Instream Flow Assessment for the Lower Ruamahanga River

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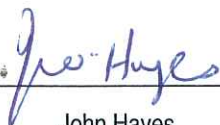
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Prepared for

greater WELLINGTON
REGIONAL COUNCIL

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EXECUTIVE SUMMARY

This report was commissioned by Greater Wellington Regional Council (GWRC), to address key information gaps identified in an instream flow issues report for the lower Ruamahanga River, prepared by GWRC. It outlines the results of habitat modelling, undertaken as part of an Instream Flow Incremental Methodology (IFIM) analysis for the Ruamahanga River, and makes recommendations on the minimum flows required to maintain instream values in two sections of the lower river. It also assesses the likely impact of implementing these minimum flows on passage for fish and recreational boating, and the likelihood of the proposed minimum flows resulting in an adverse effect on water temperature or dissolved oxygen in the lower reaches of the Ruamahanga River.

Habitat modelling was applied to assess instream flow requirements for two sections of the lower Ruamahanga River:

1. The highly sinuous part of the river between the Waiohine confluence and "Bentley's Beach", where the channel is less confined by stop-banks than it is further downstream, and large gravel/cobble beaches are common (represented by the Morrisons Bush reach),

2. The section between "Bentley's Beach" and Tuhitarata Bridge, where the channel is more confined by stop-banks, with gravel beaches occurring only infrequently down its length (represented by the Pahautea reach).

The suggested minimum flows were based on maintenance of adult brown trout feeding habitat. Brown trout were identified as a critical value because they support a highly valued fishery in the Ruamahanga River, attracting relatively high levels of angler use. The mainstem of the Ruamahanga River ranked second, in terms of angler days, among 58 water bodies in Fish & Game's Wellington Region, in the latest national angler survey, behind the Manawatu River and ahead of the Hutt River. Brown trout are also among the most flow-demanding freshwater fish in New Zealand rivers, and so providing adequate flow for them should also provide for the flow needs of other species.

The suggested minimum flows are intended to retain 90% of feeding habitat (WUA) for adult brown trout at the mean annual low flow (MALF) or at the flow at which habitat is optimal, whichever flow is least. The choice of habitat retention level is somewhat arbitrary and is based more on risk management than ecological science. The risk of ecological impact increases as habitat is reduced, and the greater the value of an instream resource, the less risk is likely to be considered acceptable by conservation stakeholders. The 90% habitat retention level suggested in this case is based on the assumption that a 10% reduction in habitat availability is unlikely to cause a detectable decline in fish populations.

The MALFs used in this report were 1-day MALFs based on naturalised flows (*i.e.* based on a flow record that had been corrected for existing abstraction), provided by GWRC.

Minimum flows to maintain 90% brown trout adult feeding habitat for the two river sections represented by the habitat modelling are:

- 8.5 m^3/s for the section between the Waiohine confluence and "Bentley's Beach"
- 7.5 m^3/s for the section between "Bentley's Beach" and Tuhitarata Bridge

Alternative minimum flows are also provided that could serve as a basis for negotiation among stakeholders on what is ultimately an acceptable minimum flow, taking into account the relative instream values and the value of out-of-stream water uses.

Maintenance of ecologically relevant flow variability should be considered when setting allocation limits in conjunction with these minimum flows to help control periphyton and sustain invertebrate productivity and fish feeding opportunities. This could be achieved using the method applied by Horizons Regional Council, perhaps adapted to include community consultation on the level of increase in the frequency and duration of occurrence of the minimum flow that is deemed acceptable.

Hydraulic modelling predictions indicate that the suggested minimum flows would not have a significant adverse effect on fish or boat passage. Although the model predicts that passage for native fish through the Morrisons Bush reach may be disrupted at the minimum flow, due to excessive water velocity, passage is still likely to be possible for many species, notwithstanding the modelling predictions, and any obstruction to passage would be temporary and probably relatively brief.

Continuous monitoring of dissolved oxygen and temperature over the summer of 2007 suggests that these water quality parameters are not directly influenced by the magnitude of low flow in the lower Ruamahanga. The duration of low flow did appear to influence the magnitude of diurnal DO fluctuations. However, control of the timing of flushing flood flows in this catchment is not in the hands of flow managers. Based on the data available it seems likely that implementing the suggested minimum flows would have no discernable effect on dissolved oxygen levels or water temperatures experienced in the lower Ruamahanga River.

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1.   INTRODUCTION

This report outlines the results of habitat modelling, undertaken as part of an Instream Flow Incremental Methodology (IFIM) analysis for the Ruamahanga River. The report was commissioned by Greater Wellington Regional Council (GWRC), to address the effect of low flows on hydraulic conditions for recreation and instream habitat, which were raised as key information gaps in an issues report for the Ruamahanga, prepared by GWRC (Watts & Perrie 2007). The issues report was prepared following consultation between GWRC, Fish & Game, Department of Conservation and Cawthron staff, during a field day in December 2006, and subsequent consultation with other interested groups.

This report provides recommendations on the minimum flows required to maintain instream fisheries values in two sections of the lower Ruamahanga River, based on modelling of flow-related changes in the availability of physical habitat, and assesses the likely effects of implementing these minimum flows on passage for fish and recreational boating. The likely effects of the proposed minimum flows on water temperature and dissolved oxygen in the lower reaches of the Ruamahanga River are also assessed.

2.   METHODS

Flow requirements for instream habitat in the Ruamahanga River were assessed by Instream Flow Incremental Methodology (IFIM) habitat modelling with the computer programme RHYHABSIM version 4.1 (developed by I. Jowett, NIWA).

2.1. Habitat modelling within the IFIM

The IFIM is a decision-support system (or framework), which provides a process for solving water allocation problems where there are concerns for maintaining instream habitat (Bovee *et al.* 1998). Within this process, computer modelling of instream habitat availability for selected species (or suitable depths and velocities for given aquatic activities), over a range of flows, provides a basis for decision making regarding allocation of water resources.

Habitat modelling within the IFIM entails measuring water depths and velocities, as well as substrate composition, across several representative stream cross-sections at a given flow (referred to as the survey flow). Points on the banks, above water level, along the cross-sections are also surveyed to allow model predictions to be made at flows higher than the survey flow. The stage (water level) at zero flow is also estimated at each cross-section to facilitate fitting of rating curves and for making model predictions at low flows. Other data for fitting rating curves are obtained from additional measurements of water level at each cross-section, relative to flow, on subsequent visits. These data allow calibration of a hydraulic

model for predicting how depths, velocities and the area of different substrate types covered by the stream will vary with discharge in the surveyed reach.

Modelled depths, velocities and substrate types can then be compared with habitat suitability criteria (HSC) describing the suitability of different depths, velocities and substrate sizes as habitat for given species of interest. These criteria take the form of habitat suitability curves, which have been developed by observing the depths and velocities used by various species, both in New Zealand and overseas. Comparison of the HSC with the modelled physical characteristics of the study stream provides a prediction of the availability of habitat in the stream. Habitat modelling is undertaken over a range of flows to predict how habitat availability will change with flow.

The modelled depths and velocities can also be used to assess how suitable conditions for water-based activities change with flow. For example, changes in water depth on shallow riffle sections can be assessed to see what flow is required to maintain adequate passage depth for recreational boating.

2.2. Weighted Usable Area - the currency of flow decision making

Modelled habitat availability is expressed as an index called Weighted Usable Area (WUA), which is calculated as the sum of the area weighted products of the combined habitat suitability scores (*i.e.* depth x velocity x substrate suitabilities) for the measurement points on the cross-sections. Traditionally WUA has often been expressed as an area per linear metre of river reach (m^2/m). However, WUA is actually a dimensionless index providing an indication of the relative quantity and quality of available habitat predicted at a given flow. Predicted changes in habitat quantity and habitat quality are integrated in WUA.

Traditionally there has also been an alternative expression of WUA as a percentage. This was intended to provide an indication of the quality of predicted habitat (I. Jowett, NIWA, pers. comm.). However, it has frequently been interpreted as another quantitative metric, indicating the percentage of the reach that will provide suitable habitat at a given flow. This metric has been changed in the latest versions of RHYHABSIM (Version 3.31 and above) to a Habitat Suitability Index (HSI, ranging between 0 and 1) in an attempt to reduce confusion around interpretation. This metric is the average combined habitat suitability score taken over the modelled reach and is intended to provide an indication of the relative quality of the predicted available habitat (I. Jowett, NIWA, pers. comm.).

It is important to realise that these metrics provide only a relative measure of how predicted habitat changes with flow. Therefore, when interpreting the WUA x flow or HSI x flow curves that are the output of modelling, it is the shape of the curves (*e.g.* the flows at which the optimum WUA and major changes in slope occur) that are of interest, rather than the magnitude (or height) of the WUA x flow curves (although the magnitude of HSI is more directly comparable between rivers). These outputs provide an indication of how habitat availability is predicted to change with flow. WUA serves as a currency which stakeholders

can use for interpreting effects of flow change on instream habitat and for negotiating flow decisions.

All of the predicted habitat x flow figures referred to in this report show the WUA metric. However, graphs of Habitat Suitability Index (HSI; the equivalent of WUA% in earlier versions of RHYHABSIM) versus flow are attached for completeness (Appendix 2). The HSI x flow curves are generally similar in shape to the WUA x flow curves, although the former often peak at lower flows. Flow decisions based on the WUA x flow curves are therefore likely to be more conservative.

2.3. Reach selection for IFIM habitat modelling

There are two approaches that can be followed when selecting locations for the cross-sections, which form the basis of the field survey component of habitat modelling; habitat mapping or the representative reach (Jowett 2004). In the habitat mapping approach the proportion of each habitat type (*e.g.* run, riffle, pool) comprising a relatively long reach of the stream is mapped and each cross-section is given a percentage weighting based on the proportion of the habitat in the reach that it represents. The predictions of subsequent modelling then relate to the reach that was mapped.

In the representative reach approach a relatively short (typically 50-150 m over at least one riffle – run – pool sequence) reach of river is selected that is thought to be representative of a longer section of river (Jowett 2004). The cross-sections are closely spaced (at a scale of metres) at longitudinal points of habitat change along the reach, with note being taken of the distance between cross-sections, and water levels on all cross-sections being surveyed to a common datum. The subsequent modelling predictions are then assumed to be applicable to the section of river that the chosen reach represents.

Whichever of these approaches is employed, the underlying assumption is that the cross-sections measured provide a reasonable representation of the variability in habitat throughout the reach of interest.

The number of cross-sections required depends on the morphological variability within the river. Studies have shown that relatively few cross-sections can reproduce the shape of the WUA – flow relationship obtained from a survey with a large number of cross-sections:

- Milhous (1990) visually compared results from sub-samples of four transects (one per sampling unit) selected from a set of 24 transects and, with some minor reservations, concluded that "the shape of the relationships are similar…" and the "number of cross sections can be relatively small…".

- In a study of 86 study sites on 58 Wisconsin streams, Simonson *et al.* (1994) found that 20 transects gave means accurate to within 5% of the true mean 95% of the time. With 13 transects, 85% of the means were within 5% of the true means.

- Bovee (1997) concluded that pocket water, a complex habitat type containing a wide variety of depths and velocities, can be accurately described with three to five transects.
- Payne *et al.* (2004) sub-sampled several very large data sets to determine how many cross-sections were required to produce a robust WUA function, and found that 18-20 cross-sections gave results nearly identical to results for 40-80 cross-sections per reach and only a few cross-sections were required to reproduce the general shape of the relationship.

The total number of cross-sections needed to generate a robust result should be proportional to the complexity of the habitat hydraulics: 6-10 for simple reaches and 18-20 for diverse reaches.

2.4.   Field data collection

The habitat mapping approach was applied in the Ruamahanga River. The surveyed reaches were selected to represent the habitat availability in two of the three reaches defined in Watts & Perrie's (2007) issues report (Figure 1). The sections addressed were:

1.   The highly sinuous part of the river between the Waiohine confluence and "Bentley's Beach" (Figure 1), where the channel is less confined by stop-banks than it is further downstream, and large gravel/cobble beaches are common (represented by the Morrisons Bush reach),

2.   The section between "Bentley's Beach" and Tuhitarata Bridge, where the channel is more confined by stop-banks, with gravel beaches occurring only infrequently down its length (represented by the Pahautea reach).

The highly channelised and straightened section of the river, downstream of the Pahautea section, was not considered in the habitat analysis because it was agreed during the field day in December 2006 that it was likely to provide only poor quality instream habitat, regardless of flow, and was probably only of value as a migratory link to the sea. Water depth and velocity in this highly channelised section of the river are likely to be relatively insensitive to changes in flow (because the channel is deep and steep sided). Consequently, it is likely that only a very large reduction in the minimum flow would have any adverse effect on fish or boat passage.

The habitat mapping and cross-section selection were carried out by the author and GWRC staff on 18-19 April 2007. A 3 km long reach was mapped in the Morrisons Bush reach and approximately a 5 km reach in the Pahautea reach. Six meso-habitat types were identified within the Morrisons Bush reach (Table 1), while the Pahautea reach was essentially continuous run, with the only distinction being between slow/deep and fast/shallower run habitat (Table 1).

