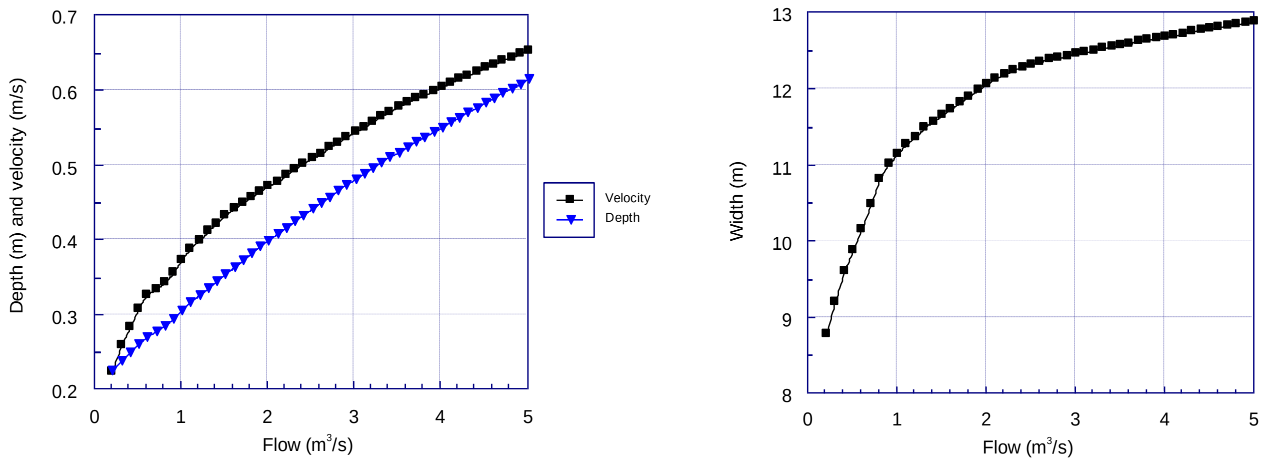
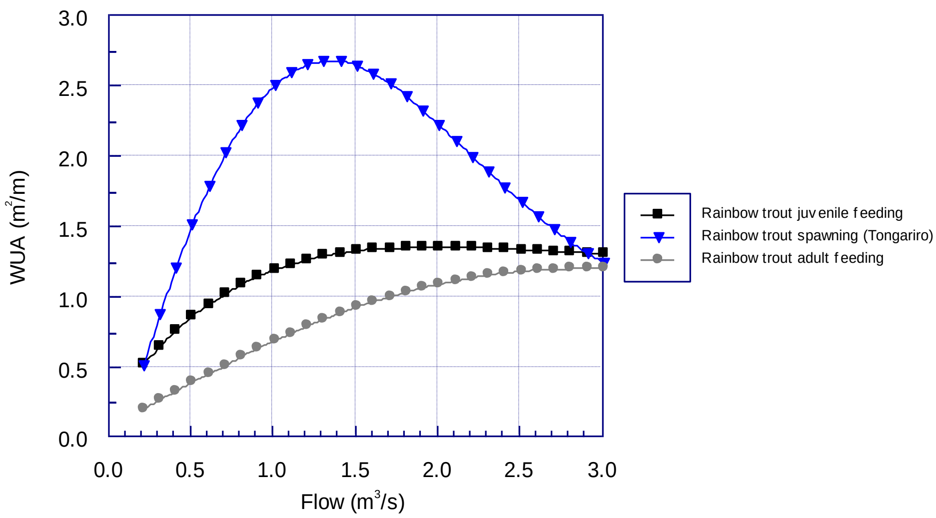


Figure 4.5: Variation of instream habitat for rainbow trout (weighted usable area WUA) with flow in the Waiomou Stream (top), for native fish (middle), and variation in depth, velocity and width (below).

The Waimakariri Stream supports a good rainbow trout population (Teirney & Jowett 1990). It was one of the few reaches that contained good rainbow trout spawning habitat and flows of 1.25 to 1.75 m^3/s provided excellent spawning and rearing (Fig. 4.6). A flow of 3 m^3/s provided maximum adult rainbow trout habitat.

The water surface width began to decrease sharply when flows fell below about 1 m^3/s and suitable velocities for benthic invertebrates (0.4 m/s) was provided by a flow of 1.25 m^3/s.



