NIWA
Taihoro Nukurangi

Flow requirements for fish habitat in the Chatto, Lindis, Manuherikia, Pomahaka and Waianakarua Rivers

NIWA Client Report: HAM2003-052
May 2003

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Prepared for

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Executive Summary

The purpose of this study was to investigate the flows required to maintain acceptable habitat for native fish and trout in Chatto Creek and the Manuherikia, Lindis, Pomahaka and Waianakarua rivers.

The Waianakarua River contains brown trout and a diverse range of diadromous native fish species. The other rivers are further inland and contain trout (mainly brown), upland bullies, longfin eels, and non-diadromous galaxiids (either roundhead or flathead galaxias). The Pomahaka River is the third most popular trout fishing river in the Otago region and the Manuherikia River is the fifth most popular.

Instream habitat surveys were carried out in each river and flow requirements for all the above species were assessed by examining the relationships between flow and suitable habitat using instream habitat modelling. Habitat suitability was determined from general habitat suitability curves developed from studies in other rivers.

The selection of appropriate minimum flows for fish is a compromise between the contrasting requirements of the different species. For example, upland bullies that prefer low velocity water require relatively low flows, whereas trout, especially adult trout, prefer moderate water velocities and thus require reasonably high flows.

The selection of an appropriate minimum flow depends on the fish species present and the flow management objectives that balance the degree of environmental protection against the value of water for other uses. Minimum flows based on the flow below which habitat declines sharply is suggested as an appropriate criterion. These flows are listed for each river and fish species in the following table.

Stream	Recorded 7-day mean annual low flow (m^3/s)	Fish species	Optimum flow (m^3/s)	Flow (m^3/s) below which habitat declines sharply
Chatto Creek (SH85)	0.1	Upland bully, roundhead galaxias	0.125	0.025
Chatto Creek (Matakanui Stn)	0.08	Upland bully, roundhead galaxias	0.04	0.025
		Juvenile brown trout	0.15	0.1
Manuherikia River below Ophir	1.72	Adult brown trout	4.25	2.5
		Yearling brown trout	2	0.9
		Juvenile brown trout	1.25	0.9
Lindis River	1.58	Upland bully, flathead galaxias roundhead galaxias	0.4	0.2
		Rainbow trout spawning (winter)	2.2	
		Juvenile brown trout	1.4	0.75

Pomahaka River (Burkes Ford)	3.36	Adult brown trout	13	7.5
		Yearling brown trout	6	2.5
Pomahaka River (The Holt)	2.58	Adult brown trout	8	4
		Yearling brown trout	4	1.5
Waianakarua below north and south branch confluence	0.20	Redfin bully, common bully	0.4	0.15

1. Introduction

1.1 Study Brief and Background

The Otago Regional Council requested NIWA carry out a study to determine the flows required to maintain acceptable habitat for the fish species present in Chatto Creek and the Manuherikia, Lindis, Pomahaka and Waianakarua rivers (Fig. 1.1).

The study brief was to:

- carry out instream habitat surveys in critical reaches of four rivers (Chatto, Manuherikia, Lindis, Pomahaka and Waianakarua)
- carry out a hydraulic analysis in the five rivers using RHYHABSIM (Jowett 1989) to determine how weighted usable area (WUA) for brown trout and native fish habitat varies with discharge
- assess flow requirements for the five rivers based on the habitat requirements of the native and introduced fish species.

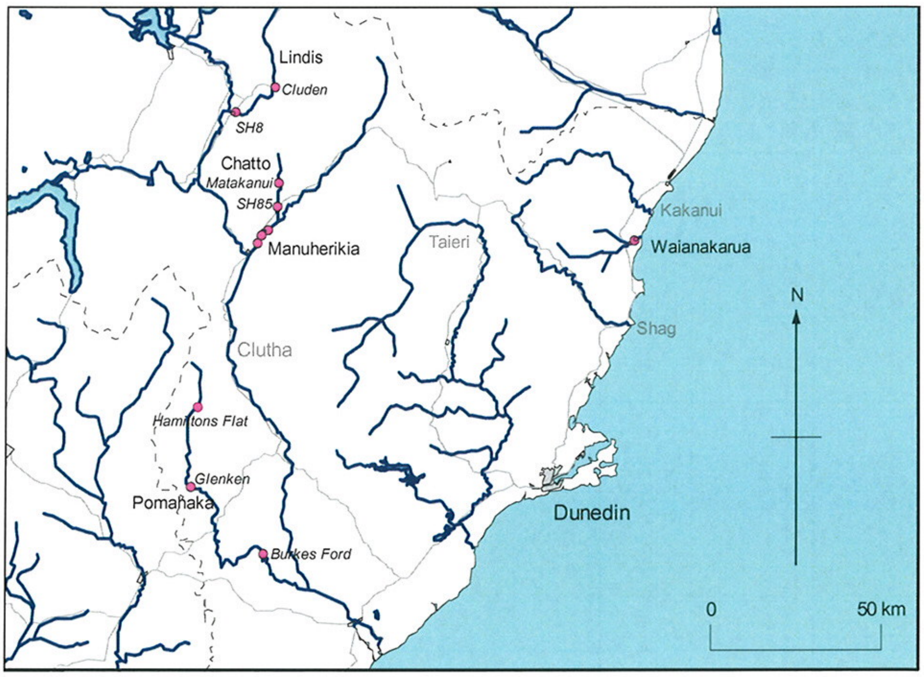

Figure 1.1: Otago Region showing location of survey reaches.

1.2 Instream Habitat Modelling

1.2.1 Flow Assessment Methods

There has been considerable debate and discussion of flow assessment methods without any real resolution as to the 'best' method (e.g., Stalnaker & Arnette 1976; Wesche & Rechard 1980; Schuytema 1982; Trihey & Stalnaker 1985; Estes & Orsborn 1986; Morhardt & Altouney 1986; Richardson 1986; Karim et al. 1995), possibly because the environmental goals of the methods are different (Jowett 1997). Quantitative instream flow methods are generally divided into three major categories: (i) historic flow regime; (ii) hydraulic; and (iii) habitat. Although all three categories aim to maintain an appropriate stream environment, they focus on different aspects of the stream, such as flow, wetted perimeter or physical habitat, and these measures are used to specify a level of environmental protection (e.g., the proportion of flow, wetted perimeter or physical habitat that is retained by a minimum flow). There is an implicit assumption that the proportion of flow, wetted perimeter or physical habitat specified as a level of protection will reflect the condition of the stream environment, and that there is some cut-off level or 'minimum' flow below which aquatic life will not be adequately sustained. However, it must be remembered that responses of habitat variables and associated organisms to different levels of flow are generally gradual and decisions need to be made as to when an acceptable level of environmental protection has been achieved.

Because habitat methods are based on quantitative biological principles, they are considered more reliable and defensible than assessments made in other ways (White 1976; Annear & Conder 1984). The physical habitat simulation component of the instream flow incremental methodology (IFIM) is the most common method used in the United States, being used or recognised in 38 states and being the preferred method in 24 of them (Reiser et al. 1989). The New Zealand equivalent, RHYHABSIM (Jowett 1989), has been applied widely in New Zealand.

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, Biggs 1996).

1.2.2 Habitat preferences and suitability curves

The terms "habitat suitability" and "habitat preference" are often used interchangeably to refer to the range in habitat conditions where an organism prefers to live. For example, if we look at the temperature requirements of humans, if given a choice most people might choose to live in areas/habitats where temperatures are always in the range of 22–28 °C. Then, all else being equal, we would expect to see lower densities of people in areas/habitats that were progressively colder or hotter than the optimal range. Stream organisms have similar desired ranges for water velocity, depth, bed sediment size and temperature. In instream flow assessment methods such as PHABSIM and RHYHABSIM, suitability curves for a range of stream organisms have been defined based on extensive research. Such suitability curves can be derived directly from surveying habitats over a range of depths, velocities etc., and plotting the abundance of organisms against habitat measures to show where they are most abundant (i.e., where they prefer to live).

Generally, native fish are found in similar habitats over a wide range of rivers. McDowall (1990) has described these habitats in descriptive terms. The quantitative approach taken in New Zealand has been to develop general habitat suitability criteria for species of interest by using data collected from several rivers. To date, general habitat suitability curves have been developed for several native fish species (e.g., Fig. 1.2), some of it published (e.g., Jowett & Richardson 1995) and some of it unpublished.