Within each habitat type, cross-sections were positioned in an attempt to encompass the full range of variability represented in each of these habitat types. In particular, one cross-section

was placed in the shallowest, fastest habitat observed in each reach, since this is where any potential fish or boat passage barrier would be expected to occur.

All subsequent field work was completed by GWRC staff over the following three weeks, with the main cross-section habitat surveys undertaken on 23 and 24 April 2007. The flow at the time of the habitat surveys was gauged at 10.28 m^3/s in the Morrisons Bush reach and 10.54 m^3/s in the Pahautea reach.

Stage – discharge relationships for each cross-section were developed based on two to four measurements in addition to the gauging and cross-section water level measurements at the survey flow. The calibration water level measurements were collected at a range of flows between 9.22 m^3/s and 19.55 m^3/s flow range in the Morrisons Bush reach, and between 14.01 m^3/s to 21.46 m^3/s in the Pahautea reach.

Within RHYHABSIM, the default calibration flow for modelling is the average of the flows gauged at all the cross-sections during the survey of depths and velocities. However, this can be unduly affected by outlier estimates from cross-sections on which accurate gauging is difficult (*e.g.* those located in turbulent riffles or deep pools). For this reason the calibration flow was specified based on the best available estimate of flow in the reach at the time of the survey.
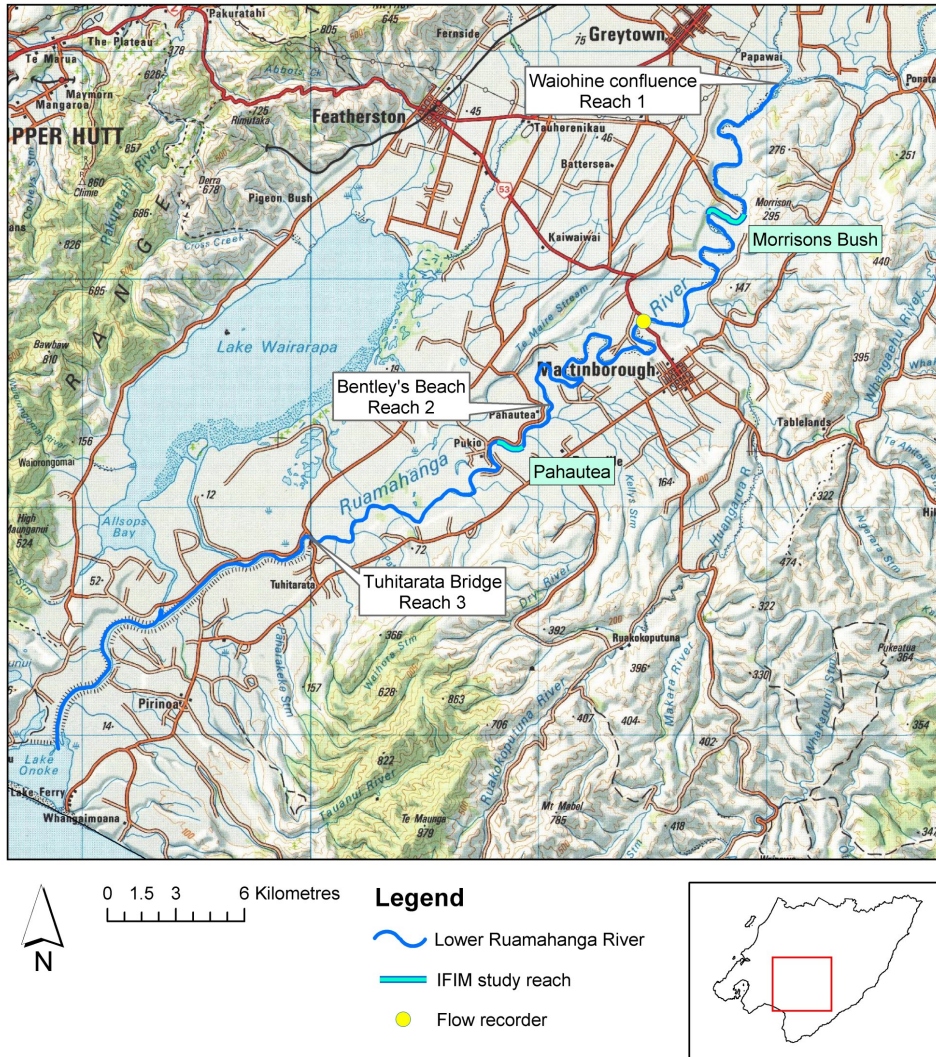
Figure 1. The lower section of the Ruamahanga River, showing the reaches on which the IFIM habitat analyses were based, and the location of the flow recorder from which the flow statistics used in these analyses were derived (Figure provided by GWRC).

Table 1.   Summary of habitat mapping and cross-section allocation in the Ruamahanga IFIM reaches.

Reach	Habitat type	Percentage of total length (%)	Number of cross-sections	Weighting per cross-section (%)
Morrisons Bush	Riffle	5	1	5
	Fast Deep Run	7	2	3.5
	Slow Deep Run	41	6	6.8
	Fast Shallow Run	18	4	4.5
	Slow Shallow Run	16	3	5.3
	Pool	13	3	4.3
	Total	100	19	
Pahautea	Deep Run	80	8	10
	Fast Shallow Run	20	4	5
	Total	100	12	

2.5. Data checking

The data sets provided by GWRC were imported into RHYHABSIM and checked to ensure that they met expectations of data quality. Aside from the standard checks performed within the programme's built in data checking function;

- Cross-sections were plotted and visually checked for any obvious anomalies (*i.e.* unrealistic depth and velocity spikes).

- Rating curves were checked to see that they exhibited a good fit to the expected power curve relationship, and that the different types of rating curves calculated in RHYHABSIM did not substantially differ from one another. Wherever possible, rating curves that had exponents falling in the recommended range, 1.5–3.5 (Jowett 2004), were used in subsequent modelling.

- The Velocity Distribution Factors (VDFs) were edited so that points falling above the water surface at the survey flow were given reasonable VDF values (*i.e.* vary around a value of one, and generally decrease with distance toward the banks (Jowett 2004); the default is that they are given the same value as the closest point which was below water level at the survey flow). This consideration is important when modelling flows above the survey flow.

In general the data sets for both reaches appeared to meet most data quality expectations. Aside from a few data entry errors, which were corrected when found, there were four other minor issues with the data sets:

1. One water level calibration measurement from each of two shallow fast run cross-sections and two from a riffle cross-section in the Morrisons Bush reach were excluded from the rating development, due to anomalous water level measurements, as was one measurement from a deep run in the Pahautea reach.

2.   The estimated stage at zero flow for one cross-section, in a slow shallow run in the Morrisons Bush reach, was lower than the minimum bed level on the cross-section. The stage at zero flow was changed to the section minimum for this cross-section.

3.   The best available rating curves for seven of the cross-sections had exponents falling outside the recommended range. However, the rating curves fitted the observed water level data reasonably well.

4.   The recorded percentage cover of different substrate types at a few points did not sum to 100%. In these instances reasonable proportions of each substrate type were interpolated based on adjacent data points such that they summed to 100%.

Discharge was assumed to be constant between cross-sections for all of my modelling predictions (*i.e.* there was assumed to be no significant inflow *e.g.* from tributaries or groundwater, and no significant losses *e.g.* to groundwater or abstraction, over the length of the modelled reach).

2.6. Habitat modelling

2.6.1. *Habitat Suitability Criteria*

The selection of species to include in habitat modelling was based on the species recorded from the Ruamahanga Catchment in the New Zealand Freshwater Fish Database (NZFFD 2007). On 10 December 2007 the NZFFD contained records of 30 species of fish from the catchment (including seven exotic species) and one species of crustacean (Table 2). However, one of the native fish, grayling, is now considered to be extinct, with the last and only record from the catchment in the database being in 1922. Another species, shortjaw kokopu, has not been recorded from the catchment since 1973 and was only recorded once from a small tributary stream near Lake Onake, and adults are not generally recorded from mainstems of rivers as large as the Ruamahunga. Three other species are largely restricted to the estuarine lower reaches of the catchment near Lake Onoke (Table 2).

Table 2. Fish species recorded from the Ruamahanga Catchment in the New Zealand Freshwater Fisheries Database. Database accessed on 10 December 2007.

	Common name	Scientific name	Number of records	Habitat modelled
Native fish	Longfin eel	*Anguilla dieffenbachii*	147	Habitat for two size classes modelled
	Shortfin eel	*Anguilla australis*	99	Habitat for one size class modelled
	Common bully	*Gobiomorphus cotidianus*	69	Habitat modelled
	Upland bully	*Gobiomorphus breviceps*	57	Habitat modelled
	Brown mudfish	*Neochanna apoda*	48	Excluded - Main channel in this area unlikely to provide suitable habitat and no HSC available
	Torrentfish	*Cheimarrichthys fosteri*	41	Habitat modelled
	Redfin bully	*Gobiomorphus huttoni*	28	Habitat modelled
	Inanga	*Galaxias maculatus*	22	Feeding habitat modelled
	Crans bully	*Gobiomorphus basalis*	16	Habitat modelled
	Giant kokopu	*Galaxias argenteus*	15	Excluded - No HSC available
	Common smelt	*Retropinna retropinna*	13	Habitat modelled
	Lamprey	*Geotria australis*	11	Juvenile habitat modelled
	Koaro	*Galaxias brevipinnis*	10	Excluded - Main channel in this area unlikely to provide suitable habitat, due to lack of forest cover
	Banded kokopu	*Galaxias fasciatus*	8	Excluded - Main channel in this area unlikely to provide suitable habitat, due to lack of forest cover
	Dwarf galaxias	*Galaxias divergens*	6	Habitat modelled
	Bluegill bully	*Gobiomorphus hubbsi*	4	Habitat modelled
	Shortjaw kokopu	*Galaxias postvectis*	1	Excluded - Main channel in this area unlikely to provide suitable habitat, due to lack of forest cover (recorded only once from a subcatchment of Lake Onake in 1973)
	Giant bully	*Gobiomorphus gobioides*	1	Excluded - No HSC available
	Grayling	*Prototroctes oxyrhynchus*	1	Excluded - Extinct
	Black flounder	*Rhombosolea retiaria*	2	Excluded - No HSC available
Estuarine fish	Estuarine triplefin	*Grahamina sp.*	2	Excluded - Main channel in this area unlikely to provide suitable habitat and no HSC available
	Yelloweyed mullet	*Aldrichetta forsteri*	2	Excluded - Main channel in this area unlikely to provide suitable habitat and no HSC available
	Grey mullet	*Mugil cephalus*	1	Excluded - Main channel in this area unlikely to provide suitable habitat and no HSC available
Exotic fish	Brown trout	*Salmo trutta*	87	Adult and yearling habitat modelled
	Perch	*Perca fluviatilis*	15	Excluded - No HSC available
	Rudd	*Scardinius erythrophthalmus*	11	Excluded - Pest fish and no HSC available
	Rainbow trout	*Oncorhynchus mykiss*	9	Excluded - Main channel in this area unlikely to provide suitable habitat (recorded from around the Tauweru River confluence and further upstream in this catchment only)
	Goldfish	*Carassius auratus*	5	Excluded - No HSC available
	Tench	*Tinca tinca*	4	Excluded - No HSC available
	Chinook salmon	*Oncorhynchus tshawytscha*	1	Excluded - Only one stray fish recorded from Lake Onake
Crustacea	Koura	*Paranephrops planifrons*	118	Excluded - No HSC available

As pointed out by Watts & Perrie (2007) in their issues report, fish data for the lower section of the Ruamahanga mainstem are sparse, with the vast majority of the records in the NZFFD being from higher in the catchment. There are only three records in the database from the river sections represented by the Morrisons Bush and Pahautea reaches combined, with four species recorded (torrentfish, bluegill bully, giant kokopu and lamprey). However, this is not to say that these are the only species that occur in these reaches, and a targeted fish survey would undoubtedly record more than these four species (*e.g.* these reaches are known to support brown trout angling, and during the habitat mapping loose shoals of small fish, likely to have been inanga and/or smelt were observed in the shallow margins of the Pahautea reach, J Hay, pers. obs.).

Predicted changes in physical habitat with flow were modelled for all of those species from Table 2, which I considered likely to occur in the mainstem of the Ruamahanga in the modelled reaches, and for which habitat suitability criteria (HSC) were available. Appendix 1 provides graphical representations of the suitability criteria applied, and their sources.

IFIM habitat modelling predictions are most sensitive to the habitat suitability criteria applied (Jowett 2004). Therefore, the HSC chosen for a study must be appropriate for the species which are known to (or are likely to) occur in the study river. When several different sets of HSC are available for a given species (as is the case with brown trout) the suitability criteria should be selected to best represent the habitat needed to maintain a population of the species of interest. Consideration must also be given to the transferability of HSC developed on other rivers to the study river. It seems reasonable to expect that HSC developed on rivers with similar physical characteristics to the study river should be more readily applicable, than HSC developed on physically different rivers.