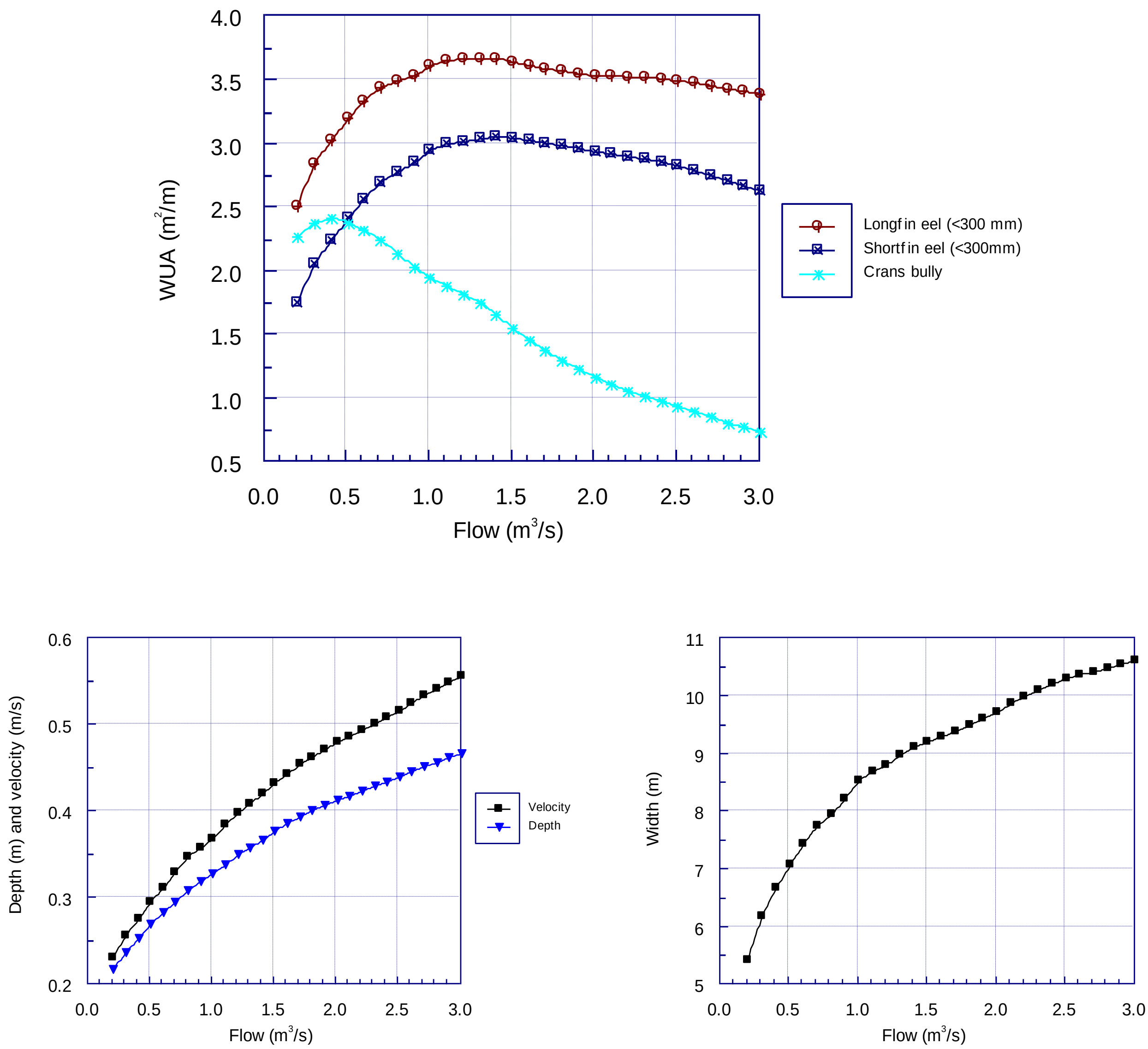
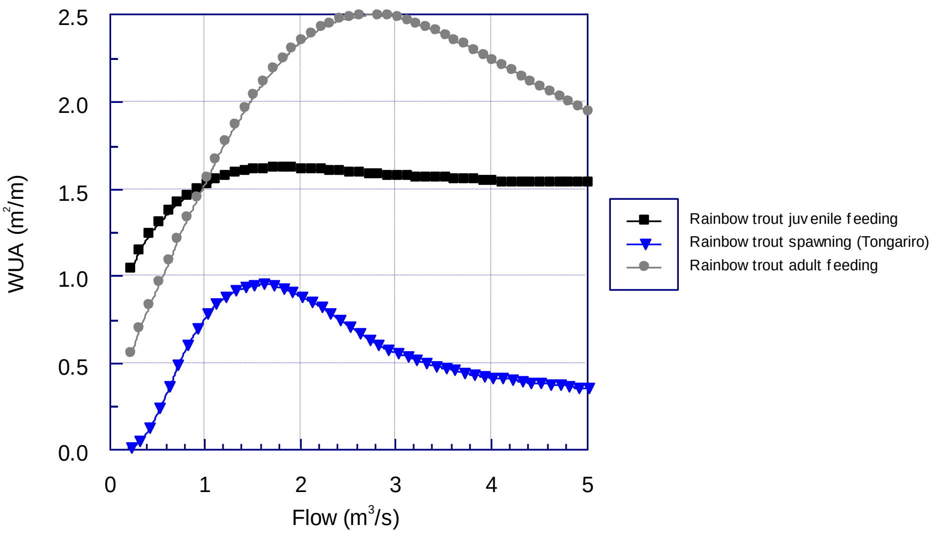
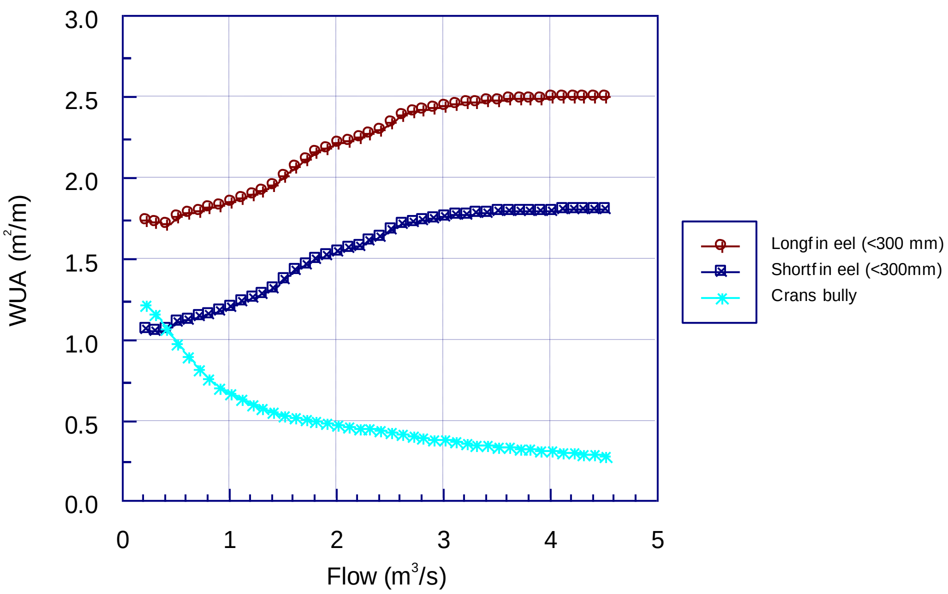


Figure 4.6: Variation of instream habitat for rainbow trout (weighted usable area WUA) with flow in the Waimakariri Stream at Waimakariri Road (top), for native fish (middle), and variation in depth, velocity and width (below).

The Waihou River at Whites Road supports very large numbers of juvenile rainbow trout and flows of 1.5-1.8 m^3/s provided excellent spawning and juvenile habitat. A flow of 2.7 m^3/s provided maximum adult rainbow trout habitat (Fig. 4.7). The river is deep with relatively low water velocities and would not provide good habitat for benthic invertebrates at low flows. A flow of 2.5 m^3/s has an average velocity of 0.4 m/s and would provide for benthic invertebrates.


2.5
2.0
1.5
1.0
0.5
0.0
WUA (m2/m)
0
1
2
3
4
5
Flow (m3/s)
Rainbow trout juvenile feeding
Rainbow trout spawning (Tongariro)
Rainbow trout adult feeding


3.0
2.5
2.0
1.5
1.0
0.5
0.0
WUA (m2/m)
0
1
2
3
4
5
Flow (m3/s)
Longfin eel (<300 mm)
Shortfin eel (<300mm)
Crans bully