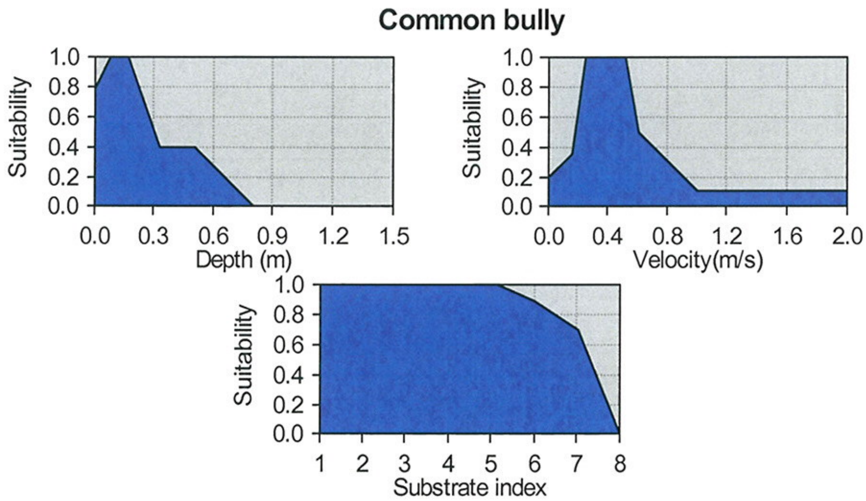

Figure 1.2: Habitat suitability curves for common bullies, where the suitability ranges from 0 (unsuitable) to 1 (optimal). Substrate index: 1=vegetation, 2=silt, 3=sand, 4=fine gravel, 5=gravel, 6=cobble, 7=boulder, 8=bedrock (Jowett & Richardson 1995).

1.2.3 Habitat Mapping, Instream Habitat Modelling, and Prediction of Habitat Suitability

A stratified random survey approach called mesohabitat typing or habitat mapping was used in this study. Mesohabitat typing first requires that habitat mapping is undertaken over the segment of river under study so that the proportions of the different habitats of interest (e.g., pool, riffle, run, etc.) can be calculated. Next, cross-sections are randomly selected to represent each of the habitat types.

At each cross-section, depths, mean column velocities, and substrate composition are recorded at intervals of between 0.2 and 2 m depending on river width and uniformity, or at locations where water depth or velocity changes across the section (Jowett 1989). Flow and water level are recorded for each cross-section and repeated at two, or more, other flows to establish a stage-discharge relationship. Water velocities and depths over each cross-section can then be predicted for a range of flows, using the stage-discharge relationships and channel geometry.

1.2.4 Procedure for Calculating Instream Habitat and Assessing Flow Requirements

The procedure in an instream habitat analysis is to select appropriate habitat suitability curves or criteria (e.g., Fig. 1.2), 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. 1.3. Instream habitat can be expressed either as the total area of suitable habitat or as the percentage of the stream area that is suitable habitat. WUA (m^2/m) is the measure of the total area of suitable habitat per metre of stream. WUA (%) is the percentage of suitable habitat within the wetted area. Both WUA (m^2/m) and WUA (%) can be used to assess minimum flow requirements for fish. 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 WUA (%).

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.

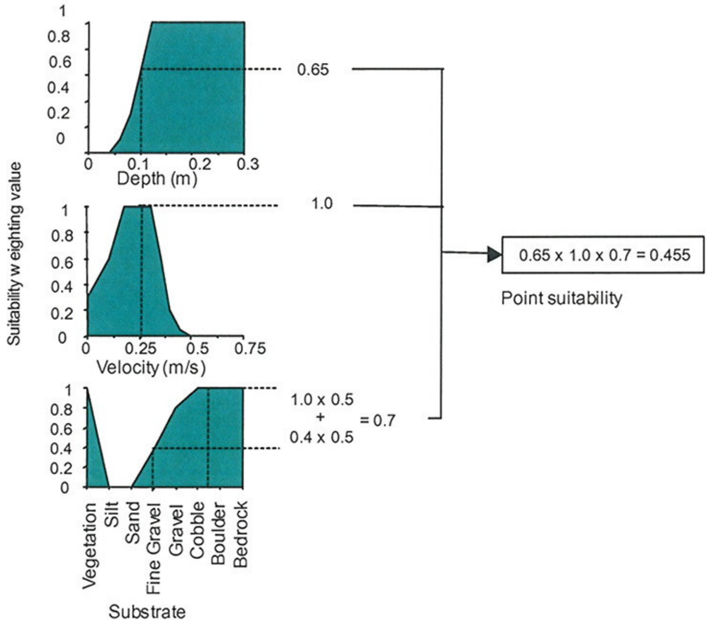

Figure 1.3: Calculation of habitat suitability for a fish species at a point with a depth of 0.1 m, velocity of 0.25 m/s, and substrate comprising 50% fine gravel and 50% cobble. The individual suitability weighting values for depth (0.65), velocity (1.0), and substrate (0.7) are multiplied together 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 with increasing the flow.

Habitat methods can also incorporate flow regime requirements, in terms of both seasonal variation and flow fluctuations. Flow fluctuations are an important component of the habitat of most naturally flowing streams. Such fluctuations remove excess accumulations of silt and accumulated organic matter (e.g., from algal slimes) and rejuvenate stream habitats. Extended periods without a flow disturbance usually result in a shift in benthic community composition such as a reduction in diversity, and an increase in biomass of a few species within plant and animal communities.

2. Survey reaches, flow characteristics, and fish species

2.1 Reach selection

Instream habitat surveys were carried out in Chatto Creek (2 reaches), Lindis River (2 reaches), Manuherikia, and Waianakarua rivers (Fig. 1.1, Table 2.1). Existing instream habitat survey data were available for the Pomahaka River (Young & Hayes 1999; ORC 2000). All but the Waianakarua River are tributaries of the Clutha River. Reaches were generally located in the sections of river where the effects of water abstraction are greatest.

Flow requirements for the Waianakarua River were assessed in the reach between the sea and the confluence of the north and south branches. The unconfined nature of this section of river, plus the probable high density and diversity of diadromous native fish species, makes it the section of river most likely to be affected by water abstraction.

Figure 2.1: Study reach in the Waianakarua River looking downstream to Brown's pump (left) and upstream (right), 17 January 2003.

Cross-sections in the Manuherikia River were located along the section of river between Tiger Hill Road and the Manorburn confluence (below Galloway Bridge). Five cross-sections were surveyed at each of three different access points (Tiger Hill Road, Fisher Lane, and Galloway Bridge) to give a representative sample of the pools, runs and riffles over the lower 8 km or so of river.

Figure 2.2: Study reach in the Manuherikia River looking downstream (upper) and upstream (lower) from the Galloway Bridge, 26 March 2003.

Chatto Creek was surveyed at the SH85 below all major abstraction points, as well as at the Matakanui Station above which there is relatively little water abstraction. In its lower reaches, Chatto Creek (SH85) flows in a well-confined channel that is steep and relatively uniform with gravel substrate. Because of the uniformity, the 15 cross-sections were located mainly in run or riffle habitats above and below the SH85 bridge. Habitat further upstream is more diverse. We surveyed 15 cross-sections in the reach below the bridge at Matakanui Station (5 pool, 5 run, 5 riffle). Because of the tributary flow contribution between the two reaches, each was calibrated and analysed separately.

Figure 2.3: SH85 reach in Chatto Creek looking downstream from SH bridge (left), 14 January 2003, and upstream from the downstream cross-section (right), 29 January 2003.

Two reaches were surveyed in the Lindis River; at SH 8 and Cluden Hill. At SH 8, the river is relatively unconfined with gravel substrate, alternating gravel bars, and varying river width. Further upstream at Cluden Hill, the river is more confined with pool/run/riffle sequences and moderate willow growth. Cross-sections were located in 4 runs and 4 riffles at SH8 and in 3 runs, 3 riffles and 1 pool at Cluden Hill. Flows differed between these reaches because of abstraction and tributary flows. Each reach was calibrated separately and then combined for the assessment of flow requirements.

Figure 2.4: Upper (Cluden Hill) reach in the Lindis River looking upstream (upper), 28 March 2003, and downstream from the third SH8 cross-section, 30 January 2003.

Figure 2.5: Lower (SH8) reach in the Lindis River looking upstream from the SH bridge on 15 January 2003 (upper) and from the same location on 28 March 2003 (lower).

Instream habitat data for the Pomahaka River at Burkes Ford, Dusky Forest, and Hamilton's Flat was provided by Cawthron Institute (Young & Hayes 1999). Data for the Pomahaka at The Holt (Dusky Forest) was collected by NIWA in 2000 for the Otago Regional Council (ORC 2000). Data for the Hamilton's Flat reach were not used for this study because the rating curves derived for individual cross-sections were poor. The reaches at The Holt and Dusky Forest were combined for an assessment of flow requirements in that section of the river.

Table 2.1: Cross-section locations including grid references (NZMS260 easting and northing, map number in brackets). Locations listed in order from furthest upstream to downstream.