Hayes & Jowett's (1994) suitability criteria have been used most widely in New Zealand for modelling adult drift-feeding brown trout habitat since their development. These HSC were developed based on observations of habitat preferences of large (45–65 cm) actively feeding brown trout on moderate-sized rivers (upper Mataura, Travers, upper Mohaka) over the flow range 2.8–4.6 m^3/s. This flow range is lower than generally experienced during periods of low flow in the Ruamahanga River in the sections of interest (Naturalised 1day-MALF 10.7 m^3/s in the Morrisons Bush reach, and 11.8 m^3/s in the Pahautea reach, based on period of record 1976-2006 at the Waihenga Bridge flow recorder site (Flow statistics provided by GWRC)). The channel gradient in the river sections where the Morrisons Bush and Pahautea surveyed reaches were located is lower than the gradients of Hayes & Jowett's (1994) study rivers (approximately 0.00077 m/m in the Morrisons Bush reach, and 0.00036 m/m in the Pahautea reach *c.f.* 0.0016-0.0074 m/m in Hayes & Jowett's study rivers). However, there are no suitability criteria available for brown trout from a river with a more similar gradient.

Bovee's (1995) criteria for adult and for juvenile brown trout were developed from observations over a more comparable flow range (7-18 m^3/s) to those in the low flow range (*i.e.* the range of interest in minimum flow setting) experienced in the lower Ruamahanga. However, the South Platte River (Colorado, United States of America), where these

observations were made, is also steeper than the Ruamahanga (0.0058 m/m). Bovee's (1995) habitat suitability criteria are based on unpublished data sourced from Ken Bovee, one of the original developers of the IFIM. The study site and methods used to gather these data are described in Thomas & Bovee (1993), which also presents rainbow trout habitat suitability data. Bovee's (1995) criteria were originally provided without substrate suitability criteria. Rather than adding substrate suitability criteria from another source, these criteria were applied here without substrate suitability criteria. Setting the index of substrate suitability to a uniform value of 1 effectively removes substrate from the calculation of WUA, since weighted usable area (WUA) is calculated as the area weighted product of the three habitat suitability criteria (depth, velocity and substrate).

The HSC for juvenile brown trout (15-25 cm) developed by Raleigh *et al.* (1986) have been used extensively in New Zealand IFIM habitat modelling applications in the past, although they may underestimate flow requirements due to the inclusion of resting fish observations in the development of the criteria, which tends to give them a bias toward slower water habitat (a common problem in older habitat suitability criteria; Hayes 2004). For this reason the criteria developed by Bovee (1995) and Hayes & Jowett (1994) may provide a more conservative estimate of habitat availability, since they were based solely on observations of actively feeding fish. As with Hayes & Jowett's (1994) criteria, those developed by Raleigh *et al.* (1986) were based on observations over a lower flow range (1.1-7.8 m^3/s), but a higher river gradient than the pertinent sections of the Ruamahanga.

Raleigh *et al.* (1986) also provided HSC for adult brown trout. These criteria also have an apparent low velocity bias, as with the juvenile HSC, and have not been in common use in New Zealand since the development of Hayes & Jowett's (1994) HSC. Furthermore, these HSC are no longer used in Colorado, where they were developed, because they were found to produce unreliable predictions of trout habitat (K. Bovee, pers. comm.). However, they were applied here for comparison. These criteria were also developed over a lower flow range, but higher river gradient than the pertinent sections of the Ruamahanga.

Trout spawning and fry rearing habitat requirements were not modelled, under the assumption that little spawning probably takes place in the mainstem Ruamahanga in its mid-lower reaches, with the majority of spawning activity probably occurring in tributaries or further upstream above the modelled reach. Moreover, flow requirements for adult drift-feeding trout are greater than for spawning, or fry rearing.

Given that there is some uncertainty regarding the applicability of the HSC available for trout, the different WUA curves predicted using various HSC may be best interpreted as providing an indication of the range of possible responses of habitat to flow changes. That said, it seems reasonable that suitability criteria should be selected to best represent the habitat needed to maintain a population of the species of interest. Trout populations cannot be expected to be maintained without sufficient feeding habitat, and consequently Hayes & Jowett's (1994) and Bovee's (1995) criteria might be expected to provide a better estimate of habitat requirements for population maintenance than criteria that are biased toward low flow velocities, by the

inclusion of resting trout positions in their development (*e.g.* Raleigh *et al.* 1986). However, drift feeding HSC (*e.g.* Hayes & Jowett 1994; Bovee 1995) may overestimate the flow requirements of trout in slow sinuous channels, where trout would tend to rely more heavily on benthic foraging and piscivory than in higher gradient reaches upstream (where trout rely more on drift feeding). Also, suitability criteria developed on markedly different-sized rivers are less likely to be transferable. For comparison, a range of trout habitat suitability criteria were applied in this report (Appendix 1). Conservative flow decisions could safely be made based on the curves predicting highest optimum flow requirements, bearing in mind the size of stream on which the HSC were developed.

The HSC applied for native fish species were mainly based on the work of Jowett & Richardson (1995 and/or subsequent work) (Appendix 1), with the exception of the HSC for longfin eels which were developed based on the work of D. Jellyman and co-workers (Jellyman *et al.* 2003), the HSC for inanga feeding which were developed by Jowett (2002), and the HSC for juvenile lamprey which were developed based on the work of G. Glova and D. Jellyman's (Glova & Jellyman 2001; Jellyman & Glova 2002).

Jellyman *et al.* (2003) studied habitat preferences of longfin and shortfin eels in three rivers of varying size (mean flow range 0.04-15 m^3/s) and substrate type. Based on their observations separate sets of HSC were developed for large longfin eels (>300 mm long) and young eels (<300 mm long), with the smaller size class generally preferring shallower, faster water (Appendix 1).

Jowett's (2002) HSC for inanga feeding habitat were based on observation of 50-60 mm long fish in three relatively small pastoral streams (flow during the observations were 0.002-0.325 m^3/s). Consequently, these HSC may underestimate the water velocity use of larger adult fish, particularly in larger rivers like the Ruamahanga. On the other hand, the optimum water velocity for these small fish was comparable with that of drift feeding brown trout, when the velocity was expressed in terms of body lengths per second (0.5-1.3 fish lengths per second for 55 mm inanga *c.f.* 0.7-1.3 fish lengths per second for 450 mm brown trout, Jowett 2002). If this relationship was extrapolated to 100 mm adult inanga, they would be expected to have a water velocity optimum for drift feeding of approximately 0.05-0.13 m/s, which is similar to the velocity optimum of the juvenile brown trout HSC developed by Raleigh *et al.* (1986). So these criteria could be interpreted as rough proxy for velocity use of larger inanga, although the Raleigh *et al.* depth criteria decrease above about 0.91 m, whereas Jowett (2002) found no evidence that inanga avoided deeper water (at least up to about 2 m).

The juvenile lamprey HSC (Glova & Jellyman 2001; Jellyman & Glova 2002) were developed based on targeted electric fishing surveys (targeting ammocetes, the blind burrow-dwelling early life stage of lamprey) in the Mataura and Waikaia rivers. The Mataura River is of a comparable size to the Ruamahanga.

With the exception of inanga, none of the native fish HSC applied in this report distinguish between feeding and resting habitat use. Consequently, the same issue of potential slow water

bias, as discussed for trout HSC, may also apply. However, the majority of the native fish considered are predominantly benthic feeders, and so probably feed in similar habitat to that which they use for cover. This arguably reduces the importance of water velocity in distinguishing feeding habitat from resting habitat for these fish, compared with drift feeding fish (such as trout and inanga), where the rate of food delivery is directly related to water velocity. In addition, the scale to which physical habitat features are resolved in IFIM habitat modelling (both in the modelling itself and in the measurements on which most of these native fish HSC are based) is probably larger than the scale of habitat use of many small native fishes, in terms of the size of their immediate foraging area. Therefore, the physical habitat conditions modelled as being suitable should be interpreted as being broadly indicative of the type of conditions experienced/preferred by these fish.

Rather than considering individual macroinvertebrate species, the general instream habitat requirements of macroinvertebrates were assessed using Water's (1976) food producing (*i.e.* food for fish) habitat suitability criteria (Appendix 1). These general HSC for benthic macroinvertebrates were developed in the United States of America, but have been widely applied to habitat analyses in New Zealand and Jowett (1992) found that WUA predictions based on them were correlated with trout abundance in New Zealand rivers.

2.6.2. *Flow range modelled*

The range of flows over which habitat availability can reasonably be modelled is constrained by the flows gauged for the development of rating curves for the survey cross-sections. The further outside the measured flow range that predictions are made the less reliable the predictions are likely to be. Denslinger *et al.* (1998) cite IFIM training documents produced by the U.S. Geological Survey, Biological Resources Division as suggesting that the "hydraulic model [in PHABSIM] can reasonably be extrapolated to a flow equal to 1.5 times the highest calibration flow and 0.6 times the lowest calibration flow. The absolute maximum range for extrapolation is to a flow 2.5 times the highest calibration flow and 0.4 times the lowest calibration flow". These limits are likely to be conservative when applied to RHYHABSIM models, due to improvements made in the way rating curve development is handled in this package (I. Jowett, NIWA, pers. comm.).

The flow range modelled in these analyses was selected to cover the likely range of interest in flow setting decisions, but still provide an indication of the flows at which predicted habitat availability would be optimised. The range extended from the about half the median flow down to approximately half the MALF. The modelled flow range fell well within the absolute maximum range for extrapolation, based on the guidelines outlined above, in both modelled reaches.

3. RESULTS AND DISCUSSION

3.1. Response of habitat to flow

3.1.1. Morrisons Bush reach

In the Morrisons Bush reach the predicted WUA optima for adult and juvenile brown trout, based on the HSC for active drift feeding habitat (Hayes & Jowett 1994; Bovee 1995), occurred above the estimated natural MALF (Figure 2). By contrast, juvenile and adult brown trout habitat predicted based on the suitability criteria developed by Raleigh *et al.* (1986) peaked well below the MALF (Figure 2). However, it should be remembered that these criteria probably underestimate flow requirements due to the inclusion of resting fish observations in their development.
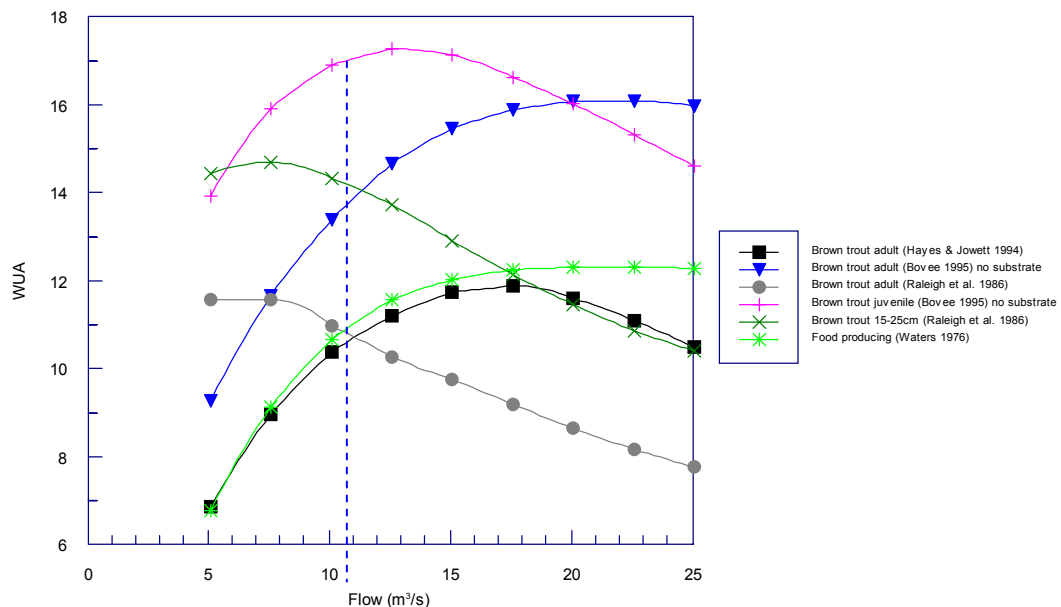

Figure 2. Predicted habitat (WUA) versus flow for trout and macroinvertebrate food producing habitat in the Ruamahanga River Morrisons Bush reach. Blue dashed line denotes naturalised MALF.

This suggests that any reduction in flow below the naturalised MALF is likely to lead to a reduction in the amount and average quality of feeding habitat for brown trout in the Morrisons Bush reach. Also habitat for invertebrate food production (Waters 1976) was predicted to increase with flow up to 21.5 m³/s, so flow reductions would be expected to reduce food supply as well as feeding habitat for trout.