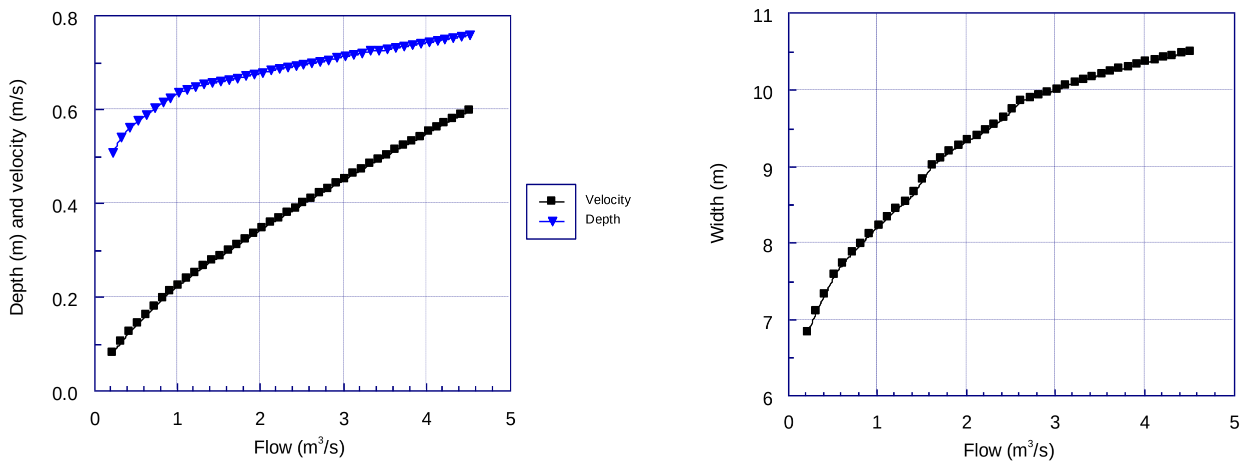
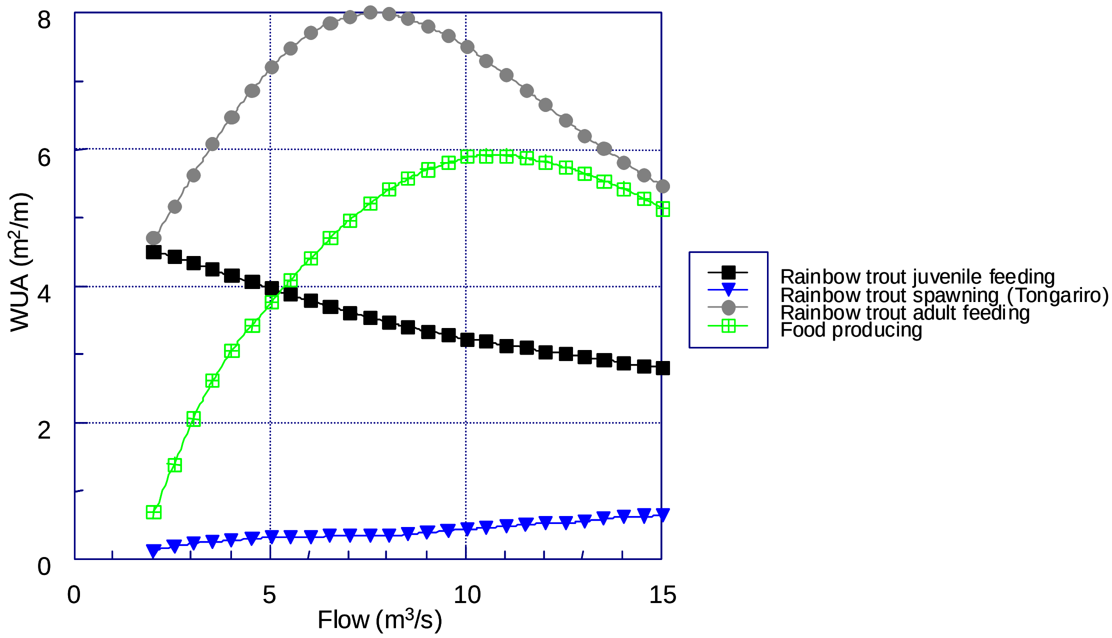
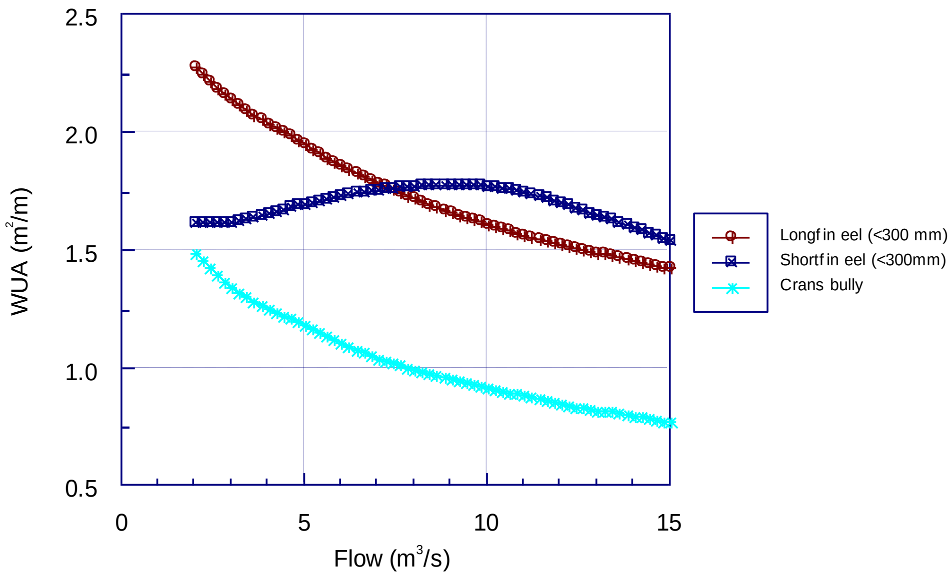


Figure 4.7: Variation of instream habitat (weighted usable area WUA) with flow in the Waihou River at Whites Road (top), for native fish (middle), and variation in depth, velocity and width (below).

The Waihou River at SH 29 was deep and swift and provided good adult rainbow trout habitat but little juvenile or spawning habitat. Any native fish habitat would be along the margins. A flow of 7.6 m^3/s provided maximum adult rainbow trout habitat (Fig. 4.8) and a flow of 10 m^3/s gave maximum food producing habitat. The water surface width began to reduce sharply when flows fell below 5 m^3/s and the average velocity was 0.5 m/s at a flow of 10 m^3/s and this would provide good invertebrate habitat, agreeing with the analysis of food producing habitat.


WUA (m²/m)
8
6
4
2
0
0
5
10
15
Flow (m³/s)
Rainbow trout juvenile feeding
Rainbow trout spawning (Tongariro)
Rainbow trout adult feeding
Food producing


WUA (m²/m)
2.5
2.0
1.5
1.0
0.5
0
5
10
15
Flow (m³/s)
Longfin eel (<300 mm)
Shortfin eel (<300mm)
Crans bully

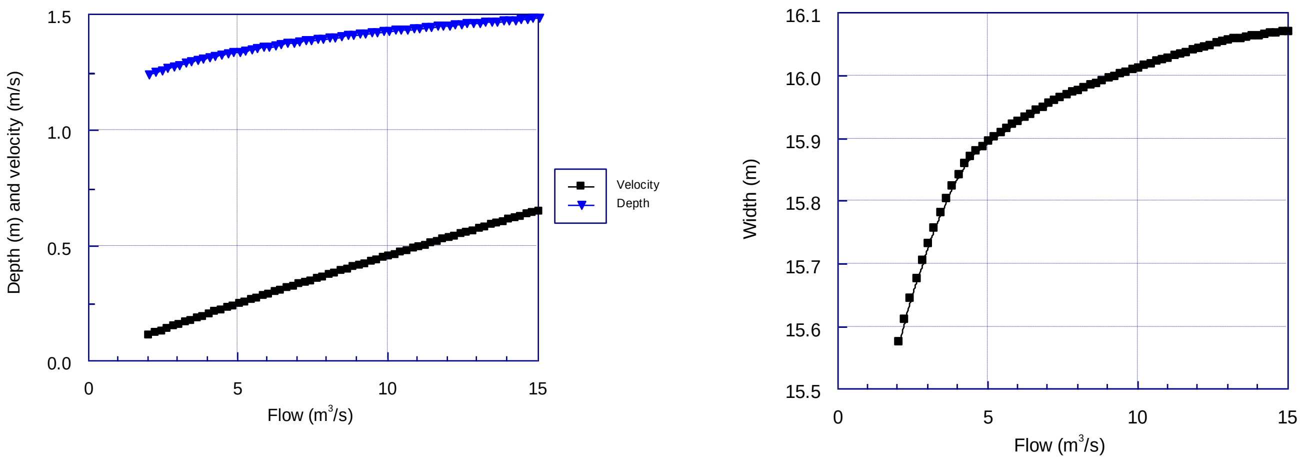


Figure 4.8: Variation of instream habitat (weighted usable area WUA) with flow in the Waihou River at SH 29 (top), for native fish (middle), and variation in depth, velocity and width (below).

The mainstem of the Waihou River between Gordon and Mangaiti is of similar character, being relatively deep and swift. This provides good adult rainbow trout habitat but normal velocities are probably too high for juvenile or spawning habitat. Any native fish habitat would be along the margins. The relationships between rainbow trout WUA and flow did not vary significantly between the Mangaiti, McKinley Road, and Gordon reaches, with optimum habitat provided by flows of 12.5, 10, and 9 m^3/s, respectively. When the three reaches were considered together, maximum habitat was provided by a flow of 11 m^3/s (Fig. 4.9) and maximum food producing habitat was provided by a flow of about 10 m^3/s.