River	Reach	Number of cross-sections	Flow (m^3/s) at time of survey	Upstream limit	Downstream limit
Waianakarua	Upper access (J42)	15	0.283	E2338955 N5547321	E2339348 N5547674
	Lower access (J42)		0.283	E2340217 N5547856	E2340413 N5548471
Manuherikia	Tiger Hill Road (G42)	15	7.404	E2232898 N5551785	E2232557 N5551290
	Fisher Lane (G42)			E2231725 N5550923	E2231091 N5550592
	Galloway Bridge (G42)			E2229873 N5547823	E2229697 N5547261
Chatto	Matakanui Station (G41)	15	0.072	E2235762 N5565651	E2235877 N5564992
	SH85 (G42)	15	0.422	E2235525 N5557985	E2235432 N5557105
Lindis	Cluden Hill (G40)	7	5.995	E2234202 N5594063	E2234682 N5593375
	SH8 (G41)	8	5.625	E2223008 N5585700	E2222077 N5585556
Pomahaka	Hamilton's Flat (G44)	18		E2212060 N5498760	
	Dusky Forest (G44)	18	5.17	E2210500 N5475400	
	The Holt (G44)	15	3.355	E2211500 N5475100	
	Burkes Ford (G45)	15	8.70	E2231550 N5455540	

2.2 Flows

Flow records were available for all rivers and the mean flow, median flow and the 7-day mean annual low flow were calculated for each river and recorder site (Table 2.2).

Table 2.2: Recorded flow statistics (m^3/s) from water level recorders near study reaches.

River	Recorder, number, and period of record	Mean flow (m^3/s)	Median flow (m^3/s)	7-day mean annual low flow (m^3/s)
Waianakarua	D/S confluence (72004, 1969-1974)	4.15	1.20	0.20
Manuherikia	Ophir (75253, 1971-)	15.16	9.57	1.72
Chatto	Above borough race (75249, 1986-1987)	0.92	0.66	0.10
Lindis	Lindis Peak (75219, 1976-)	6.88	4.86	1.58
Pomahaka	Burkes Ford (75232, 1961-)	27.09	17.63	3.36
	Glenkenich (75234, 1992-)	13.39	8.62	2.58

2.3 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 Otago region, with high fish diversity in rivers at low elevations, and low diversity at inland sites, especially where fish access is prevented by large dams.

Records in the New Zealand Freshwater Fish Database (NZFFD) were examined to determine the fish species present in each of the rivers (Table 2.2). The survey reach in the Waianakarua River is within a few kilometres of the coast and supports a diverse native fish community, with at least six diadromous species present in the lower reaches (Table 2.2). However, the other four river reaches are likely to contain four fish species (trout *Salmo trutta*, longfin eels *Anguilla dieffenbachii*, and two non-diadromous native fish species, upland bullies *Gobiomorphus breviceps* and either flathead galaxias *Galaxias depressiceps* or roundhead galaxias *Galaxias anomalus*), although occasionally other species may be present, especially in the Pomahaka River where there is good access to the sea. Longfin eels were recorded in most rivers, but were most abundant in the Pomahaka River. Roxburgh Dam has been a partial barrier to the upstream migration of young eels (elvers). However, elver transfer past Roxburgh Dam may result in the increased occurrence of eels in Chatto Creek and the Manuherikia and Lindis rivers. Common bullies *Gobiomorphus cotidianus* were also reported from most inland streams and are probably fish derived from lake stocks.

The latest angling survey (Unwin & Brown 1998) was used to determine the relative importance of angling in each river. The Pomahaka and Manuherikia represent significant brown trout fisheries with high angler usage and rank 27th and 40th, respectively, out of over 500 river fisheries around New Zealand. The only more popular angling rivers in the Otago region are the Clutha and Taieri, with the Catlins River intermediate between the Pomahaka and Manuherikia. Chinook salmon *Oncorhynchus tshawytscha* have been reported from one tributary of the Pomahaka River. Some angling takes place in the Lindis River, where both brown and rainbow trout are present. Brook char *Salvelinus fontinalis* are present in the headwaters of the Manuherikia River. Brown trout were recorded in the Chatto Stream. The lower reaches of this stream probably provide spawning and rearing habitat for the Manuherikia (into which the Chatto flows) and the upper reaches contain a resident population of brown trout, but these do not grow to a large size (C. Arbuckle pers. comm.).

Table 2.2: Fish records from the New Zealand Freshwater Fish Database and angler usage (angler-days) from Unwin & Brown (1998).

River	NZFFD records	Angler-days
Waianakarua	longfin eel*, common bully*, common smelt*, bluegill bully*, redfin bully*, inanga*	
Manuherikia	brown trout, upland bully, longfin eel*, common bully, roundhead galaxias, brook char (in headwaters), rainbow trout (in Manorburn), flathead galaxias (in Coal Creek)	3566
Chatto	brown trout, upland bully, roundhead galaxias	
Lindis	brown trout, rainbow trout, upland bully, longfin eel*, common bully, flathead galaxias	280
Pomahaka	Brown trout, upland bully, shortfin eel*, longfin eel*, lamprey*, koaro* (in Spylaw Burn), common bully*, Chinook salmon* (Waipahi River), roundhead galaxias, flathead galaxias (in Heriot Burn)	6783

* diadromous

A survey of these streams near the habitat survey sites was carried out by Chris Arbuckle in summer 2002/03 and this confirmed the species composition obtained from the NZFFD. He also suspected that roundhead galaxias and alpine galaxias *Galaxias paucispondylus* might be present in the Lindis River.

2.4 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. The fish species that are relatively common in the study reaches and for which habitat suitability curves are available are longfin eel, shortfin eel, inanga, upland bully, redfin bully, bluegill bully, common bully, roundhead galaxias, flathead galaxias, adult brown trout, and juvenile brown trout. Habitat suitability curves for shortfin eels, upland bully, redfin bully, and common bully were derived from data collected in 32 New Zealand rivers (Jowett & Richardson 1995). Longfin eel preference curves were taken from Jellyman et al. (in press), inanga habitat preferences are based on Jowett (2002) and roundhead and flathead galaxias curves are taken from Baker et al. (in press). There are no habitat suitability curves for alpine galaxias and lamprey. Koaro habitat was not evaluated in the Pomahaka River because the main stem was not considered to be typical of adult koaro habitat. Brown trout habitat suitability curves are based on Hayes & Jowett (1994) for adults, Shirvell & Dungey (1983) for spawning, and Raleigh et al. (1984) for brown trout yearlings and juveniles. Rainbow trout spawning criteria were taken from a study carried out in the Tongariro River (Jowett et al. 1996). All habitat suitability curves used are shown in Appendix I.

Jowett & Richardson (1995) suggested that flow recommendations be based on redfin bully and common bully habitat, because these fish represented a habitat guild with preferences that were intermediate between the fish that preferred slow, shallow water and those that preferred deeper, swift water.

2.5 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 would include both steep and narrow, and wide and shallow riffles. Pool cross-sections would be alternately located at heads, middles, and tails of pools.

2.6 Instream Habitat Survey and Analysis

Water velocities, depths, and substrate composition were recorded at an average spacing that varied with the size of the river, from 1.5 m in the Pomahaka River at Burkes Ford to 0.2 m spacing in the upper reach of Chatto Creek. 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 one or two 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, 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).

3. Results

3.1 Waianakarua River

The instream habitat survey was carried out at a flow of 0.28 m^3/s and calibration measurements for stage/discharge relationships at each cross-section were made at flows of 0.21 m^3/s and 0.13 m^3/s. At the survey flow of 0.28 m^3/s, the average river width was 13.1 m, the depth 0.23 m, and velocity 0.11 m/s. At the mean annual flow of 0.20 m^3/s, the average width, depth and velocity were 9.6 m, 0.18 m, and 0.11 m/s, respectively. The substrate comprised mainly cobble (27%), gravel (34%) and fine gravel (12%), with cobbles dominating riffles and gravel and fine gravel in runs and pools.

The amount of native fish habitat did not vary greatly with flow (Fig. 3.1). Maximum habitat for common bullies and redfin bullies was provided by a flow of 0.4 m^3/s, with habitat declining sharply as flows fell below 0.15 m^3/s. Maximum inanga habitat was provided by a flow of 0.15 m^3/s, although generally the river would not provide sufficient cover for inanga. Maximum habitat for bluegill bullies was provided by a flow of 0.8 m^3/s, and there was a gradual decline in the amount of bluegill habitat as flows reduced below 0.8 m^3/s.