By contrast the habitat availability (WUA) for most native fish modelled was predicted to increase or remain relatively constant with moderate flow reductions below the naturalised

MALF (Figure 3). This suggests that moderate reductions in flow from the naturalised MALF should be beneficial for many species of native fish in this reach, at least with respect to habitat availability.
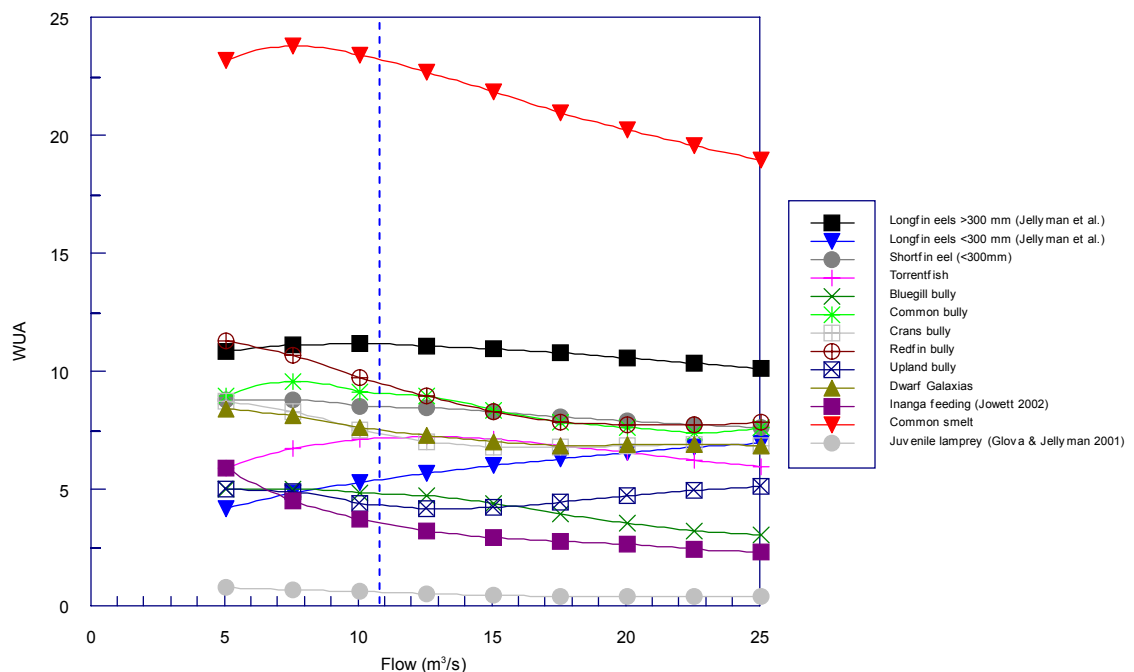

Figure 3. Predicted habitat (WUA) versus flow for native fish habitat in the Ruamahanga River Morrisons Bush reach. Blue dashed line denotes naturalised MALF.

The key exceptions to this were torrentfish and young longfin eels <300 mm long (Figure 3). These smaller eels tend to favour faster water, riffle-type habitat, which is likely to increase in area with flow, at least until depths become excessive. Torrentfish, being fast water specialists, showed a slightly steeper initial rate of increase of WUA than that of longfin eels <300 mm, but WUA began to decline above about 13 m^3/s, as water depth over most of the reach began to exceed about 0.7 m (the upper depth suitability limit specified in their HSC, Appendix 1).

Inanga feeding (Jowett 2002) WUA declined with increasing flow over the range modelled (Figure 3), and relatively steeply up to about the naturalised MALF (10.7 m^3/s). The WUA response of juvenile brown trout based on Raleigh *et al.* (1986), which I suggested might be applicable as a rough proxy for larger inanga feeding habitat peaked at approximately 7 m^3/s, and also declined through the MALF.

3.1.2. *Pahautea reach*

The predicted WUA optima for adult and juvenile brown trout, and food producing habitat all occurred at lower flows in the Pahautea reach than in the Morrisons Bush reach (Figure 4 *c.f.* Figure 2). The optima for adult trout based on the HSC that excluded resting habitat (Hayes & Jowett 1994; Bovee 1995) still occurred above the estimated natural MALF (Figure 4). However, the predicted optimum for juvenile brown trout based on Bovee (1995) HSC occurred below the naturalised MALF in this reach (Figure 2), as did both juvenile and adult brown trout habitat predicted based on the suitability criteria developed by Raleigh *et al.* (1986).
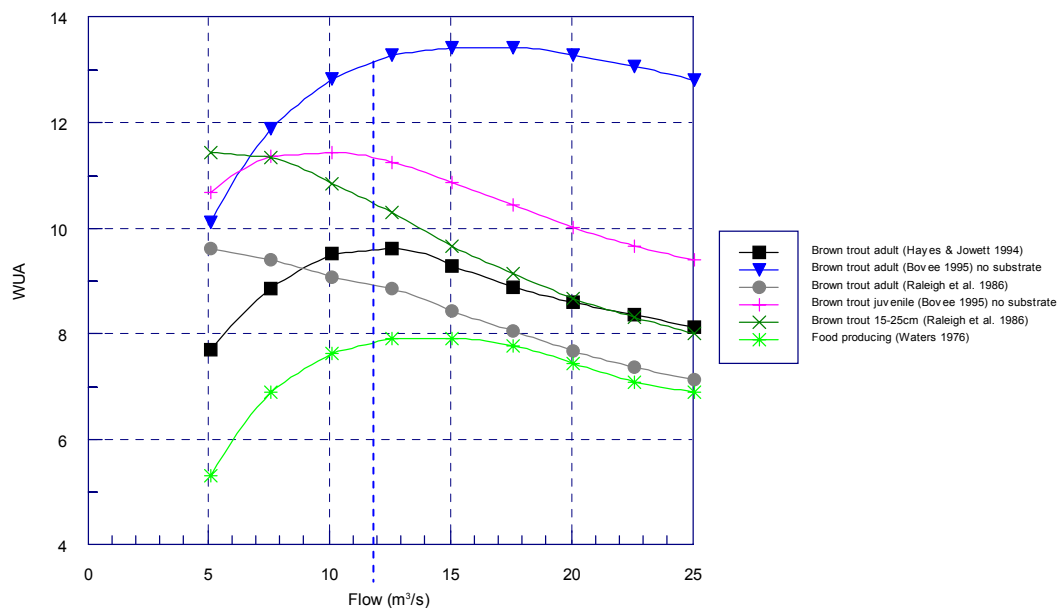

Figure 4.   Predicted habitat (WUA) versus flow for trout and macroinvertebrate food producing habitat in the Ruamahanga River Pahautea reach. Blue dashed line denotes naturalised MALF.

The optimum for food-producing habitat (Waters 1976) also occurred above the naturalised MALF in this reach. So as for the Morrisons Bush reach any reduction in flow below the naturalised MALF would be expected to reduce food supply as well as feeding habitat, at least for adult brown trout in the Pahautea reach, although the habitat reduction would be slight, down to about 10 m³/s. By contrast a moderate flow reduction would be expected to result in an increase in the amount and average quality of feeding habitat for juvenile brown trout (in terms of appropriate depths and velocities for drift feeding), although their food supply may be reduced.

In the Pahautea reach eels, torrentfish and bluegill bullies exhibited a relatively flat response to flow over the modelled range (Figure 5). This suggests that moderate reductions in flow from

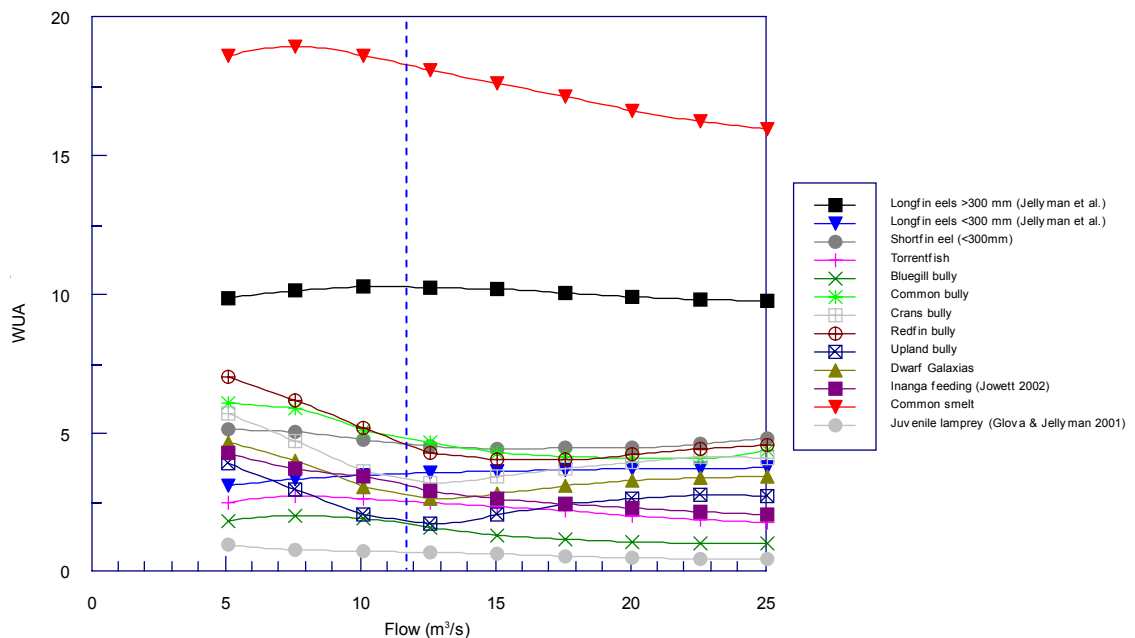the naturalised MALF would have little effect on habitat availability for these species in this reach.

Figure 5. Predicted habitat (WUA) versus flow for native fish habitat in the Ruamahanga River Pahautea reach. Blue dashed line denotes naturalised MALF.

For all of the other native fish modelled, available habitat (WUA) would increase with moderate flow reductions below the naturalised MALF (Figure 5). Many of these species also showed a slight increase in predicted habitat with flow increases of >1 m^3/s above the MALF. This is probably due to additional areas of shallow-edge water habitat becoming available, in parts of the reach, as gravel beaches are inundated at higher flows.

3.2. Interpretation of WUA curves for flow management

3.2.1. Ecological relevance of the MALF

When setting minimum flows for instream values the assumption is made that low flow is a limiting factor. Research in New Zealand indicates that the mean annual low flow and median flows are ecologically relevant flow statistics governing trout carrying capacity and stream productivity. Jowett (1990, 1992) found that instream habitat for adult brown trout at the mean annual low flow (MALF) was correlated with adult brown trout abundance in New Zealand rivers. The habitat metric that he used to quantify instream habitat was percent WUA (equivalent to HSI). The adult brown trout habitat suitability criteria used in Jowett's analysis were developed by Hayes & Jowett (1994). The inference arising from Jowett's research was that adult trout habitat (WUA%) about the MALF acts as a bottleneck to brown trout numbers.

He also found that invertebrate food producing habitat (WUA%, defined by Waters' (1976) general invertebrate habitat suitability criteria) at the median flow was strongly associated with trout abundance (Jowett 1990, 1992). These two habitat metrics are surrogate measures of space and food, which are considered to be primary factors regulating stream salmonid populations (Chapman 1966).

The reason why the MALF is a potential limiting factor, for trout populations, is that it is the most commonly used flow statistic that is indicative of the average annual minimum living space for adult trout. Trout populations respond to annual limiting events because their cohorts (year classes) are annual (*i.e.* they reproduce only once per year). This contrasts with aquatic invertebrates, which in New Zealand generally have asynchronous lifecycles (*i.e.* a range of different life stages are likely to be present at any given time) and may also have multiple cohorts per year so their populations respond to more frequent limiting events (*e.g.* floods or low flows that occur over the time-scale of months). Other flow statistics that define, or are closely correlated with, average annual minimum flows should be similarly relevant as the MALF to adult trout abundance.

Jowett's research provides empirical and conceptual justification for the validity of WUA as a habitat index for trout populations in New Zealand rivers. The insights gained from this research can also provide a basis for identifying hydrological statistics that are ecologically relevant to trout populations. It seems reasonable that the MALF should be similarly relevant to native fish species with generation cycles longer than one year, at least in situations where habitat declines toward the MALF. If the minimum flow restricts habitat for any species, there is potential for a detrimental effect on that population if abstraction draws flow below the MALF.