The water surface width begins to reduce sharply when flows fall below 10 m^3/s and an average velocity of 0.5 m/s is maintained by a flow of 17.5 m^3/s.

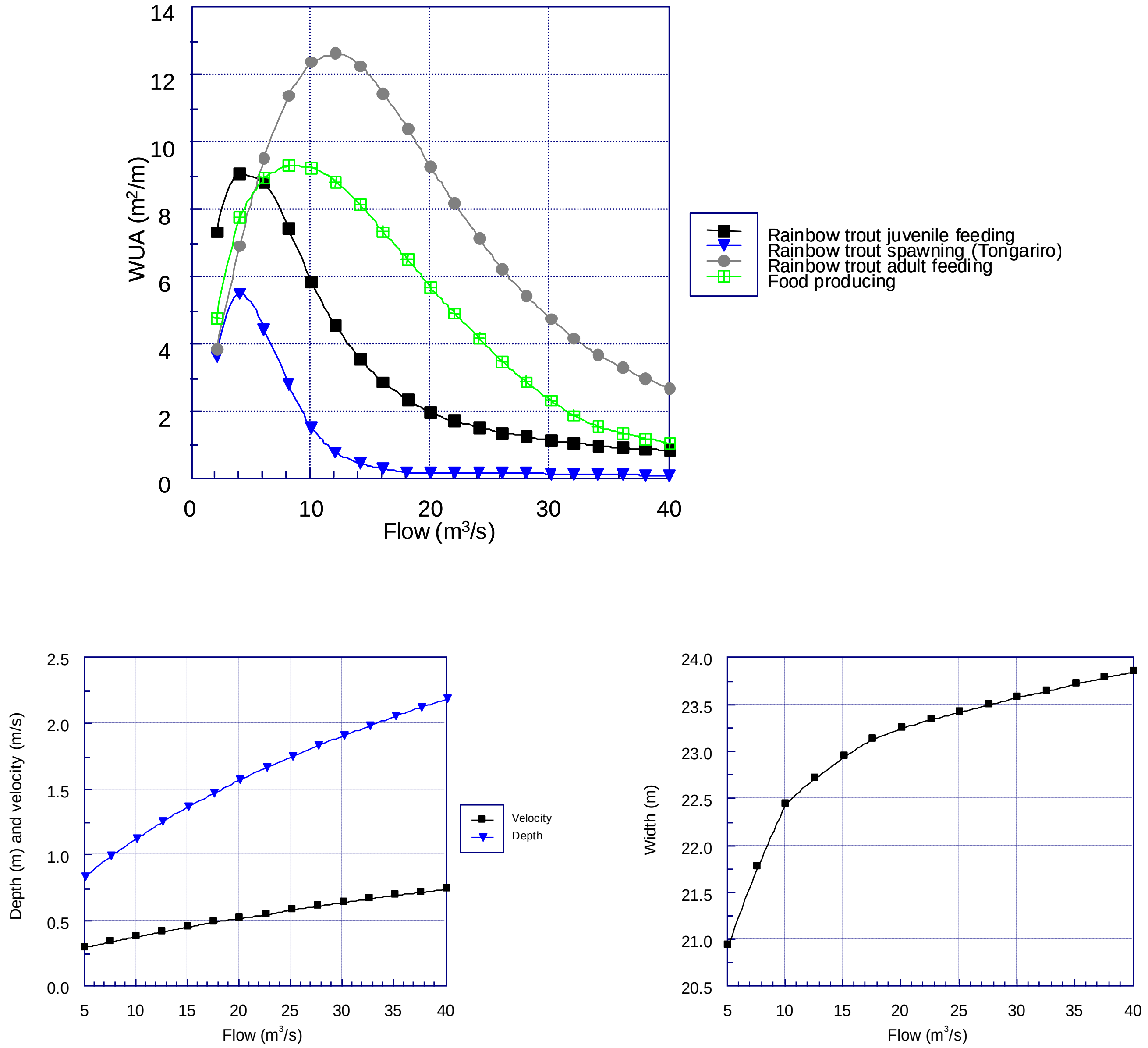


Figure 4.9: Variation of instream habitat (weighted usable area WUA) with flow in the Waihou River between Gordon and Mangaiti (top), and variation in depth, velocity and width (below).

5. Minimum flow requirements

5.1 Instream habitat

The differences in habitat preferences are reflected in the habitat-flow relationships. Maximum areas of habitat for native fish occur at lower flows than for adult or juvenile rainbow trout. In this study, many of the streams were relatively deep and swift, and were more suited to rainbow trout than native fish. The Ohinemuri River and Waiomou Stream were the only cobble/gravel bedded streams. Benthic invertebrate habitat preferences vary with species and any reduction in flow will tend to change the community composition, with low velocity species becoming more common. However, benthic invertebrates are more short-lived than fish and can quickly recover from the effects of short-term reductions in flow.

Survey flows were close to the 5 year low flow yet many of the streams had average velocities close to or above 0.5 m/s. The Ohinemuri reaches and Mangawhero Stream were the only streams where velocities were below the level required to keep the stream substantially free from fine sediment deposits (i.e., their average velocity was less than 0.25 m/s).

The selection of an appropriate flow for fish is a matter of judgement, where the requirements and perceived values of the different species must be considered. Flow recommendations are necessarily a compromise between species, and are usually made to prevent a sharp decline in habitat for most species, thus aiming to retain some habitat for all species that make up the fish community. Rainbow trout have higher flow requirements than native fish and, given the angling use of these rivers and lack of suitable native fish habitat, rainbow trout habitat would appear to be the appropriate use for which to set minimum flow requirements. Habitat requirements for food production and benthic invertebrates were similar to habitat requirements for adult rainbow trout. The headwaters of the streams tend to be used for rearing juvenile trout, whereas the deeper waters further downstream are probably more suited to adult trout. For example, the Waihou River at Whites Road and Waimakariri Stream both contain very high densities of juvenile rainbow trout but few large trout (Teirney & Jowett 1990). Brown trout habitat was not evaluated although there are a few brown trout in some of the streams. Flow requirements for brown trout are slightly less than for rainbow trout, so that provision of habitat for the more numerous rainbow trout will also provide brown trout habitat. Eels tend to be relatively flexible and can exist in a wide range of conditions.

Flow requirements can be selected so that they provide maximum habitat (the optimum flow in Table 5.1), a proportion of maximum, or can be selected so that they prevent a serious decline in fish habitat, the breakpoint or flow below which habitat declines sharply. The choice depends on the importance and appropriateness of the species and/or fishery and life stage. Selection of minimum flows based on the flow below which habitat declines sharply is suggested as an appropriate criterion, although for very small streams this flow may be higher than normal low flows. The method used to define a breakpoint is described in Jowett & Biggs (2006) and Jowett et al. (2008). The use of the flow at which the water surface width begins to reduce sharply might be considered as an appropriate criterion in some streams, as channel width represents the productive stream area.

Table 5.1 shows that the highest flow requirements for most reaches are flows that provide rainbow trout habitat, and this is consistent with the high angling usage (Table 3.4). Flows that provided maximum habitat for adult rainbow trout also provided close to maximum food producing habitat. Table 5.2 shows the flows below which the water surface width begins to reduce sharply and flows that were considered to provide good benthic invertebrate habitat.