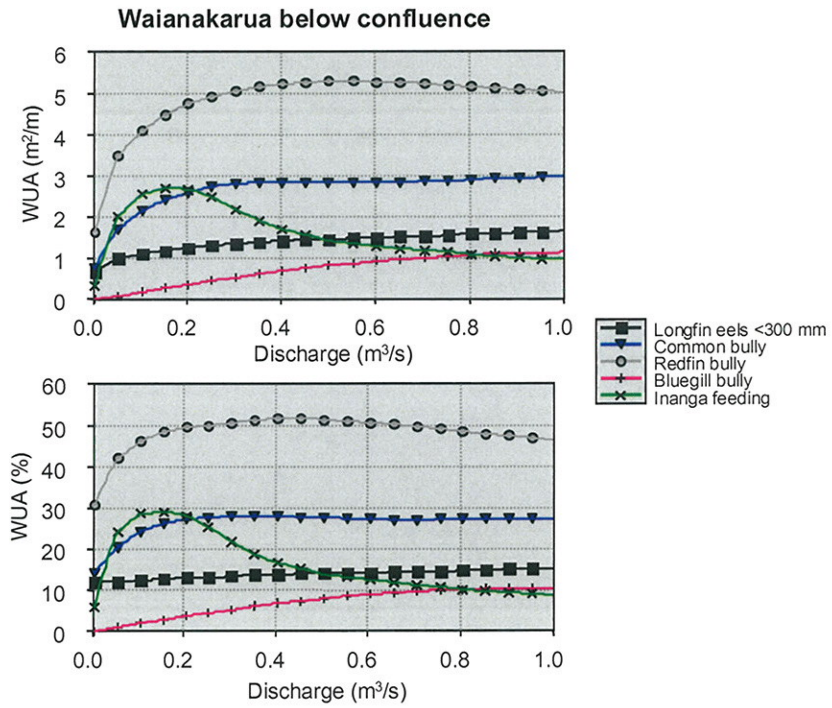

Figure 3.1: Variation of instream habitat with flow in the Waianakarua River as weighted usable area (WUA) expressed in area per unit length (above) and as the percentage of river width (below).

3.2 Chatto Creek

SH85

This reach was surveyed at a flow of 0.42 m^3/s when the average width was 4.7 m, depth 0.16 m and velocity 0.52 m/s. Calibration measurements for cross-section stage/discharge relationships were carried out at flows of 0.25 m^3/s and 0.045 m^3/s. The substrate comprised 61% gravel (8-64 mm) and 23% fine gravel (2-8 mm), with 3.5% of cobble and boulder substrate and the remainder fine substrate or vegetation. The estimated average width, depth, and velocity at the 7-day mean annual low flow of 0.10 m^3/s was 3.7 m, 0.11 m, and 0.26 m/s, respectively.

Maximum habitat for upland bullies and roundhead galaxias was provided by a flow of 0.10-0.125 m^3/s, with the amount of suitable habitat for these species reducing sharply as flows fell below 0.025 m^3/s (Fig. 3.2.1). The amount of suitable habitat for longfin eels increased with flow, with maximum habitat provided by flows greater than 0.50 m^3/s. There was little suitable habitat for juvenile trout in the reach and the amount of habitat was relatively constant at flows greater than about 0.050 m^3/s.

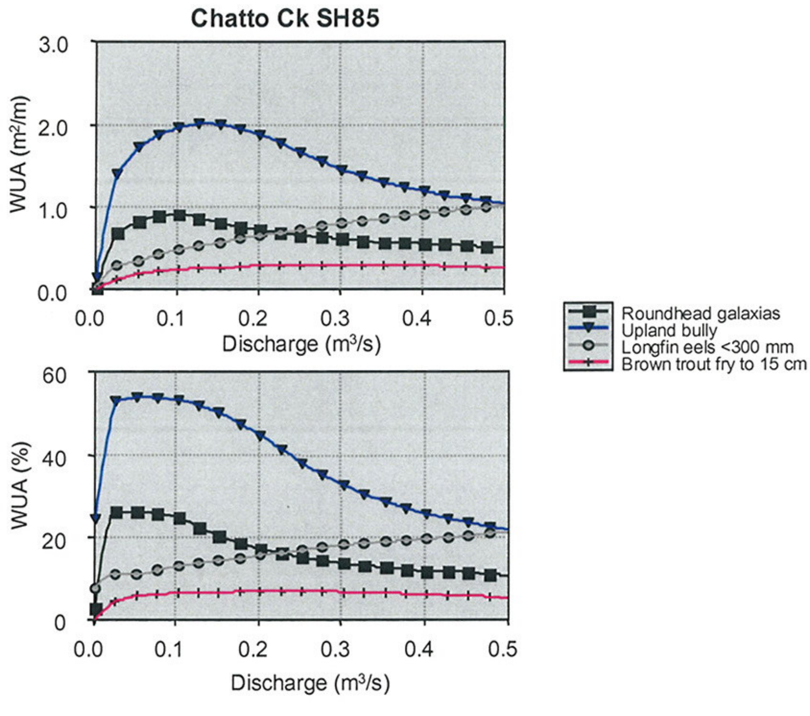

Figure 3.2.1: Variation of instream habitat with flow in the Chatto Creek at SH85 as weighted usable area (WUA) expressed in area per unit length (above) and as the percentage of river width (below).

Matakanui Stn

This reach was surveyed at a flow of 0.072 m^3/s and had an average width of 3.1 m, depth of 0.27 m and velocity of 0.11 m/s. A calibration measurement was carried out at a flow of 0.162 m^3/s. The substrate was fine, with 39% fine gravel (2-8 mm), 22% sand, and 12% gravel (8-64 mm). The remainder of the substrate was either silt or vegetation. The estimated average width, depth, and velocity at the estimated 7-day mean annual low flow of 0.10 m^3/s was 3.3 m, 0.30 m, and 0.13 m/s, respectively, indicating that depths in this reach were greater and water velocities were lower than in the SH85 reach.

Upland bullies and roundhead galaxias are the two native species most likely to be found in this section of stream, and the amount of suitable habitat for these species was a maximum at 0.03-0.04 m^3/s and began to decline sharply when flows fell below 0.025 m^3/s (Fig 3.2.2). Longfin eel habitat showed very little variation with flow. This reach provided better habitat for juvenile trout than the SH8 reach. Juvenile trout had higher flow requirements than native fish, with maximum habitat provided by a flow of 0.15 m^3/s and the amount of juvenile trout habitat declining sharply at flows less than 0.10 m^3/s.

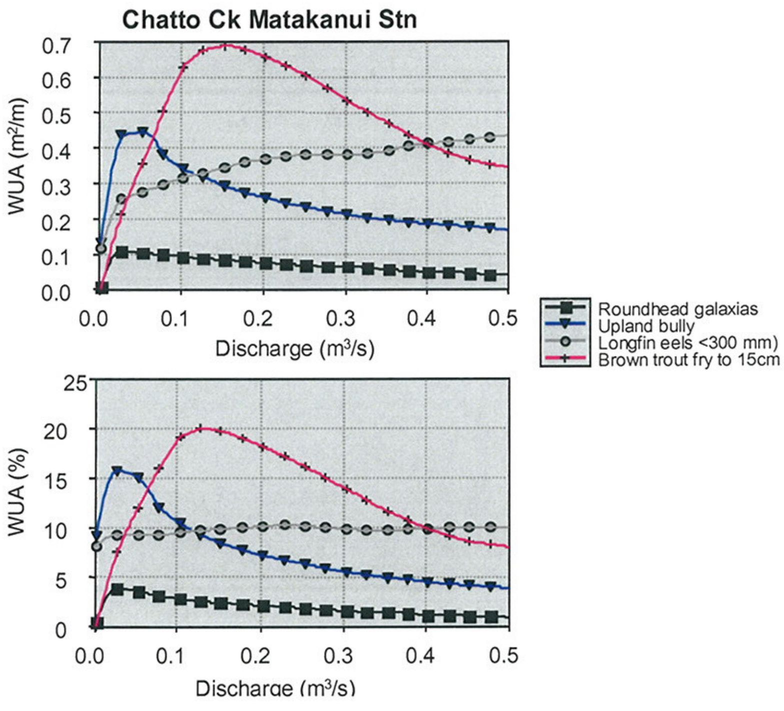

Figure 3.2.2: Variation of instream habitat with flow in the Chatto Creek at Matakanui Station as weighted usable area (WUA) expressed in area per unit length (above) and as the percentage of river width (below).

3.3 Manuherikia River below Ophir

The habitat survey of the Manuherikia River was carried out at a flow of 7.4 m^3/s, with calibration measurements at flows of 1.4 and 1 m^3/s. At the survey flow of 7.4 m^3/s, the average width of the river was 24 m, depth 0.40 m, and velocity 0.71 m/s. The substrate in riffles was mainly cobbles (64-256 mm), whereas gravel (8-64 mm) dominated runs. Overall, gravel was the dominant substrate (51%), with 16% cobble, and 26% fine gravel (2-8 mm).

The estimated average width, depth, and velocity at the 7-day mean annual low flow of 1.72 m^3/s was 15 m, 0.27 m, and 0.40 m/s, respectively.

This reach is a recognised brown trout fishery and maximum adult trout habitat was provided by a flow of 4.25 m^3/s, with the amount of suitable trout habitat falling sharply when flows fall below about 2.5 m^3/s (Fig. 3.3). Maximum juvenile trout habitat was provided by a flow of 1.25 m^3/s, whereas yearling trout had slightly higher flow requirements, with maximum habitat provided by a flow of 2 m^3/s. However, the amount of both yearling and juvenile habitat began to reduce sharply at a flow of 0.9 m^3/s. Maximum habitat for upland bullies and roundhead galaxias was provided by very low flows (0.25 m^3/s) but common bully habitat was greatest at a flow of 1.25 m^3/s, and began to fall sharply when flows fell below about 0.5 m^3/s.