These insights have led to a recent move toward interpreting WUA curves in conjunction with flow statistics (notably the MALF) when making decisions on minimum flows (Jowett & Hayes 2004). It has been suggested that if the WUA optimum should occur at flows above the MALF, then habitat availability will be limited by the MALF. In this case, flow decisions should be made so as to preserve a proportion of the habitat (*i.e.* WUA) available at the MALF (Figure 5a), in order to cater for the needs of both instream values and out-of-stream water uses. In the case where predicted optimum WUA occurs below the MALF, then flows should be managed to maintain a proportion of the habitat available at optimum WUA (Figure 5b).
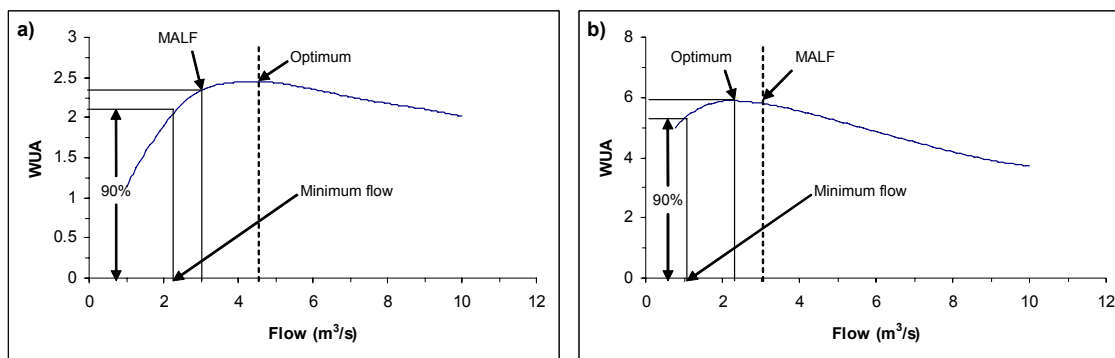
Figure 6. Derivation of minimum flow based on retention of a proportion (90% in this case) of available habitat (WUA) at a) the MALF, or b) the habitat optimum, whichever occurs at the lower flow, as recommended by Jowett & Hayes (2004).

3.2.2. Reconciling flow requirements of multiple instream values

It is then necessary to address how the flow requirements predicted by various WUA versus flow relationships for different species can be reconciled. Jowett & Hayes (2004) suggest that flow-dependant critical instream values should be identified and flow decisions made with a focus on managing these values. Candidates for critical value status might include flow-sensitive rare or endangered species, or species with high fishery value. "The concept of critical values is that by providing sufficient flow to sustain the most flow sensitive, important value (species, life stage, or recreational activity), the other significant values will also be sustained" (Jowett & Hayes 2004, Pp. 8). In their document "Flow guidelines for instream values", Ministry for the Environment recommend a similar approach (MfE 1998), although the terminology used differs slightly. Basing decision-making on critical instream values circumvents the complexities of interpreting all the different species' WUA curves independently.

Of those native fish species recorded from the Ruamahanga in the NZFFD (Table 2), six are of conservation concern based on the latest Department of Conservation threat classification listings (Hitchmough *et al.* 2007). These are longfin eel, giant kokopu, dwarf galaxias, and brown mudfish, which are all listed as being in "Gradual decline", and shortjaw kokopu, and lamprey which are listed as "Sparse". However, of these, brown mudfish and adult shortjaw kokopu are unlikely to occur in the mainstem of the Ruamahanga River in the lower section, although it is possible that juvenile shortjaw kokopu might use the lower river as a migratory conduit to reach more suitable habitat in tributaries upstream. This species has not been recorded from higher in the catchment (shortjaw kokopu has been recorded only once from the catchment in the NZFFD, from a small tributary stream near Lake Onake in 1973). Also, none of these six species are particularly flow demanding.

By contrast, trout are recognised as being among the most flow-demanding fish in New Zealand rivers. As discussed by Watts & Perrie (2007) brown trout support a highly valued fishery in the Ruamahanga River, with both the Morrisons Bush and Pahautea reaches having

excellent fly and spin fishing opportunities. The mainstem of the Ruamahanga River ranked second, in terms of angler days, among 58 water bodies in Fish & Game's Wellington Region, in the latest national angler survey (Unwin & Image 2003), behind the Manawatu River and ahead of the Hutt River.

This suggests trout as a candidate for critical value status in the lower Ruamahanga River. Providing for the flow needs of trout will, arguably, provide for the flow needs of less flow demanding species, because these will be able to utilise slower or shallower habitat along the river margins, or in riffles or pools. The habitat requirements of adult brown trout for feeding are arguably the most pertinent to minimum flow setting for this river.

3.2.3. Habitat retention levels

Finally, the decision remains as to what level of habitat availability should be maintained. The level of habitat retention is arbitrary, and scientific knowledge of the response of river ecosystems, and fish populations in particular, is insufficient to identify levels of habitat below which ecological impacts will occur. A carefully designed and well funded monitoring programme might detect effects of a 50% reduction in habitat on fish populations but is unlikely to detect effects of a 10% reduction in habitat – due mainly to the large natural spatial and temporal variability typical of fish populations. It is uncertain whether any effects of a 20-30% reduction in habitat on fish populations would be detectable.

Jowett & Hayes (2004) recognise that, in practice, the choice of a habitat retention level is based more on risk management than ecological science. The risk of ecological impact increases as habitat is reduced. When instream resource values are factored into the decision-making process, then the greater the resource value the less risk is acceptable. With this in mind, Jowett & Hayes (2004) suggest that water managers could consider varying the percent habitat retention level, depending on the value of instream and out-of-stream resources (*i.e.* highly valued instream resources warrant a higher level of habitat retention than low valued instream resources). This concept is consistent with conservative flow decisions in national water conservation orders (usually no more than 5% habitat reduction). Table 3 shows how Jowett & Hayes (2004) envisage that percentage habitat retention could be varied to take account of variation in instream values.

Table 3. Suggested significance ranking (from highest (1) to lowest (5)) of critical values and levels of habitat retention.

Critical value	Fishery quality	Significance ranking	% habitat retention
Large adult trout – perennial fishery	High	1	90
Diadromous galaxiid	High	1	90
Non-diadromous galaxiid	-	2	80
Trout spawning/juvenile rearing	High	3	70
Large adult trout – perennial fishery	Low	3	70
Diadromous galaxiid	Low	3	70
Trout spawning/juvenile rearing	Low	5	60
Redfin/common bully	-	5	60

Table taken from Jowett & Hayes (2004)

3.3. Flow variability and allocation limits

It is important that maintenance of flow variability be considered in conjunction with setting minimum flows, to maintain channel and riparian structure, control periphyton, and sustain invertebrate productivity and fish feeding opportunities. Along with the magnitude of the minimum flow, increasing the frequency and duration of occurrence of the minimum flow is likely to have ecological effects.

Perhaps the most obvious potential ecological effect of prolonged low flow, due to abstraction, is proliferation of periphyton to nuisance levels. But impacts are likely to extend to higher trophic levels (*i.e.* invertebrates and fish) as well. In the past, minimum flows in New Zealand have generally been set under the assumption that abstraction is unlikely to have a significant impact on the hydrograph other than low flows (except when large dams with substantial storage capacity are involved). However, nowadays there is more demand on water and moderate to large scale water abstraction may well significantly alter other features of flow regimes, although this is more likely with water abstraction from relatively small streams. These changes generally do not affect flood and flushing flows but may affect the availability of invertebrate food resources for fish and birds by temporarily reducing invertebrate habitat, with associated reduction in invertebrate production. Generally, optimal invertebrate habitat occurs at higher flows than optimal fish habitat and because they have high rates of colonisation, invertebrates can make productive use of extended flow recessions. For instance, they may take as little as 15-30 days to fully colonise previously dry channels (or margins) (Sagar 1983). For this reason the median flow can be thought of as providing an approximation of the habitat conditions experienced, and able to be utilised, by benthic invertebrates most of the time (Jowett 1992).

In comparison, the minimum flow can be viewed as providing essentially a habitat refuge for fish during periods of low flow. It should not be viewed as providing adequate habitat to support fish populations over the long-term, if flow is consistently held at the minimum,

because food supply for fish is likely to be reduced. Setting a minimum flow at or below the MALF with no safeguards for maintenance of flow variability has been likened to a doctor prescribing a patient's worst state of health as a life-time condition. The aim in setting the minimum flow is to provide enough suitable habitat for fish to survive in, hopefully fairly comfortably, for a relatively short period before flow increases again. NIWA research in the Waipara River, where fish habitat is limited at low flow, showed that the detrimental effect on fish numbers increased with the duration and decreasing magnitude of the minimum flow (Jowett & Hayes 2004).

Maintenance of invertebrate production (which fish depend on for food) is arguably more dependent on allocation limits or flow sharing rules, which ensure that the median flow is not substantially reduced by abstraction, than on the minimum flow *per se.*

There are various methods of deriving allocation limits in conjunction with a minimum flow. One method, which has been used by Horizons Regional Council (*e.g.* Roygard & Carlyon 2004; Hurndell *et al.* 2007), quantifies the expected increase in the frequency and duration of occurrence of the minimum flow in response to different total allocation volume scenarios. A possible alternative method, outlined in Jowett & Hayes (2004, Section 6. Total allocation), involves trading off the magnitude of the minimum flow against the total allocation volume.

The frequency of occurrence and duration of the minimum flow will impinge on the surety of supply for abstractors (through abstraction restrictions), but also has the potential to have ecological effects, as discussed above. The method employed by Horizons Regional Council would lend itself well to community consultation, whereby stakeholders could negotiate the frequency and duration of minimum flow occurrence that they deem acceptable, on the basis of relative instream values and out-of-stream water uses (including requirements for surety of supply).

3.4. Proposed minimum flows

On the basis of the rationale outlined above, the proposed minimum flows provided here are based on retention of a proportion of the predicted habitat (WUA) available at the MALF for adult brown trout (since their WUA optima occurred at flows above the MALF). Minimum flows based on two levels of habitat retention are presented (Table 4), with the intention that these might provide options for negotiations on the relative values of instream and out-of-stream water use. However, given that the Ruamahanga River ranks so highly in terms of angler use a relatively high level of protection for adult trout habitat (*i.e.* 90% habitat retention level, see Table 3) is arguably warranted.

For both reaches the minimum flows based on adult brown trout feeding (Bovee 1995) HSC are the most conservative of those calculated (Table 4), at the 90% habitat retention level. These HSC are arguably the best suited to application in the lower Ruamahanga on the basis of the flow range over which they were developed (see Section 2.6.1. Habitat suitability criteria), although the lower gradient of the lower Ruamahanga compared with the South Platte River

(where these HSC were developed) is likely to mean that these criteria tend to over-estimate flow requirements in this instance. On this basis, referencing the minimum flow to adult brown trout feeding habitat retention based on Bovee's (1995) HSC ought to be environmentally conservative.

Hayes & Jowett (1994) adult brown trout HSC are arguably the most viable alternative set of criteria for this application. However, these criteria were also developed on higher gradient rivers than the lower Ruamahanga, but over a lower flow range. In practise the there is little difference in the minimum flows based on Bovee's (1995) criteria and those based on Hayes & Jowett's (1994). At the 80% habitat retention level the minimum flow based on Hayes & Jowett's (1994) HSC for adult brown trout feeding is slightly more conservative in the Morrisons Bush reach (Table 4).

The minimum flows based on habitat retention for the native fish modelled were consistently lower than brown trout. This conforms to expectation, given that trout are recognised as relatively flow demanding, while most native fish are not. Even the fast water specialist native fish (torrentfish and bluegill bullies) had lower minimum flow requirements than trout based on habitat (WUA) retention, due to the lower depth optima in the HSC for these native fish. This supports the contention that setting a minimum flow to protect trout habitat availability should also accommodate the minimum flow requirements of native fish.

Table 4. Flows at predicted WUA optima and flows predicted to retain 90% and 80% of the WUA at the MALF or the flow at the WUA optimum (which ever is lowest) for all species and lifestages modelled in the Morrisons Bush and Pahautea reaches of the lower Ruamahanga River. The proposed minimum flows are highlighted in bold.

Reach	MALF (m³/s) *	Habitat Suitability Criteria	Flow at WUA Optimum (m³/s)	Flow that retains 90% of WUA at MALF or the WUA optimum flow (m³/s)	Flow that retains 80% of WUA at MALF or the WUA optimum flow (m³/s)
Morrisons Bush	10.7	Brown trout adult (Hayes & Jowett 1994)	17.0	8.4	**7.0**
		Brown trout adult (Bovee 1995) no substrate	21.5	**8.5**	6.8
		Brown trout adult (Raleigh *et al.* 1986)	6.0	3.1	2.0
		Brown trout juvenile (Bovee 1995) no substrate	13.0	6.7	4.7
		Brown trout 15-25cm (Raleigh *et al.* 1986)	6.5	2.9	**
		Longfin eels >300 mm (Jellyman *et al.* 2003)	10.0	2.3	**
		Longfin eels <300 mm (Jellyman *et al.* 2003)	>25.0	7.5	5.5
		Shortfin eel (<300mm)	6.5	**	**
		Torrentfish	12.0	6.4	4.8
		Bluegill bully	6.0	3.6	2.8
		Common bully	7.5	3.5	**
		Crans bully	2.0	**	**
		Redfin bully	2.0	**	**
		Upland bully	2.0	**	**
		Dwarf Galaxias	2.0	**	**
		Inanga feeding (Jowett 2002)	2.0	**	**
		Common smelt	7.5	2.9	**
		Juvenile lamprey (Glova & Jellyman 2001)	3.0	**	**
Pahautea	11.8	Brown trout adult (Hayes & Jowett 1994)	11.5	7.0	5.0
		Brown trout adult (Bovee 1995) no substrate	16.0	**7.5**	**5.5**
		Brown trout adult (Raleigh *et al.* 1986)	4.5	2.3	**
		Brown trout juvenile (Bovee 1995) no substrate	9.0	4.1	2.4
		Brown trout 15-25cm (Raleigh *et al.* 1986)	5.5	2.3	**
		Longfin eels >300 mm (Jellyman *et al.* 2003)	10.5	3.1	**
		Longfin eels <300 mm (Jellyman *et al.* 2003)	24.5	5.5	3.1
		Shortfin eel (<300mm)	3.0	**	**
		Torrentfish	7.5	4.7	3.5
		Bluegill bully	7.5	3.7	**
		Common bully	6.0	2.8	**
		Crans bully	3.5	**	**
		Redfin bully	3.5	**	**
		Upland bully	3.5	**	**
		Dwarf Galaxias	3.5	**	**
		Inanga feeding (Jowett 2002)	2.0	**	**
		Common smelt	7.0	2.9	**
		Juvenile lamprey (Glova & Jellyman 2001)	3.0	**	**

* naturalised one day MALFs provided by GWRC
** below modelled range

3.5. Fish and boat passage

The hydraulic models constructed in RHYHABSIM can be used to predict the minimum width of channel with suitable depths and velocities for fish and boat passage within the cross-sections in the modelled reach, and how this changes with incremental changes in flow. The criteria required to make these predictions are a minimum depth and maximum water velocity that will allow passage for a given species of fish or type of boat.