Flow can also affect water temperature and dissolved oxygen and in some circumstances should be taken into account in assessing minimum flow requirements. Usually, changes in water temperature are small and confined to increased daily variation and dissolved oxygen is only problem in slow flowing streams dominated by macrophytes. In this study, dissolved oxygen concentrations in the Mangawhero Stream may fall below acceptable limits in periods of low natural flow. If dissolved oxygen is a problem in this stream, shading and consequent reduction in macrophyte density may help maintain acceptable oxygen levels.

Table 5.1: Suggested flow requirements for fish habitat in the study rivers.

Ohinemuri Golden Cross Valley Road	**Habitat**	**Flow (m^3/s) that provides:**				**Flow (m^3/s) below which habitat declines sharply**
		optimum	**90% of optimum**	**80% of optimum**	**70% of optimum**	
Estimated 5 year 7-day low flow:	Rainbow trout spawning	1.4	0.75	0.55	0.35	0.6
0.26 m^3/s	Rainbow trout rearing	1.0	0.7	0.55	0.45	0.65
	Longfin eel	0.3	<0.1	<0.1	<0.1	<0.1

	Shortfin eel	0.5	<0.1	<0.1	<0.1	<0.1
	Common bully	0.3	0.18	0.12	0.1	0.25
	Redfin bully	0.3	<0.1	<0.1	<0.1	<0.1
	Torrentfish	1.8	1.1	0.9	0.65	0.9

Ohinemuri Karangahake	**Habitat**	**Flow (m^3/s) that provides:**				**Flow (m^3/s) below which habitat declines sharply**
		optimum	**90% of optimum**	**80% of optimum**	**70% of optimum**	
Estimated 5 year 7-day low flow:	Rainbow trout spawning	4.2	3.1	2.6	2.3	3.4
1.6 m^3/s	Rainbow trout rearing	3.8	1.8	1.1	0.65	2.3
	Rainbow trout adult	12.5	6.6	5.4	4.1	7
	Longfin eel	0.8	<0.2	<0.2	<0.2	na
	Shortfin eel	0.6	<0.2	<0.2	<0.2	na
	Common bully	2.0	1.1	0.6	0.4	na
	Redfin bully	1.0	0.5	0.3	<0.2	na
	Torrentfish	6.0	3.6	2.8	2	4.4
	Common smelt	5.4	1.8	0.6	0.3	na
	Inanga	0.6	0.4	0.3	<0.2	na

Oraka (Tirau to Lake Road)	Habitat	Flow (m^3/s) that provides:				Flow (m^3/s) below which habitat declines sharply
		optimum	90% of optimum	80% of optimum	70% of optimum	
Estimated 5 year 7-day low flow:	Rainbow trout spawning	1.60	1.00	0.80	0.65	1.00
3.2-3.6 m^3/s	Rainbow trout rearing	2.30	1.30	1.00	0.70	1.50
	Rainbow trout adult	5.60	3.65	2.90	2.40	3.60
	Longfin eel	1.10	0.70	0.50	0.35	0.90
	Shortfin eel	1.10	0.70	0.55	0.10	0.90
	Common smelt	2.40	1.10	0.65	0.45	1.20
	Inanga	<0.10	<0.10	<0.10	<0.10	na

Mangawhero Matamata - Tauranga Road	Habitat	Flow (m^3/s) that provides:				Flow (m^3/s) below which habitat declines sharply
		optimum	90% of optimum	80% of optimum	70% of optimum	
Estimated 5 year 7-day low flow:	Rainbow trout spawning	na	na	na	na	na
0.6 m^3/s	Rainbow trout rearing	0.25	<0.05	<0.05	<0.05	0.20
	Rainbow trout adult	2.20	1.25	0.90	0.70	1.05
	Longfin eel	<0.05	<0.05	<0.05	<0.05	<0.05
	Shortfin eel	<0.05	<0.05	<0.05	<0.05	<0.05
	Common bully	<0.05	<0.05	<0.05	<0.05	<0.05

	Common smelt	0.95	0.57	0.15	0.07	0.40
	Inanga	0.10	<0.05	<0.05	<0.05	0.07
	Crans bully	<0.05	<0.05	<0.05	<0.05	<0.05

Waiomou Dawsons farm	**Habitat**	**Flow (m^3/s) that provides:**				**Flow (m^3/s) below which habitat declines sharply**
		optimum	**90% of optimum**	**80% of optimum**	**70% of optimum**	
Estimated 5 year 7-day low flow: 3.1 m^3/s	Rainbow trout spawning	2.30	1.60	1.30	1.05	1.50
	Rainbow trout rearing	2.90	1.50	1.05	0.75	1.60
	Rainbow trout adult	8.60	6.60	3.90	3.20	4.90
	Longfin eel	1.30	0.60	0.30	<0.20	0.90
	Shortfin eel	1.30	0.70	0.50	0.25	0.95
	Common bully	1.10	0.80	0.45	0.30	0.90
	Redfin bully	0.90	0.30	<0.20	<0.20	0.60
	Torrentfish	3.30	2.05	1.65	1.30	1.85
	Common smelt	1.10	0.60	0.35	<0.20	0.95
	Inanga	<0.20	<0.20	<0.20	<0.20	<0.20
	Crans bully	0.30	0.70	0.45	0.30	<0.20

Waimakariri SH 5	Habitat	Flow (m³/s) that provides:				Flow (m³/s) below which habitat declines sharply
		optimum	90% of optimum	80% of optimum	70% of optimum	
Estimated 5 year 7-day low flow: 2.5 m³/s	Rainbow trout spawning	1.3	0.95	0.75	0.65	0.9
	Rainbow trout rearing	2.0	1.1	0.8	0.6	1.05
	Rainbow trout adult	3.0	2.0	1.6	1.3	2.0
	Longfin eel	1.3	0.55	0.35	0.2	0.7
	Shortfin eel	1.4	0.8	0.5	0.35	0.7
	Crans bully	0.4	<0.2	<0.2	<0.2	0.25

Waihou Whites Road	Habitat	Flow (m³/s) that provides:				Flow (m³/s) below which habitat declines sharply
		optimum	90% of optimum	80% of optimum	70% of optimum	
Estimated 5 year 7-day low flow: 4.2 m³/s	Rainbow trout spawning	1.6	1.15	1.0	0.9	1.25
	Rainbow trout rearing	1.8	0.8	0.5	0.3	1.1
	Rainbow trout adult	2.7	1.8	1.5	1.2	2.0
	Longfin eel	na	na	na	na	na
	Shortfin eel	na	na	na	na	na
	Crans bully	<0.1	<0.1	<0.1	<0.1	<0.1

Waihou SH 29	**Habitat**	**Flow (m^3/s) that provides:**				**Flow (m^3/s) below which habitat declines sharply**
		optimum	**90% of optimum**	**80% of optimum**	**70% of optimum**	
Estimated 5 year 7-day low flow: 12.6 m^3/s	Rainbow trout spawning	na	na	na	na	na
	Rainbow trout rearing	<2.0	<2.0	<2.0	<2.0	<2.0
	Rainbow trout adult	7.6	5.0	3.9	3.0	6.05
	Longfin eel	<2.0	<2.0	<2.0	<2.0	<2.0
	Shortfin eel	<2.0	<2.0	<2.0	<2.0	<2.0
	Crans bully	<2.0	<2.0	<2.0	<2.0	<2.0

Waihou below Gordon	**Habitat**	**Flow (m^3/s) that provides:**				**Flow (m^3/s) below which habitat declines sharply**
		optimum	**90% of optimum**	**80% of optimum**	**70% of optimum**	
Estimated 5 year 7-day low flow (m^3/s): 21.3-24.6 m^3/s	Rainbow trout spawning	4.0	3.0	2.5	2.0	3.25
	Rainbow trout rearing	4.5	2.7	2.0	1.5	3.5
	Rainbow trout adult	11.5	8.0	6.5	5.5	9.0

Table 5.2: Flow requirements for maintaining water surface width and benthic invertebrates.