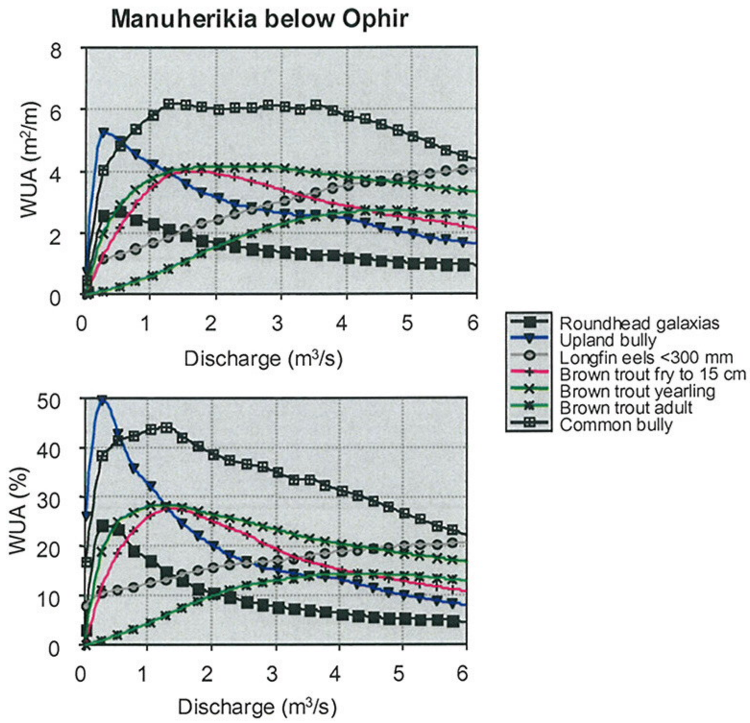

Figure 3.3: Variation of instream habitat with flow in the Manuherikia River below Ophir as weighted usable area (WUA) expressed in area per unit length (above) and as the percentage of river width (below).

3.4 Lindis River

The habitat survey of the lower reach, just upstream of the SH8 bridge, was carried out at a flow of 5.2 m^3/s, with a calibration measurement at 1.2 m^3/s. This reach was dry at the time of the second calibration measurement. The upper reach at Cluden Hill was surveyed at the same time, but the flow was slightly higher at 6 m^3/s, with calibration at flows of 1.8 m^3/s and 0.4 m^3/s. At the survey flows of 5.2-6 m^3/s, the average width of the river was 18.6 m, depth 0.37 m, and velocity 0.72 m/s. Boulder substrate (>256 mm) was common (65%) in the upper reach, with gravel and cobbles making up the remaining substrate. The lower reach contained finer substrate, made up of mainly cobbles (45%) and gravels (38%).

The estimated average width, depth, and velocity at the 7-day mean annual low flow of 1.58 m^3/s was 14 m, 0.24 m, and 0.43 m/s, respectively.

The Lindis River provides spawning for brown and rainbow trout from the Clutha River and Lake Dunstan. Maximum habitat for brown and rainbow trout spawning was provided by flows of 1.4 m^3/s and 2.2 m^3/s, respectively (Fig. 3.4.1). Maximum adult brown trout habitat was provided by a flow of 4 m^3/s, and the amount of suitable adult trout habitat began to fall sharply when flows fell below 2 m^3/s (Fig. 3.4.2). Maximum juvenile brown trout habitat was provided by a flow of 1.4 m^3/s, with a sharp reduction beginning when flows fell below 0.75 m^3/s. Flow requirements of native fish were lower than those of trout, with a flow of 0.4 m^3/s providing maximum habitat for upland bullies and flathead galaxias and a sharp reduction in suitable habitat as flows fell below 0.2 m^3/s.

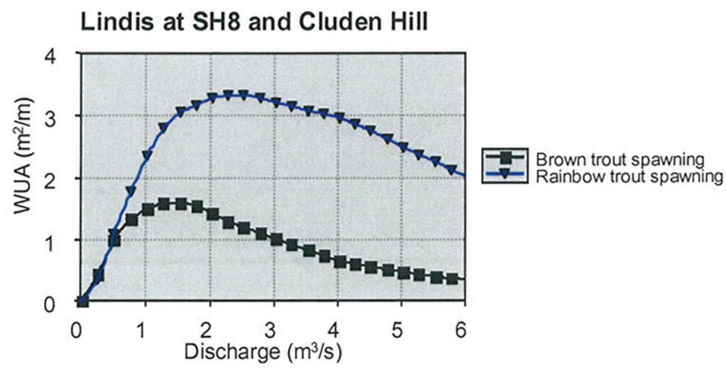

Figure 3.4.1: Variation of trout spawning habitat with flow in the Lindis River.

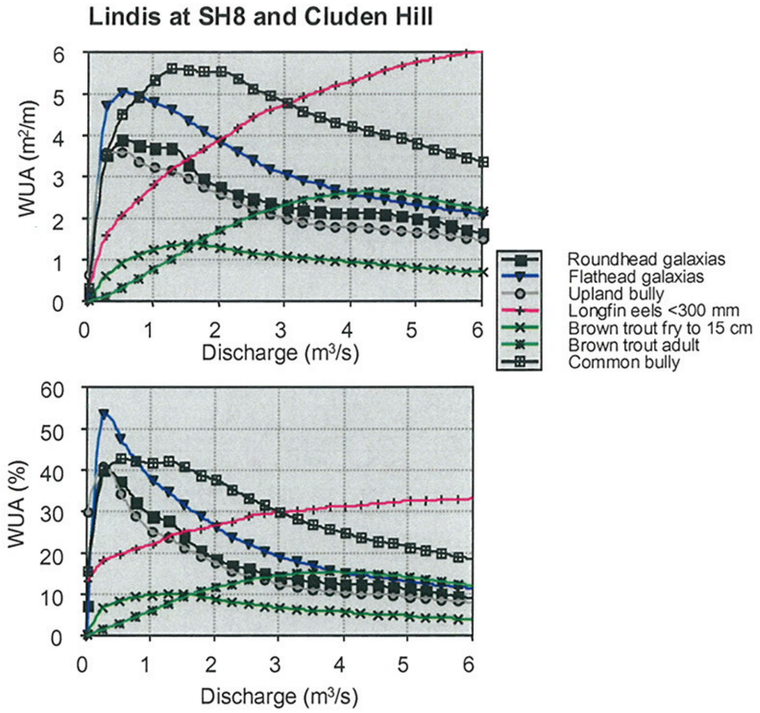

Figure 3.4.2: Variation of instream habitat with flow in the Lindis River as weighted usable area (WUA) expressed in area per unit length (above) and as the percentage of river width (below).

3.5 Pomahaka River

The Holt (Glenkenich)

The habitat surveys of this reach were carried out at a flow of 4.5 m^3/s, with calibration measurements at 11 m^3/s and 16 m^3/s and at a flow of 3.35 m^3/s, with calibration at 3.6 m^3/s and 4.6 m^3/s. At the survey flow of 3.35-4.5 m^3/s, the average width of the river was 23.8 m, depth 0.49 m, and velocity 0.37 m/s. Substrate assessments were similar, with 29-31% bedrock and the remaining substrate a mixture of cobbles, gravels and fine gravel.

The estimated average width, depth, and velocity at the 7-day mean annual low flow of 2.58 m^3/s was 22.3 m, 0.42 m, and 0.29 m/s, respectively.

Maximum habitat for adult brown trout was provided by a flow of 8 m^3/s, and the amount of suitable adult trout habitat began to fall sharply when flows fell below 4 m^3/s (Fig. 3.5.1). Maximum juvenile brown trout habitat was provided by a flow of 3.5 m^3/s, with a sharp reduction beginning when flows fell below 1.0 m^3/s. Flow requirements of native fish were lower than those of trout, with a flow of 1.5 m^3/s

providing maximum habitat for upland bullies and roundhead galaxias and a sharp reduction in suitable habitat as flows fell below 0.5 m^3/s.