3.5.1. *Fish passage*

As discussed above, the lower Ruamahanga River is important as a conduit for migrating fish to access habitat in the upper reaches and tributaries (Watts & Perrie 2007). Fifteen of the native fish species recorded from the Ruamahanga catchment in the NZFFD are diadromous, requiring access to and from the sea to complete their lifecycles. A high proportion of the brown trout in the catchment are also thought to be "sea run" (Watts & Perrie 2007).

Hudson (2007) recently conducted a similar fish passage analysis on the Hutt River for GWRC. The depth and velocity criteria he applied were gleaned from the literature. I have applied the same criteria here for the sake of consistency, and because I believe these criteria to be conservative.

The criteria for trout were sourced from guidelines on fish passage past stream road crossings, produced by the Oregon Department of Fish and Wildlife. Two sets of criteria were adopted from this source, one set for large trout (>50 cm), with a minimum passage depth of 25 cm and a maximum passage velocity of 1.2 m/s, and another set for smaller adult trout and juveniles, with a minimum passage depth of 20 cm and a maximum passage velocity of 0.6 m/s. These criteria are conservative in terms of depth, since they are deeper than the likely body depth of fish in these size classes, whereas trout are known to be able to negotiate short sections of shallow water with much of their body protruding above the water surface. They are also conservative in terms of velocity, since 0.6 m/s is close to the expected maximum sustainable swimming speed for 15 cm trout[1] and likely to be within the burst swimming speed of smaller fish (*e.g.* 7 cm rainbow trout are able to maintain a burst swimming speed of about 1 m/s for more than 10 seconds, Boubee *et al.* 1999). Also trout smaller than about 150 cm are unlikely to migrate upstream through the lower reaches of the Ruamahanga; they would be more likely move downstream from the spawning tributaries. Likewise, 1.2 m/s is likely to be well within the burst swimming speed[2] of trout larger than 50cm.

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[1] Maximum sustainable swimming speed for a 15 cm trout is approximately 0.61 m/s, based on the equation: $V_{max} = (36.23 \cdot FL^{0.19})/100$, where V_{max} is maximum sustainable swimming speed (m/s), and FL is fork length (cm) (from Jones *et al.* 1974, cited in Hayes *et al.* 2000).
[2] Burst swimming speed of for a 50 cm brown trout is approximately 1.73 m/s for 10 seconds, based on the equation: $V = 8.74 \cdot TL^{0.68} \cdot t^{-0.5}$, where V is burst swimming speed (m/s), TL is total length (m), and t is time (s) (from Hunter & Mayor 1986, cited in Fish Xing - Fish performance - Swim speed table http://www.fsl.orst.edu/geowater/FX3/help/FX3_Help.html#2_Introduction/Credits.htm, accessed on 13 November 2007)

The velocity criterion for native fish were sourced from Boubee *et al.* (1999). The criterion of 0.3 m/s is slightly less than the mean steady swimming speed, maintained over >30 seconds, (mean 0.32 m/s, range 0.27-0.36 m/s) based on observations of juvenile shortfin eel, common bully, common smelt, inanga, and banded kokopu, from Mitchell (1989). This is likely to be conservative when compared with burst swimming speeds, *e.g.* burst swimming speeds reported by Mitchell (1989) for the same species ranged between 0.43-0.6 m/s, and 7 cm inanga are able to maintain a burst swimming speed of 1 m/s for approximately 10 seconds (Boubee *et al.* 1999).

The minimum depth criterion applied by Hudson (2007) for native fish (5 cm) was suggested by Allibone (2000) as a suitable depth for fish passages designed for non-migratory galaxiids. He did not cite any research to support this suggested depth. Nevertheless, in my opinion 5 cm is a conservative minimum depth criterion for native fish passage. This depth is greater than the body depth of most native fishes, especially the juvenile migratory life stages of the diadromous species. Adult eels are an exception but they are able to travel overland and other species can progress upstream over moist surfaces (*e.g.* koaro). Downstream migration tends to be associated with flood flows, so passage depth is unlikely to be an issue.

Figure 7 shows how the predicted passage widths based on these criteria vary with incremental changes in flow in the Morrisons Bush reach. The interaction between the minimum depth and maximum velocity criteria cause the available passage width to fluctuate with increasing flow. This occurs because rising water levels successively inundate new areas in the channel margins, producing sufficient depths, but continuing increases in flow ultimately cause the maximum water velocity criteria to be exceeded in these areas. This type of fluctuation was particularly evident in the case of native fish passage in this reach (Figure 7c).

Figure 7a suggests that there would be little difference in the minimum width of channel passable by large trout at the recommended minimum flow in this reach (8.5 m^3/s) than at the naturalised MALF (10.7 m^3/s). Passage for small trout was predicted to be blocked even at the naturalised MALF (Figure 7b), due to excessive velocities in the riffle sections with adequate depth. Consequently, these fish may have to wait for higher flows before they are able to move freely about the reach (but see discussion in the next paragraphs).

Minimum passage width for native fish was predicted to decrease to zero at the recommended minimum flow (Figure 7c). On this basis a slightly higher minimum flow, of say 9 m^3/s may seem warranted. However, it should be borne in mind that many native fish are still likely to be able to move upstream in the very shallow margins, since several species are known to be able to pass through shallower water than the 5 cm minimum criterion applied here. Also, the hydraulic model predicts mean column velocity, which may be substantially higher than the water velocity actually experienced close to the bed, particularly in deeper water and where the substrate elements are large. Consequently, fish (especially relatively small fish) are likely to be able to progress upstream by taking advantage of near-bed velocity refuges and turbulence. This is also applicable to small trout. Therefore, the prediction that minimum passage width would reduce to zero for small trout at about 14 m^3/s (Figure 7b) is also likely to be overly

conservative. Furthermore, the accuracy of predicted mean column velocity in very shallow water (*e.g.* 5 cm deep) is not likely to be as good as in deeper water, particularly where the substrate elements are large relative to water depth and the influence of boundary layer flow conditions becomes more prominent. With these issues in mind, Figure 8 shows predicted passage widths based solely on depth (*i.e.* discounting the maximum velocity criteria), using the same minimum depth criteria used in Figure 7.