River	Flow (m^3/s) that provides good invertebrate habitat	Flow (m^3/s) below which width declines sharply
Ohinemuri Golden Cross Valley Road	0.8	0.15
Ohinemuri Karangahake	12.5	1.2
Oraka (Tirau to Lake Road)	1.0	1.2
Mangawhero Matamata - Tauranga Road	macrophytes with no benthic habitat	no clear break point
Waiomou Dawsons farm	1.6	1.0
Waimakariri SH 5	1.25	1.0
Waihou Whites Road	2.5	no clear break point
Waihou SH 29	10.0	5.0
Waihou below Gordon	10.0	10.0

6. Acknowledgments

Wayne McGrath, assisted by other members of the NIWA Rotorua team, carried out the fieldwork and Jody Richardson supplied information from the New Zealand Freshwater Fish Database. Flow information was supplied by Environment Waikato.

7. References

Arthington, A.H.; King, J.M.; O'Keeffe, J.H.; Bunn, S.E.; Day, J.A.; Pusey, B.J.; Bluhdorn, B.R.; Tharme, R. (1992). Development of an holistic approach for assessing environmental flow requirements of riverine ecosystems. In: Pilgram, J. J.; Hooper, B.P. eds. *Water allocation for the environment.* The Centre for Water Policy Research, University of New England, Armidale. Pp. 69-76.

Bovee, K.D. (1982). A guide to stream habitat analysis using the instream flow incremental methodology. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-82/26, Instream flow information paper 12. 248 p.

Jowett, I.G. (1989). River hydraulic and habitat simulation, RHYHABSIM computer manual. New Zealand Fisheries Miscellaneous Report 49. Ministry of Agriculture and Fisheries, Christchurch.

Jowett, I.G. (1992). Models of the abundance of large brown trout in New Zealand rivers. *North American Journal of Fisheries Management 12*: 417-432.

Jowett, I.G. (1995). Spatial and temporal variability in brown trout abundance: a test of regression models. *Rivers 5*: 1-12.

Jowett, I.G. (1997). Instream flow methods: a comparison of approaches. *Regulated Rivers 13*: 115-127.

Jowett, I.G. (2000). Flow management. In: Collier, K.J.; Winterbourn, M.J. (eds). *New Zealand stream invertebrates: ecology and implications for management*. Hamilton, New Zealand Limnological Society. Pp 289-312.

Jowett, I.G.; Biggs, B.J.F. (2006). Flow regime requirements and the biological effectiveness of habitat-based minimum flow assessments for six rivers. *Journal of River Basin Management 4(3)*: 179-189.

Jowett, I.G.; Hayes, J.W.; Duncan, M.J. (2008). A guide to instream habitat survey methods and analysis. NIWA Science and Technology Series No. 54. 118p.

Jowett, I.G.; Richardson, J. (1995). Habitat preferences of common, riverine New Zealand native fishes and implications for minimum flow assessments. *New Zealand Journal of Marine and Freshwater Research 29*: 13-24.

Jowett, I.G.; Richardson, J. (2008). Habitat use by New Zealand fish and habitat suitability models. NIWA Science and Technology Series No. 55.

Jowett, I.G.; Richardson, J.; Biggs, B.J.F.; Hickey, C.W.; Quinn, J.M. (1991). Microhabitat preferences of benthic invertebrates and the development of generalised Deleatidium spp. habitat suitability curves, applied to four New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research 25*: 187-199.

Jowett, I.G.; Rowe, D.; West, D. (1996). Fishery flow requirements of the Tongariro River. Consultancy report ELE301, National Institute of Water and Atmospheric Research, Hamilton. 140 p.

King, J.M.; Tharme, R.E.; de Villiers, M.S. (2000). Environmental Flow Assessments for Rivers: Manual for the building block methodology. WRC Report TT 131/00. Freshwater Research Unit, University of Cape Town, South Africa.

McBride, G.B.; Chapra, S.C. (2005). Approximate delta method for rapid calculation of stream re-aeration, primary production and respiration. *Journal of Environmental Engineering 131*: 336-342.

Orth, D.J. (1987). Ecological considerations in the development and application of instream flow-habitat models. *Regulated Rivers: Research and Management 1*: 171-181.

Poff, N.L.; Allan, J.D.; Bain, M.B.; Karr, J.R.; Prestegaard, K.L.; Richter, B.D.; Sparks, R.E.; Stromberg, J.C. (1997). The natural flow regime. *BioScience 47*: 769-784.

Richter, B.D.; Baumgartner, J.V.; Wigington, R.; Braun, D.P. (1997). How much water does a river need? *Freshwater Biology 37*: 231-249.

Teirney, L.D.; Jowett, I.G. (1990). Trout abundance in New Zealand rivers: an assessment by drift diving. Freshwater Fisheries Report 118. Freshwater Fisheries Centre, Ministry of Agriculture and Fisheries, Christchurch. 47 p.

Thomas, J.A.; Bovee, K.D. (1993). Application and testing of a procedure to evaluate transferability of habitat suitability criteria. *Regulated Rivers 8*: 285-294.

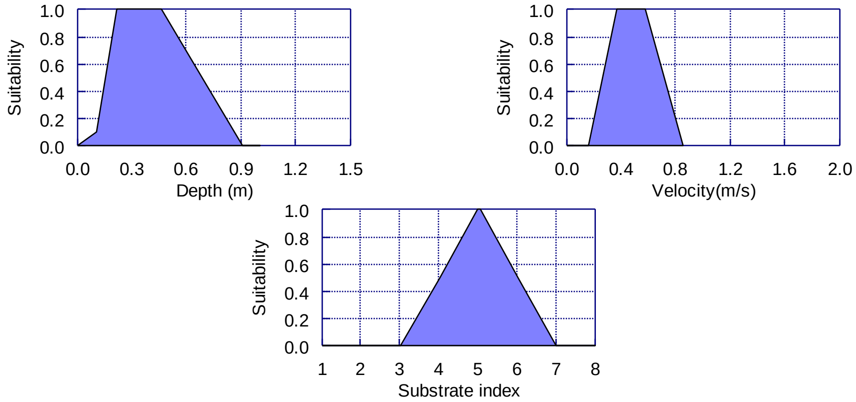
Unwin, M.; Image, K. (2003). Angler usage of lake and river fisheries managed by Fish & Game New Zealand: results from the 2001/02 National Angling Survey. NIWA Client Report No. CHC2003-114. NIWA Christchurch.

Waters, B.F. (1976). A methodology for evaluating the effects of different streamflows on salmonid habitat. In Orsborn, J. F. and Allman, C. H. (Eds), Proceedings of the Symposium and Speciality Conference on Instream Flow Needs II. American Fisheries Society, Bethesda, Maryland. pp. 224-234.