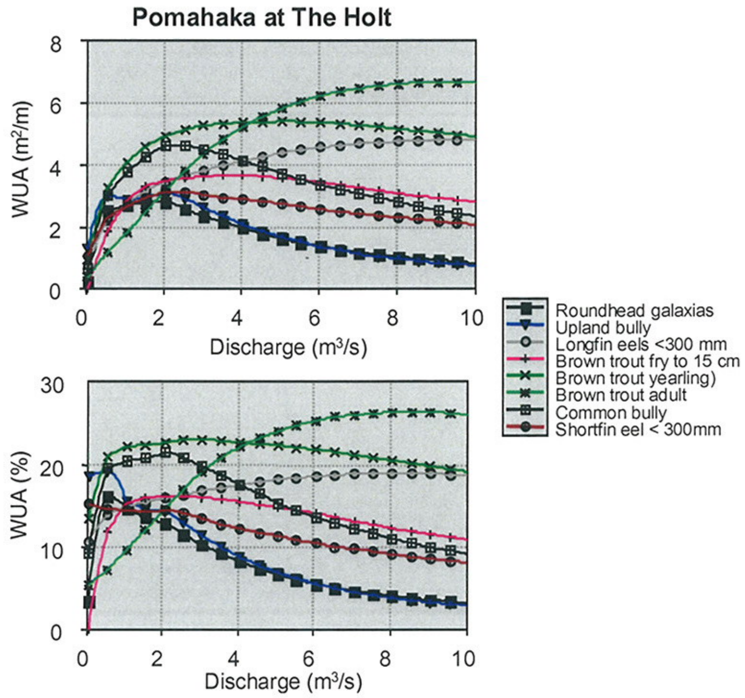

Figure 3.5.1: Variation of instream habitat with flow in the Pomahaka River at The Holt as weighted usable area (WUA) expressed in area per unit length (above) and as the percentage of river width (below).

Burkes Ford

The habitat surveys of this reach were carried out at a flow of 8.7 m^3/s, with calibration measurements at 12 m^3/s and 62 m^3/s. At the survey flow of 8.7 m^3/s, the average width of the river was 36.5 m, depth 1.06 m, and velocity 0.28 m/s. As at The Holt, substrate was dominated by bedrock (29%), with cobbles (25%) and gravels (19%) making up most of the remaining substrate.

The estimated average width, depth, and velocity at the 7-day mean annual low flow of 3.36 m^3/s was 34.1 m, 0.95 m, and 0.16 m/s, respectively.

Maximum habitat for adult brown trout was provided by a flow of 13 m^3/s, and the amount of suitable adult trout habitat began to fall sharply when flows fell below 7.5 m^3/s (Fig. 3.5.2). Maximum juvenile brown trout habitat was provided by a flow of 5 m^3/s, with a sharp reduction beginning when flows fell below 2.5 m^3/s. Yearling brown trout required slightly higher flows than juveniles, with maximum habitat at a flow of about 6 m^3/s, and a sharp reduction when flows fell below about 2.5 m^3/s. Flow requirements of native fish were lower than those of trout, with a flow of 2.5

m^3/s providing maximum habitat for upland bullies and roundhead galaxias and a sharp reduction in suitable habitat as flows fell below 1 m^3/s.

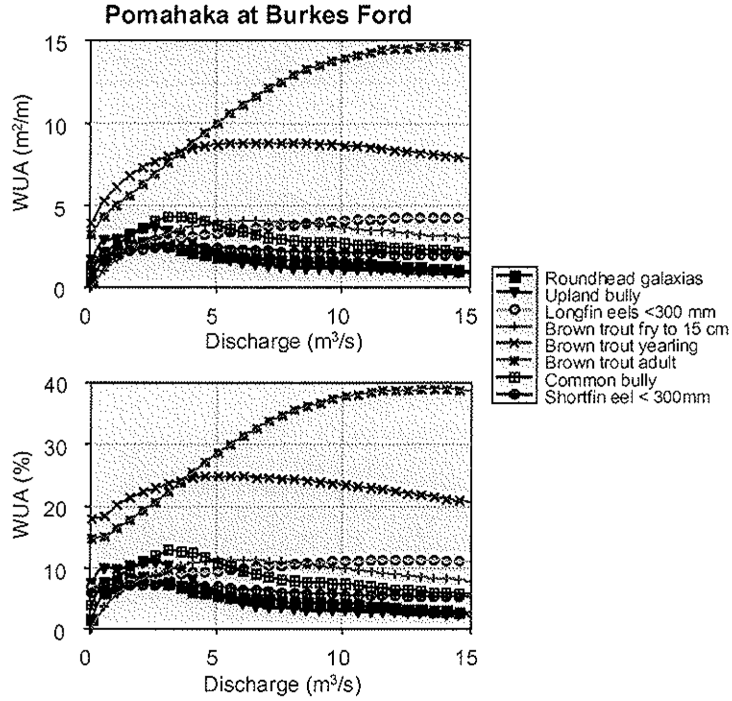

Figure 3.5.2: Variation of instream habitat with flow in the Pomahaka River at Burkes Ford as weighted usable area (WUA) expressed in area per unit length (above) and as the percentage of river width (below).

4. Minimum flow requirements

The differences in habitat preferences are reflected in the habitat-flow relationships. Maximum areas of habitat for upland bullies, non-diadromous galaxiids (roundhead and flathead) occur at lower flows than for adult or juvenile trout. Eels have broad depth and velocity preferences, so that habitat-flow curves either change little with flow or continue to increase with flow because the river area increases with flow. Common bully and redfin bully have intermediate habitat preferences, and flows that provide maximum habitat for these species are usually intermediate between maximum habitat flows for the low velocity species, such as upland bully, and species with high velocity preferences like adult trout and bluegill bullies.

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. For example, if inanga, the principal whitebait species, were considered the most desirable fish in the Waianakarua River, flows that maximise habitat for bluegill bullies would reduce habitat for inanga. Eels tend to be relatively flexible and can exist in a wide range of conditions. Flow recommendations are necessarily a compromise between species and are usually made to prevent a sharp decline in habitat for most species, and thus aim to retain the some habitat for all species that make up the fish community.

Flow requirements can be selected so that they provide maximum habitat (the optimum flow in Table 4.1) or can be selected so that they prevent a serious decline in fish habitat, the point of "inflection" or flow below which habitat declines sharply. The choice depends on the importance of the species and/or fishery. For example, the Pomahaka River is one of the most important brown trout fisheries in the Otago region and it is probably appropriate to set minimum flows so that they provide adult brown trout habitat. On the other hand, the brown trout fishery in the Waianakarua River is relatively poor and the river could be managed to sustain the diverse native fish community in its lower reaches.

Selection of minimum flows based on the flow below which habitat declines sharply is suggested as an appropriate criterion. This is supported by NIWA studies of the fish population in the Waipara River that showed that populations of upland bullies and a non-diadromous galaxiid, Canterbury galaxias, were robust with respect to low flows. Jowett (1994) recommended a minimum flow of 0.12 m^3/s for the Waipara River, basing his decision on the flow below which common bully habitat began to decline sharply. Subsequent studies of the fish population showed that upland bully populations were not affected when flows were less than 0.05 m^3/s for 47 days, although the numbers of Canterbury galaxias, torrentfish, and bluegill bullies reduced. However, when flows were below the recommended minimum for a short time (10 days), the only fish species affected detrimentally was torrentfish, with no reduction in the numbers of upland bullies, Canterbury galaxias, and bluegill bullies.

In making these decisions, the natural flow regime should be considered. For example, habitat for adult brown trout in the Manuherikia River begins to decline when the flow falls below 2.5 m^3/s. If this were applied as a minimum flow requirement, it would have little effect on the trout fishery, because the trout population would be constrained by the natural low flow which is less than 2.5 m^3/s most years.

Table 4.1: Suggested flow requirements for fish habitat in the study rivers.

Stream	Recorded 7-day mean annual low flow (m^3/s)	Target fish species	Optimum flow (m^3/s)	Flow (m^3/s) below which habitat declines sharply
Chatto Creek (SH85)	0.1	Upland bully, roundhead galaxias	0.125	0.025
		Juvenile brown trout	0.05	0.025
Chatto Creek (Matakanui Stn)	0.08	Upland bully, roundhead galaxias	0.04	0.025
		Juvenile brown trout	0.15	0.1
Manuherikia River below Ophir	1.72	Adult brown trout	4.25	2.5
		Yearling brown trout	2	0.9
		Juvenile brown trout	1.25	0.9
Lindis River	1.58	Upland bully, flathead galaxias, roundhead galaxias	0.4	0.2
		Rainbow trout spawning (winter)	2.2	
		Juvenile brown trout	1.4	0.75
Pomahaka River (Burkes Ford)	3.36	Adult brown trout	13	7.5
		Yearling brown trout	6	2.5
Pomahaka River (The Holt)	2.58	Adult brown trout	8	4
		Yearling brown trout	4	1.5
Waianakarua below north and south branch confluence	0.20	Redfin bully, common bully	0.4	0.15