Comparison of Figure 7 with Figure 8 demonstrates the strong influence that water velocity had on the predicted passage widths in the former, particularly for small trout (Figure 7b *c.f.* Figure 8b) and native fish (Figure 7c *c.f.* Figure 8c). Given that the mean column velocities predicted by the hydraulic model are likely to be higher than velocities actually experienced by fish moving close to the bed, or amongst large substrate in very shallow water, the actual passage width response to flow change probably lies somewhere between the predictions shown in these two figures (*i.e.* Figure 7 and 8). At least a 9 m wide contiguous section of the channel was predicted to have suitable depth for fish passage at the recommended minimum flow (~15 m for small trout, and ~25 m for native fish), and it is highly likely that some sections of this would also have suitable near bed water velocities to allow fish passage.
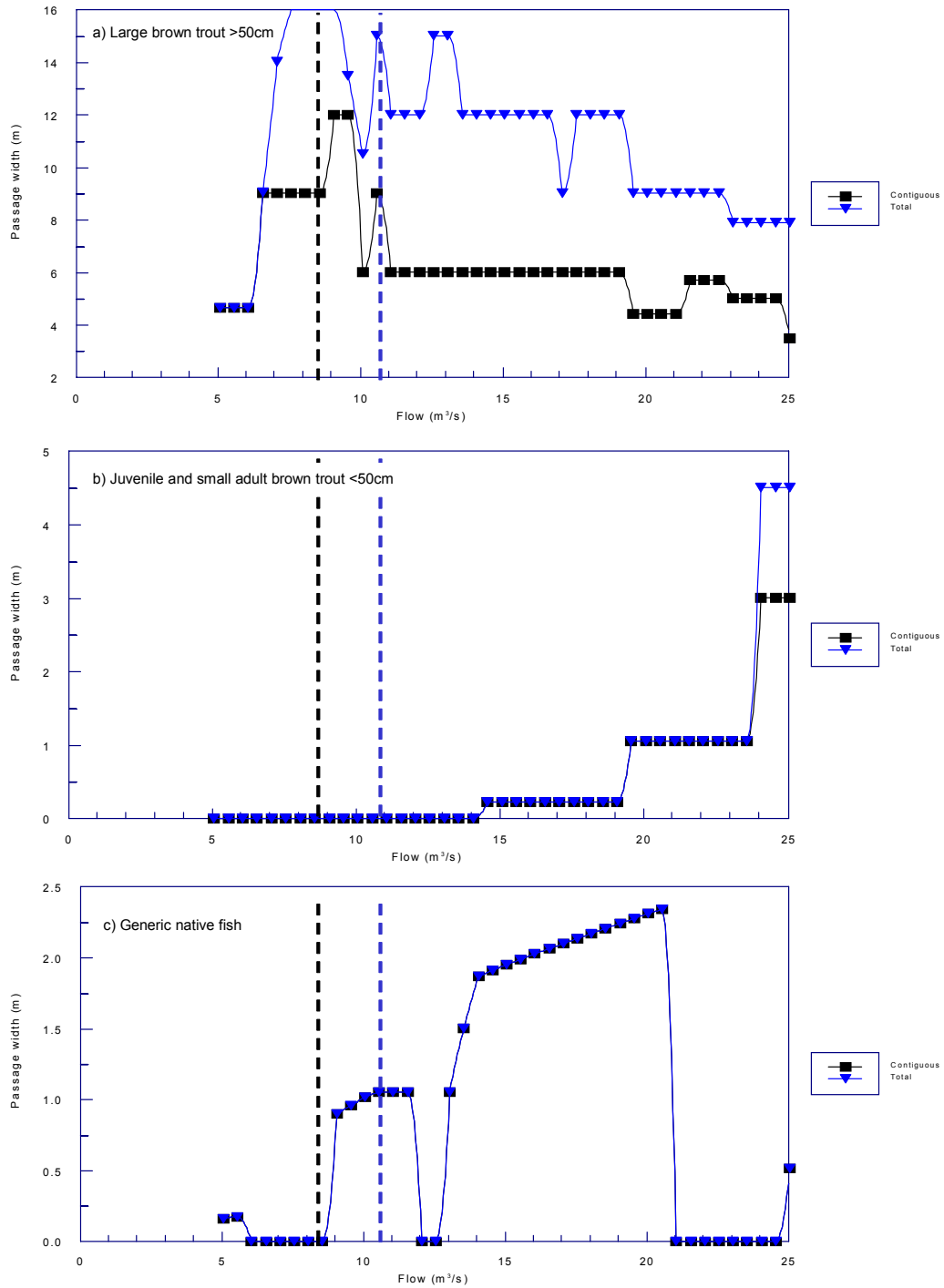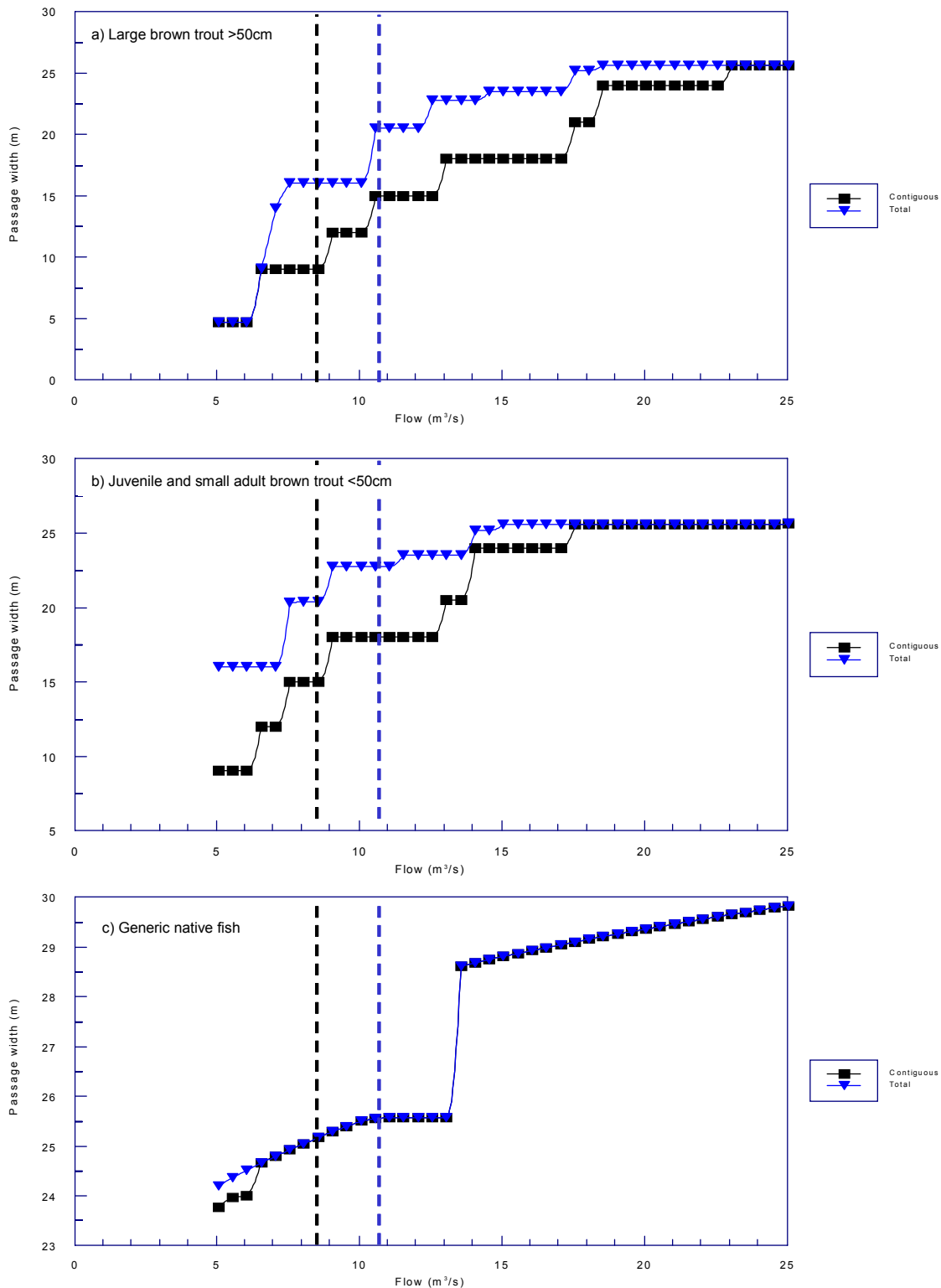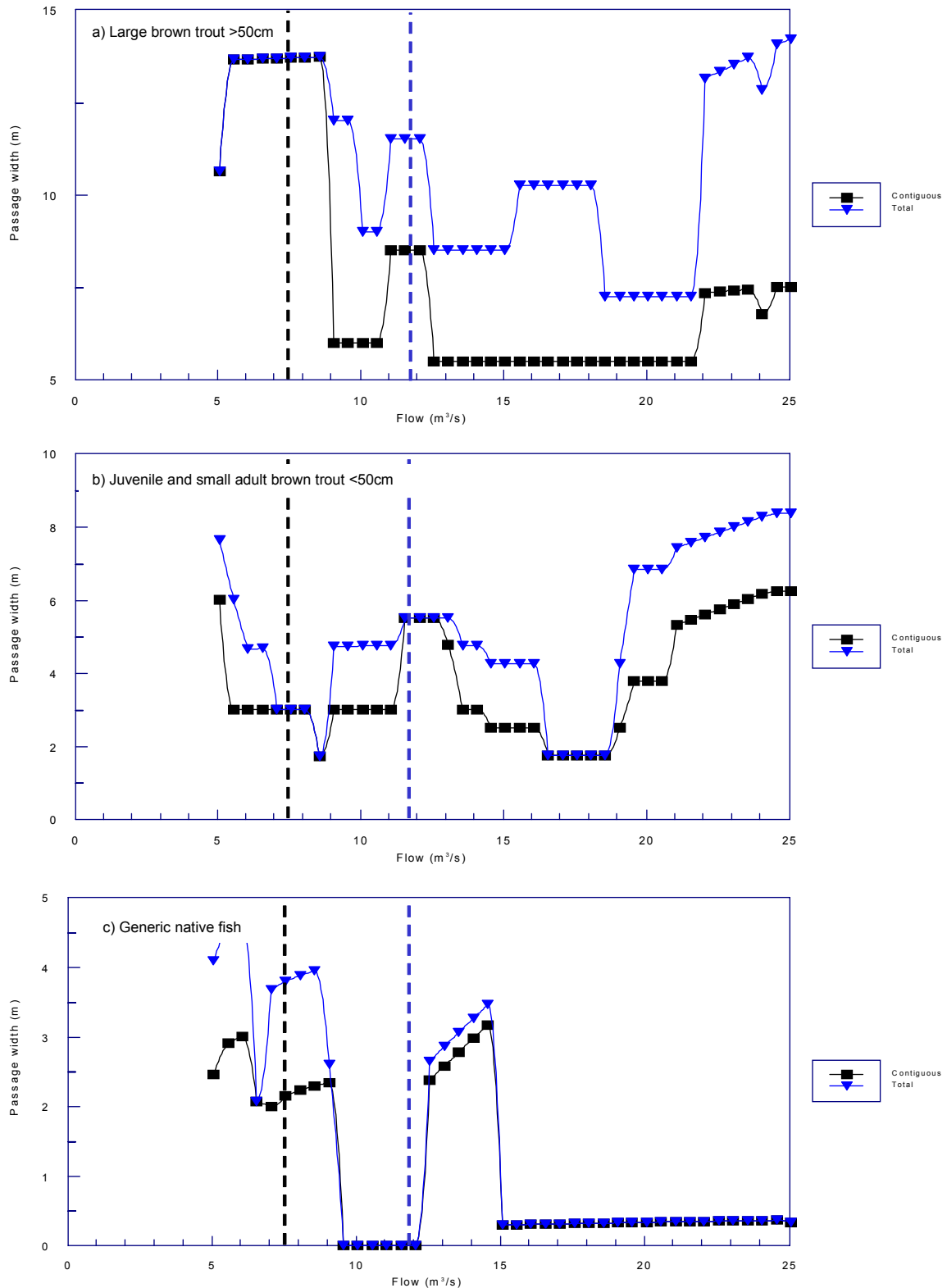
Figure 7. Predicted changes in the minimum width of channel with suitable depth and velocity for fish passage, with incremental changes in flow in the Morrisons Bush reach. Contiguous width is the largest single portion of the channel with suitable depths and velocities for passage, while total width is the sum of all the suitable portions of the channel. Vertical blue dashed line is the naturalised MALF for the reach, vertical black dashed line is the recommended minimum flow based on retention of 90% of adult brown trout feeding habitat at the naturalised MALF. Note: Y-axis scales vary between plots.

Figure 8. Predicted changes in the minimum width of channel with suitable depth for fish passage, with incremental changes in flow in the Morrisons Bush reach. Contiguous width is the largest single portion of the channel with suitable depths for passage, while total width is the sum of all the suitable portions of the channel. Vertical blue dashed line is the naturalised MALF for the reach, vertical black dashed line is the recommended minimum flow based on retention of 90% of adult brown trout feeding habitat at the naturalised MALF. Note: Y-axis scales vary between plots.
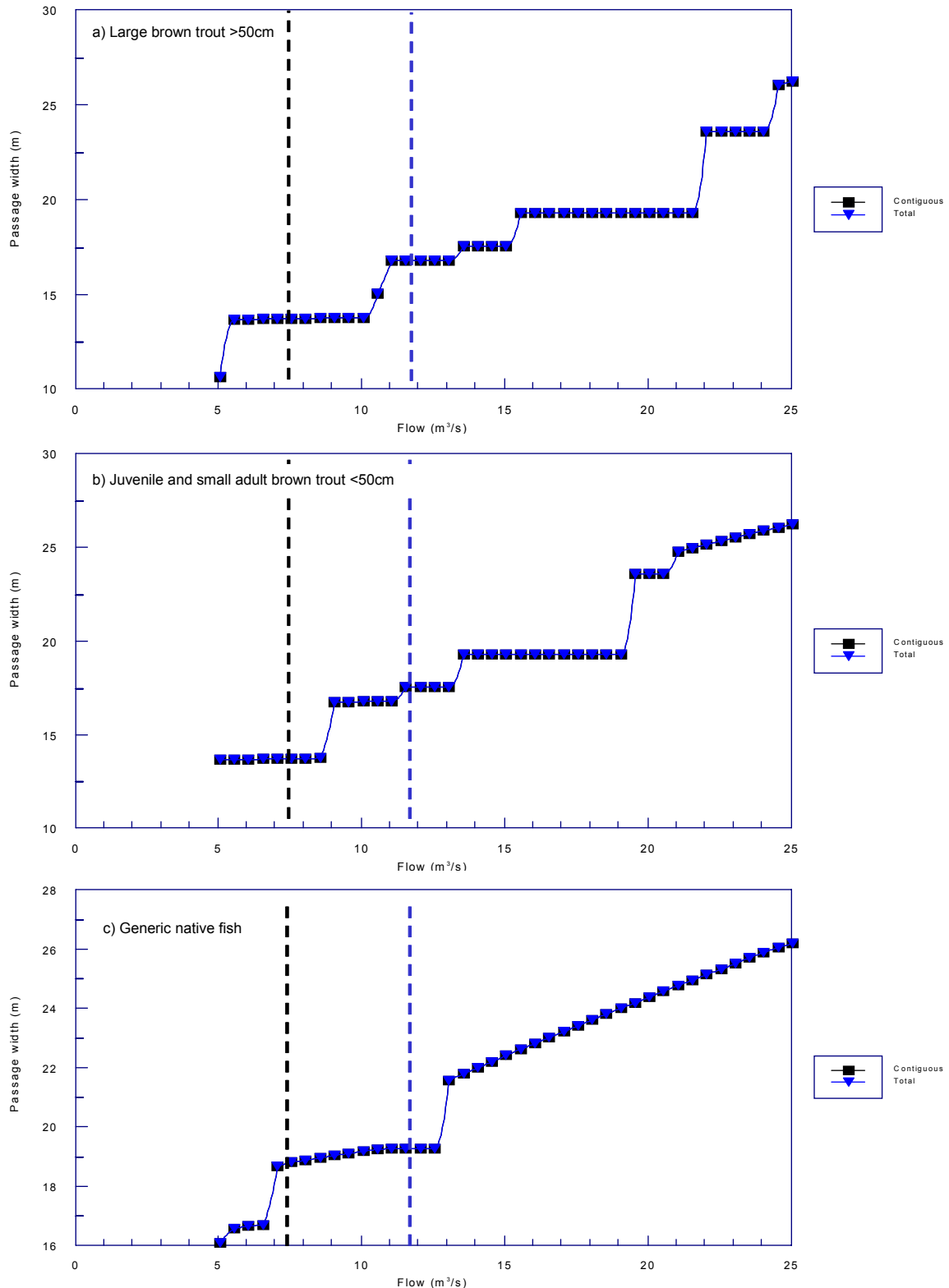
In the Pahautea reach the minimum width of passage, base on both depth and velocity criteria, was predicted to increase for large trout (Figure 9a) with a reduction in flow from the naturalised MALF (11.8 m³/s) to the recommended minimum flow (7.5 m³/s). For smaller trout the available passage width was predicted to reduce by close to 50% (Figure 9b), but a minimum 3 m of the channel width would still be passable. Native fish passage was predicted to be improved at the recommended minimum flow, relative to the naturalised MALF (Figure 9c).

Based solely on depth (*i.e.* ignoring water velocity) minimum passage width was predicted to decline between the naturalised MALF and the recommended flow in all three cases in the Pahautea reach (Figure 10a, b, c). However, there was still predicted to be about a 14 m wide section with suitable depth for trout passage (Figure 10a and b) at the recommended minimum flow, and between 18-19 m for native fish (Figure 10c).

Figure 9. Predicted changes in the minimum width of channel with suitable depth and velocity for fish passage, with incremental changes in flow in the Pahautea reach. Contiguous width is the widest single portion of the channel with suitable depths and velocities for passage, while total width is the sum of all the suitable portions of the channel. Vertical blue dashed line is the naturalised MALF for the reach, vertical black dashed line is the recommended minimum flow based on retention of 90% of adult brown trout feeding habitat at the naturalised MALF. Note: Y-axis scales vary between plots.

Figure 10. Predicted changes in the minimum width of channel with suitable depth for fish passage, with incremental changes in flow in the Pahautea reach. Contiguous width is the widest single portion of the channel with suitable depths for passage, while total width is the sum of all the suitable portions of the channel. Vertical blue dashed line is the naturalised MALF for the reach, vertical black dashed line is the recommended minimum flow based on retention of 90% of adult brown trout feeding habitat at the naturalised MALF. Note: Y-axis scales vary between plots.