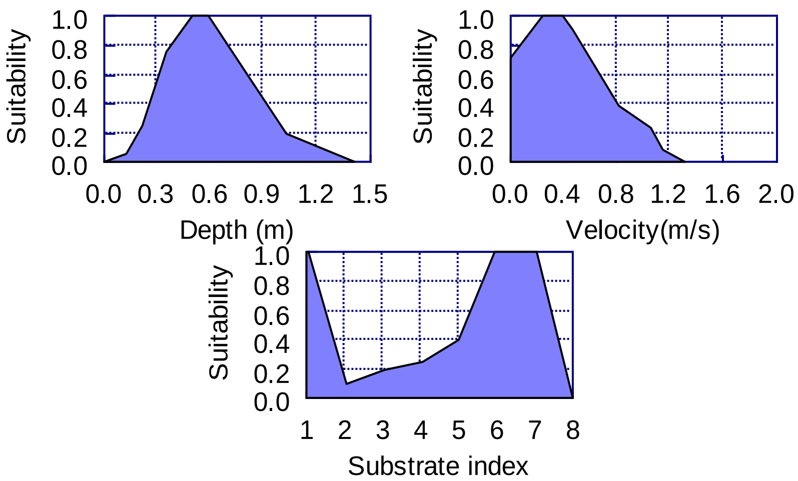
Wilding, T. (2006). Minimum flows for ecosystem health in selected Coromandel streams: Awaroa, Tapu, Waiomu and Wharekawa. NIWA Client Report No. HAM2006-148.

8. Appendix I: Habitat suitability curves used in this study

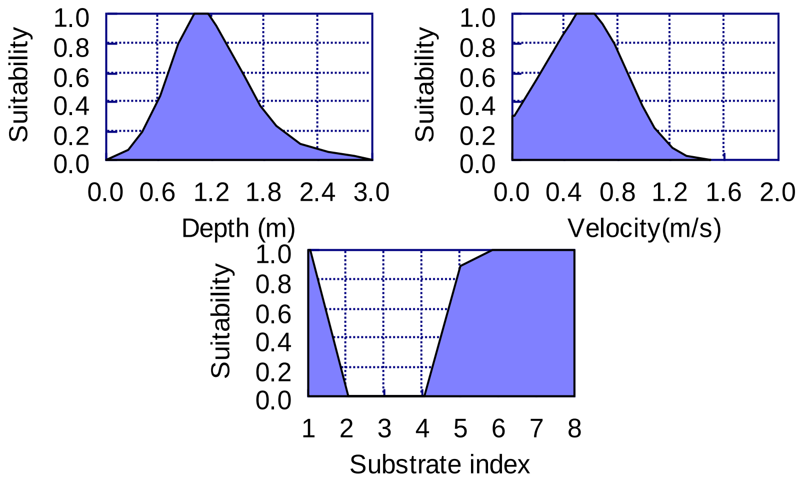
Rainbow trout spawning (Tongariro)



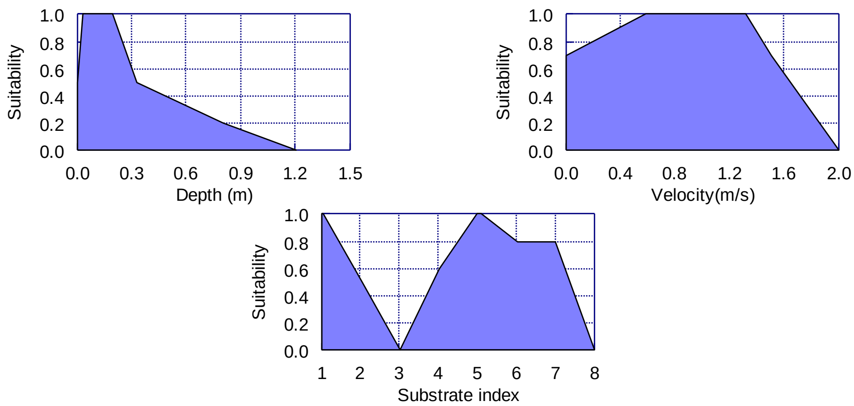
Rainbow trout juvenile feeding (Thomas & Bovee 1993)



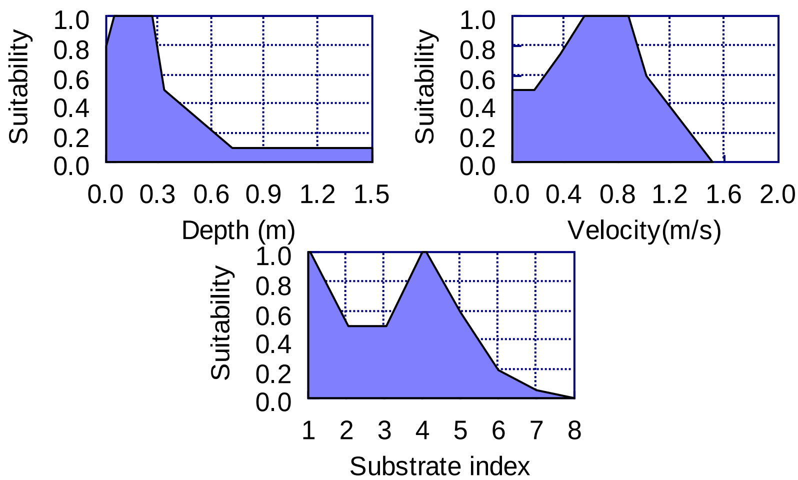
Rainbow trout adult feeding (Thomas & Bovee 1993)



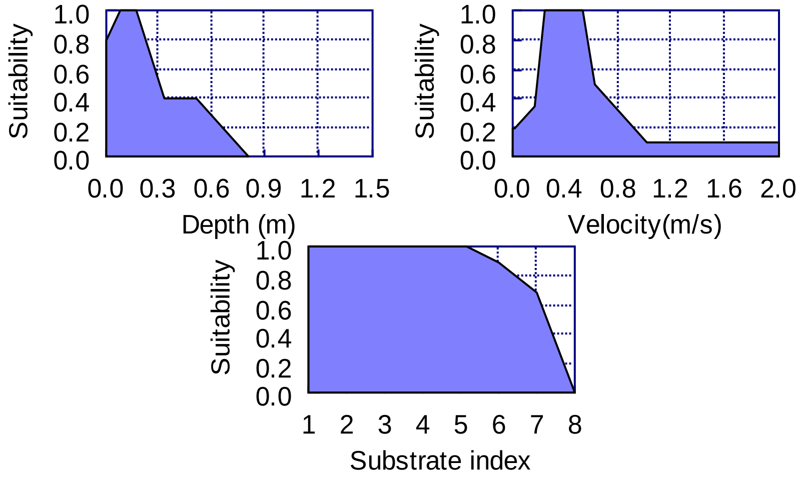
Longfin eel (<300 mm)



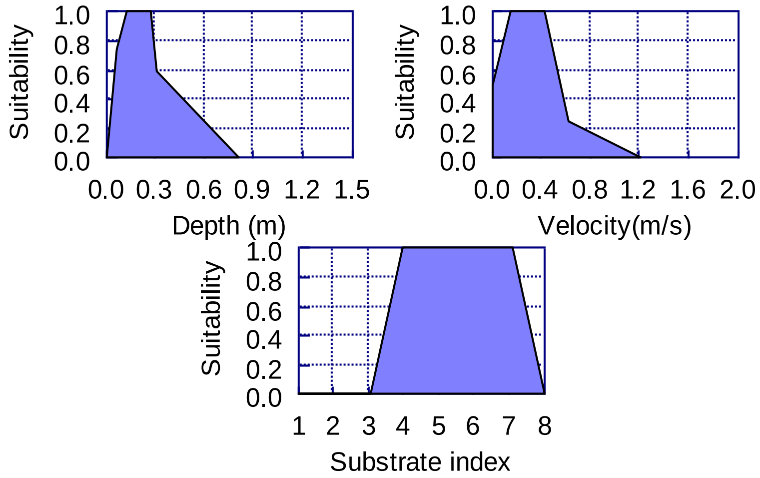
Shortfin eel (<300mm) (Jowett and Richardson 1995)