5. Acknowledgments

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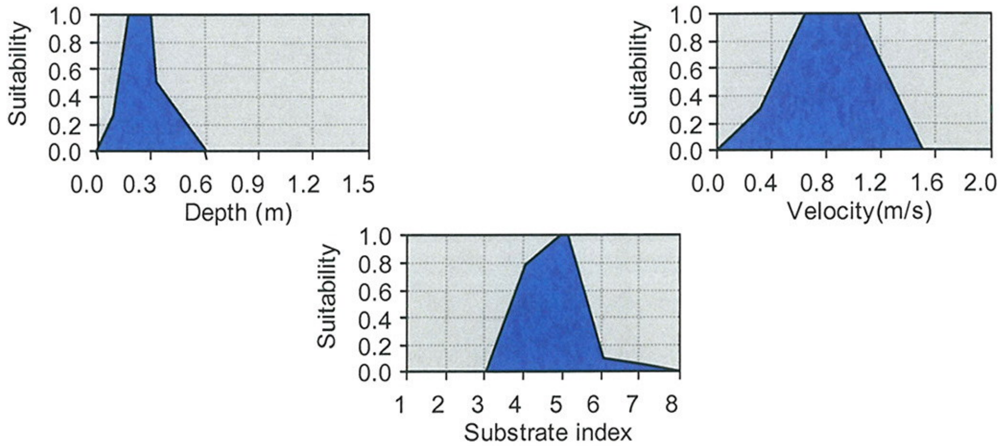
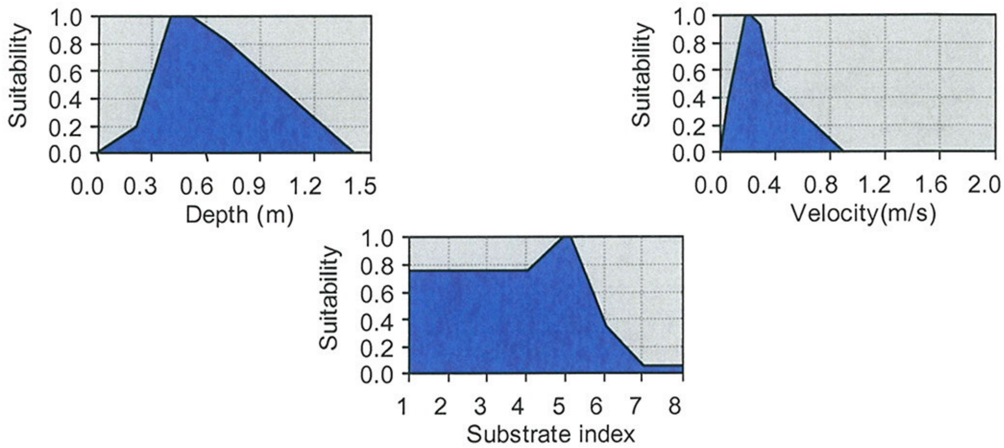
7. Appendix I