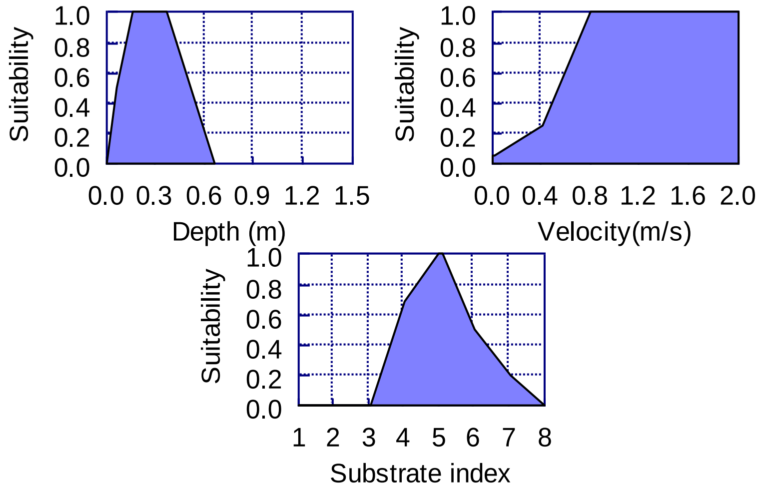
Common bully (Jowett and Richardson 1995)



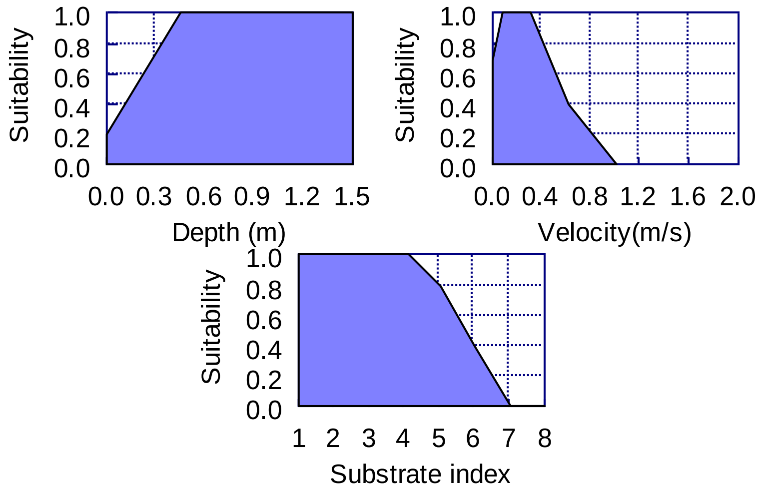
Redfin bully (Jowett and Richardson 1995)



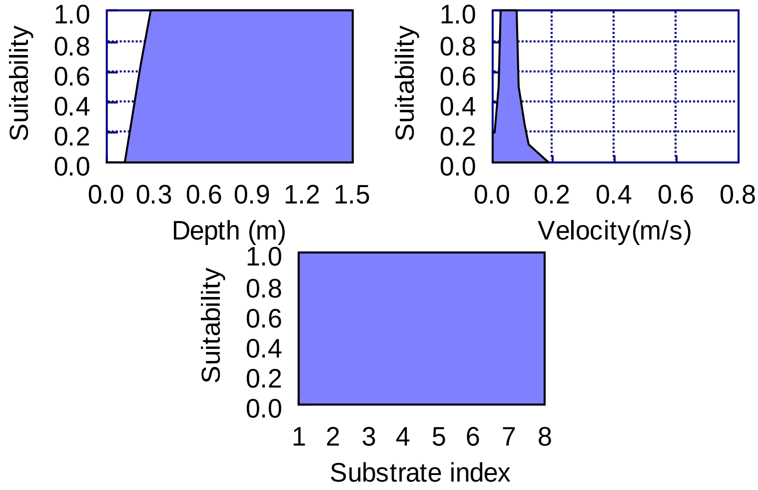
Torrentfish (Jowett and Richardson 1995)



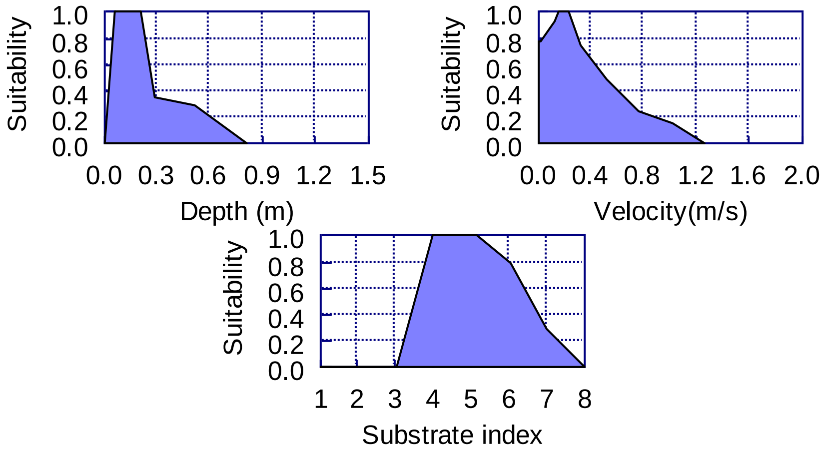
Common smelt

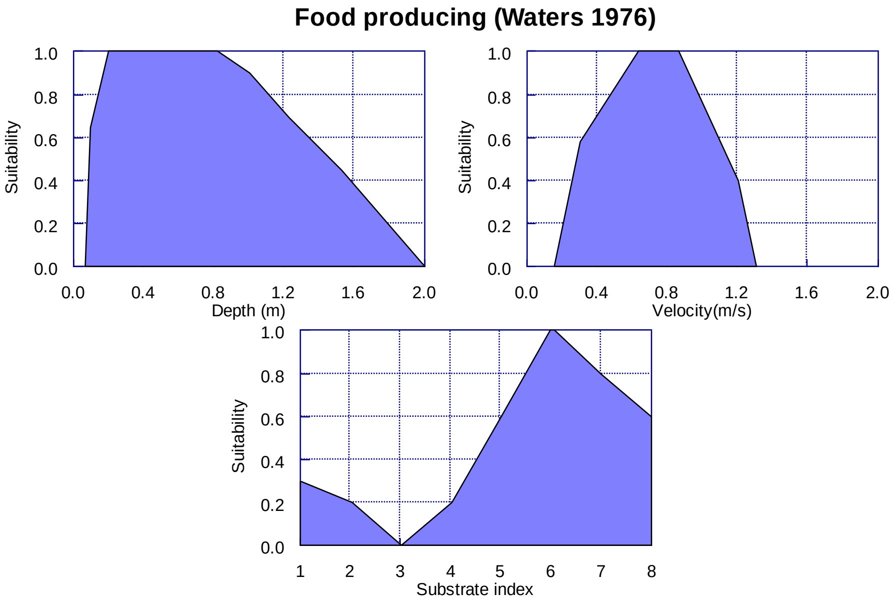


Inanga feeding (Jowett 2002)



Crans bully (Jowett and Richardson 1995)




Food producing (Waters 1976)
Suitability
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.4
0.8
1.2
1.6
2.0
Depth (m)
Velocity(m/s)
1
2
3
4
5
6
7
8
Substrate index