7.1 Habitat suitability curves used in this study

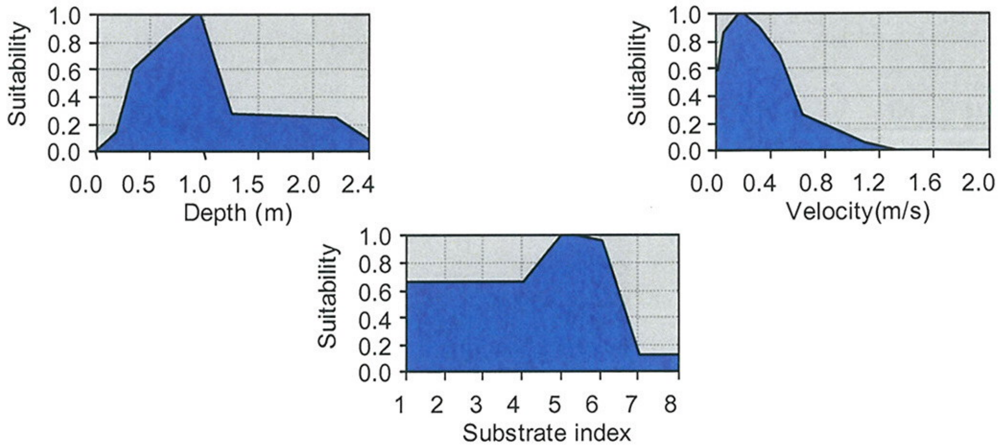
Bluegill bully



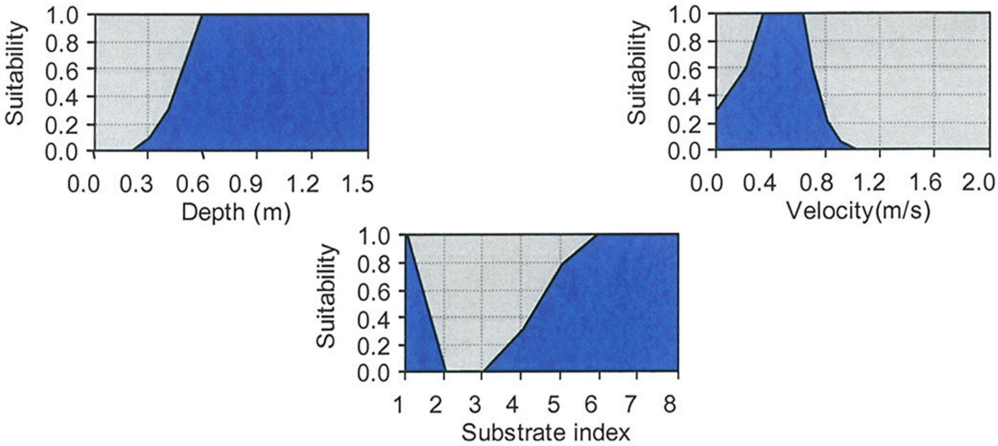
Brown trout fry to 15 cm



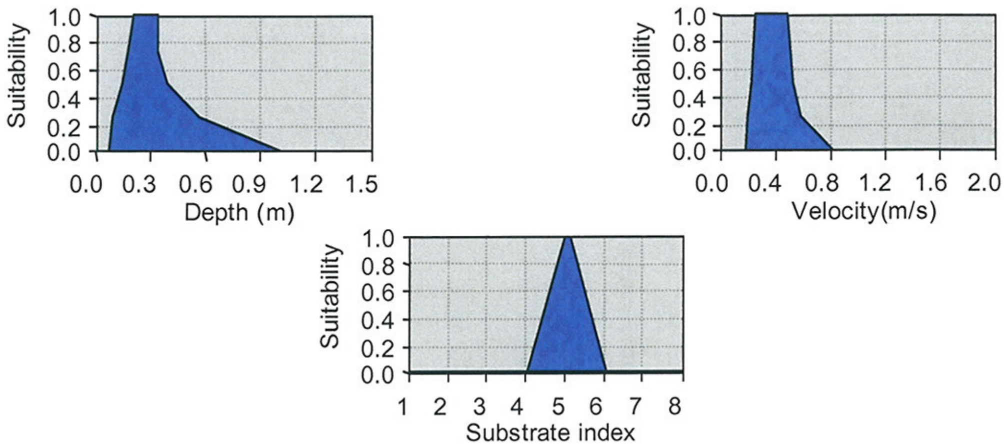
Brown trout yearling



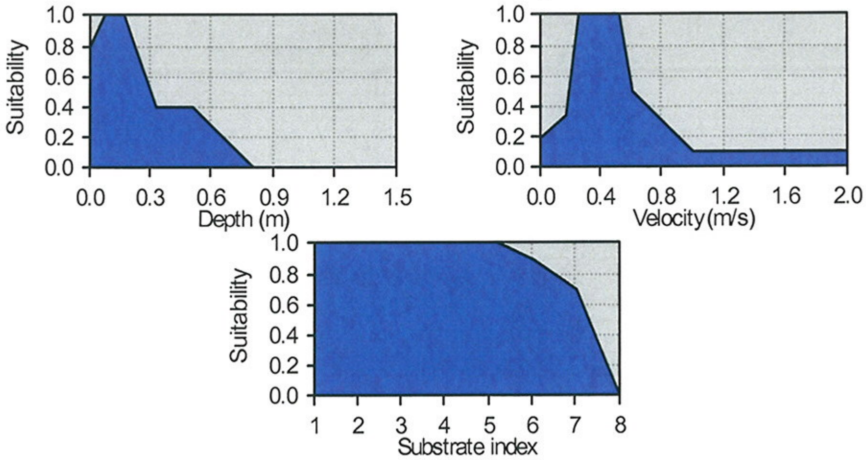
Brown trout adult



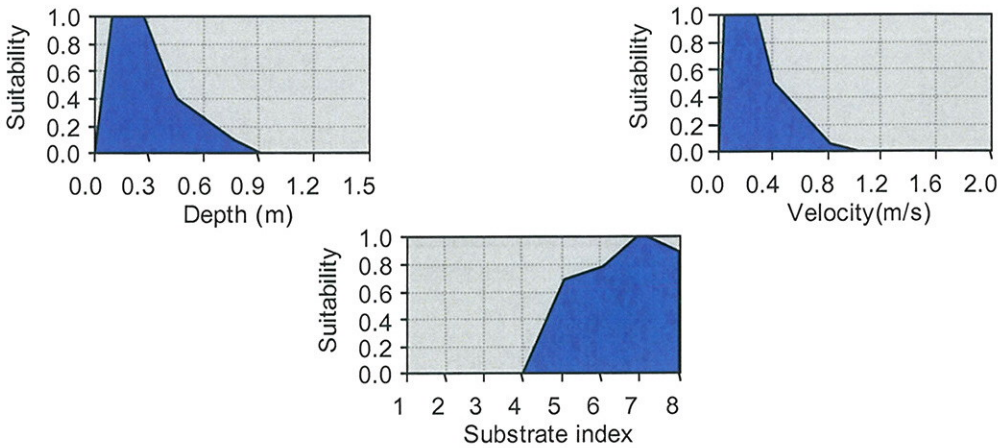
Brown trout spawning



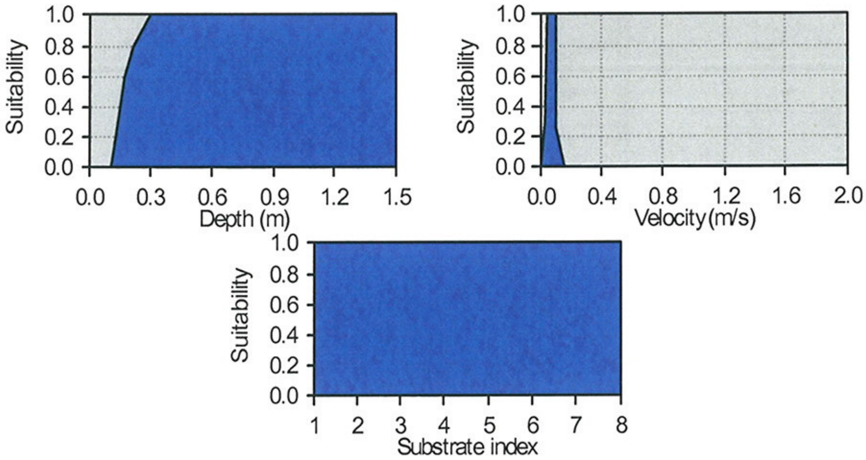
Common bully



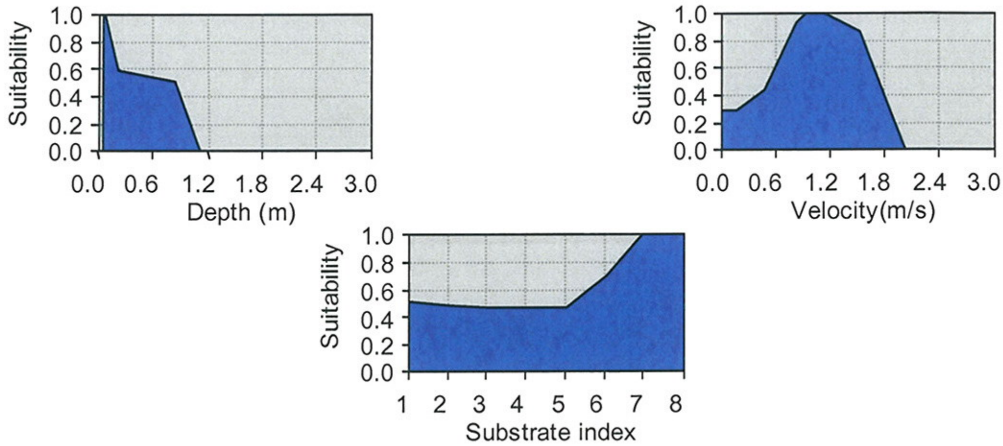
Flathead galaxias



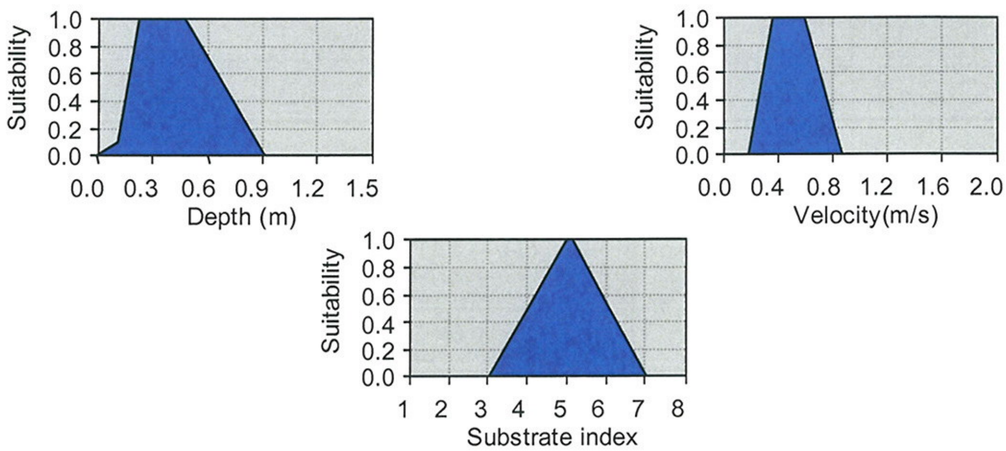
Inanga feeding habitat



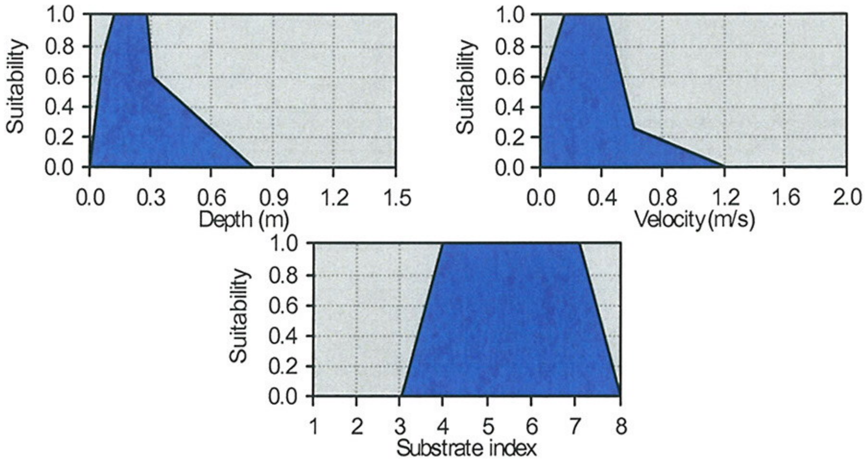
Longfin eels <300 mm



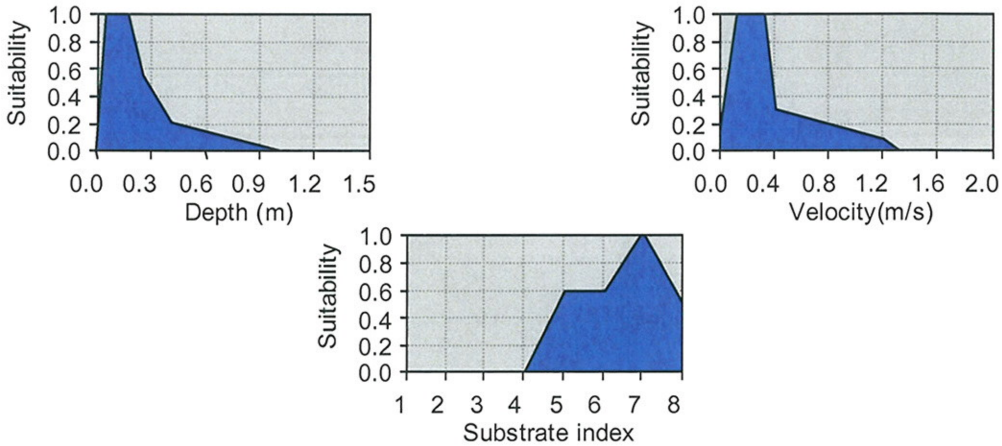
Rainbow trout spawning



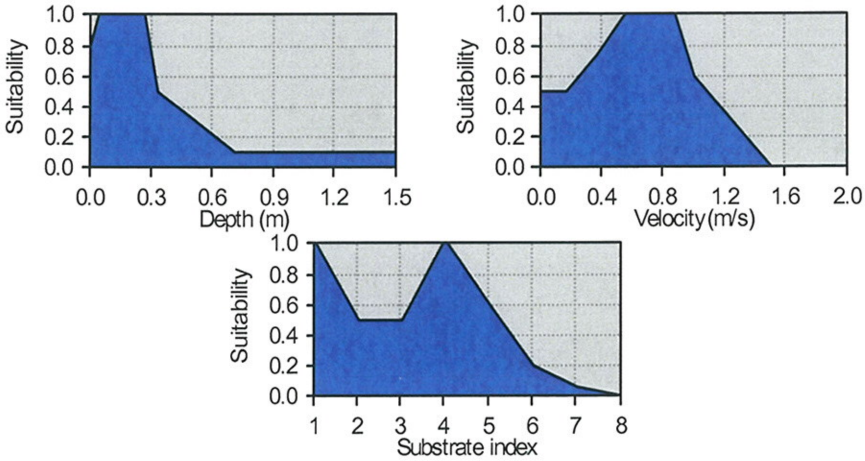
Redfin bully



Roundhead galaxias



Shortfin eel (<300 mm)



Upland bully