3.5.2. Boat passage

The lower Ruamahanga River receives a high level of recreational boating use (Watts & Perrie 2007). It is considered one of the best rivers in the North Island for jet boating (Watts & Perrie 2007), and the section represented by the Pahautea reach is particularly popular for canoeing, including commercially operated tours.

Mosley (1983) provided guideline depth, velocity and wetted width requirements for various recreational activities. He suggested a maximum water velocity of 4.5 m/s and a minimum depth of 0.1 m for jet boating (although he suggested that a minimum depth of 0.2 m over riffles would be preferable). He suggested similar criteria for white water rafting and canoeing, which also presumably includes kayaking (0.2 m minimum depth and 4.5 m/s maximum velocity). For flat water canoeing he suggested a minimum depth of 0.5 m and a maximum velocity of 1.5 m/s. These minimum depth and maximum velocity criteria were used to predict minimum boat passage width with changing flow in the two modelled reaches.

Mosley (1983) also suggested a minimum wetted width of 7.5 m for canoeing and 5 m for jet boating. Both of these criteria would easily be exceeded at any flow above 5 m^3/s in both modelled reaches (the minimum wetted width at 5 m^3/s was predicted to be >19 m in both reaches).

A reduction in flow from the naturalised MALF to the proposed minimum flow based on habitat retention would cause a slight reduction in the minimum passage width for jet boating (Figure 11a) and white water canoeing/kayaking and rafting (Figure 11b) in the Morrisons Bush reach. However, there would still be ample channel width with appropriate depths and velocities for either of these activities.

The modelling results suggest that shallowest and fastest sections of the Morrisons Bush reach would not be suitable for flat water canoeing/kayaking at most flows (Figure 11c). However, if these shallow, high velocity sections were portaged, there are large sections of the reach that would provide suitable conditions for this activity.
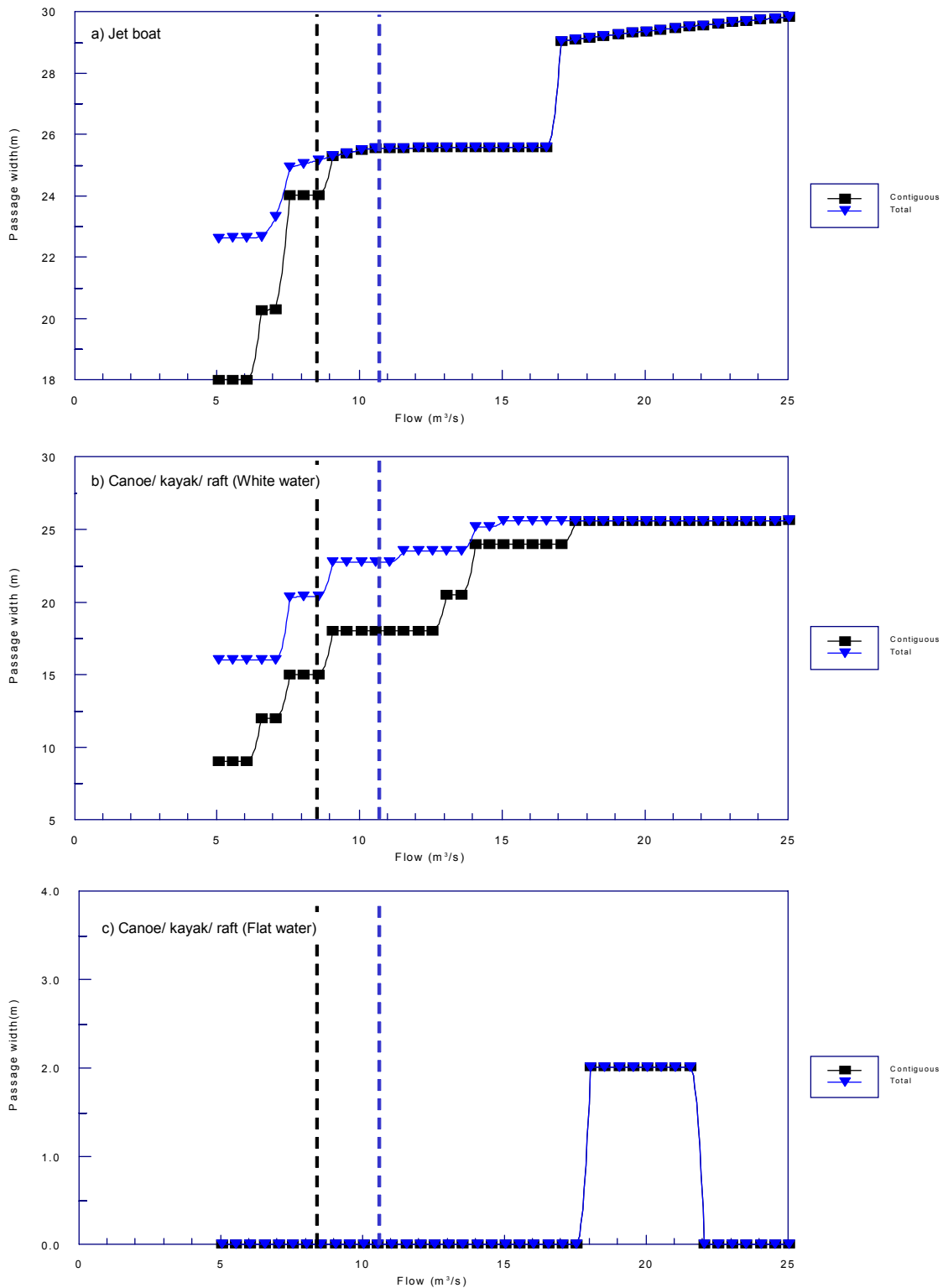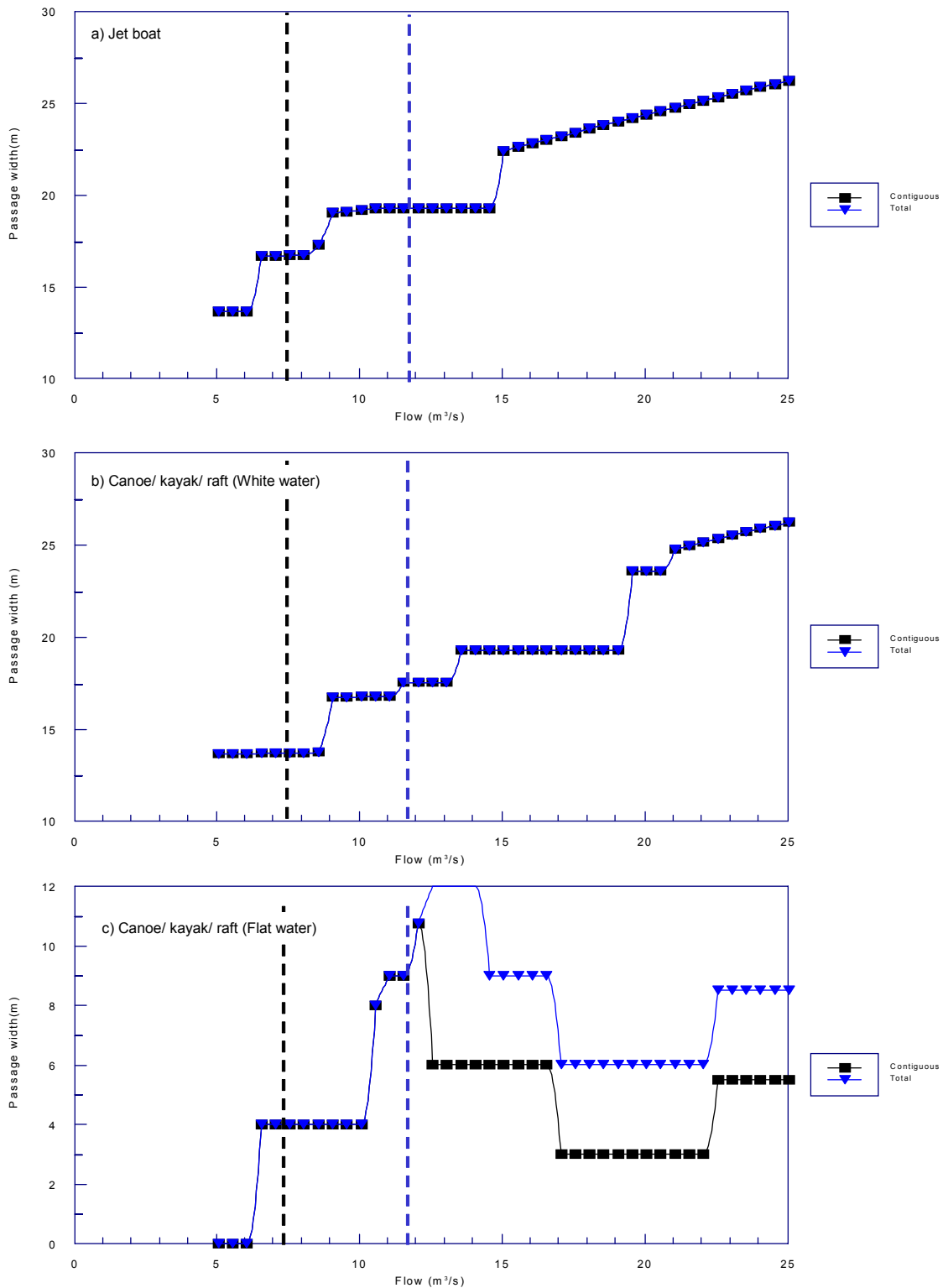
Figure 11. Predicted changes in the minimum width of channel with suitable depth and velocity for recreational boat passage, with incremental changes in flow in the Morrisons Bush reach. Contiguous width is the widest single portion of the channel with suitable depths and velocities for passage, while total width is the sum of all the suitable portions of the channel. Vertical blue dashed line is the naturalised MALF for the reach, vertical black dashed line is the recommended minimum flow based on retention of 90% of adult brown trout feeding habitat at the naturalised MALF. Note: Y-axis scales vary between plots.

In the Pahautea reach the minimum passage width for all of the boating activities modelled were predicted to be lower at the proposed minimum flow than at the naturalised MALF (Figure 12a, b, c). However, there would still be sufficient width of passable water for all boating activities at the proposed minimum flow. The narrowest minimum passage width was predicted for flat water canoeing/kayaking, but there would still be at least a 4 m wide section of channel with suitable conditions for this activity at 7.5 m^3/s.

Figure 12. Predicted changes in the minimum width of channel with suitable depth and velocity for recreational boat passage, with incremental changes in flow in the Pahautea reach. Contiguous width is the widest single portion of the channel with suitable depths and velocities for passage, while total width is the sum of all the suitable portions of the channel. Vertical blue dashed line is the naturalised MALF for the reach, vertical black dashed line is the recommended minimum flow based on retention of 90% of adult brown trout feeding habitat at the naturalised MALF. Note: Y-axis scales vary between plots.

3.5.3. Fish and Boat Passage Summary

In general a reduction in flow from the respective naturalised MALFs to the proposed minimum flows in each reach is not expected to curtail passage for fish or boats through the reaches. In some cases passage was predicted to already be blocked by excessive water velocities even at the naturalised MALF, and a reduction in flow was predicted to improve the situation in one case. The one case where passage was predicted to be blocked by reducing flow from the naturalised MALF to the proposed minimum flow was for native fish passage in the Morrisons Bush reach. However, as argued above it is highly likely that many species of native fish would still to be able to find passable water velocities in either close to the bed, or in shallow edge water - places that are beyond the resolution of the hydraulic modelling. Furthermore, the flow is not likely to be at the minimum for much of the time. Consequently, even if fish passage was obstructed at the minimum flow this should be a transient problem (depending on the low flow duration).

4. FLOW EFFECTS ON WATER QUALITY

The relationship between low flow and water quality in the lower Ruamahanga River was highlighted as another knowledge gap by Watts & Perrie (2007). In order to partially address this question a temperature and dissolved oxygen (DO) logger was deployed adjacent to GWRC's regular State of the Environment monitoring site at Pukio, approximately 1 km downstream of the Pahautea habitat modelling reach (Figure 1). Data were recorded at half hourly intervals at this site.

Water temperature and dissolved oxygen are arguably two of the most directly relevant water quality parameters to fish and invertebrates, because they directly affect metabolism, and mediate the effects of some potential toxicants. Dissolved oxygen fluctuations can also give some indication of the ecosystem scale effects of nutrient enrichment.

Excessively high water temperature can be lethal for fish, but even moderately high temperature can induce behavioural responses and retard growth. The thermal tolerance of New Zealand native fishes is generally higher than that of trout (Richardson *et al.* 1994). Consequently, interpreting temperature data with respect to the thermal tolerances of trout should provide a conservative assessment of the likely effects on native fish.

The incipient lethal temperature[3] for brown trout increases with acclimation to a plateau at 24.7°C, while the ultimate lethal temperature reaches a plateau at 29.7°C (Elliott 1981; Elliott 1994; Elliott & Elliott 1995). Behavioural disturbances can be expected at temperatures less

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[3] The incipient lethal temperature is usually defined as that which fish (usually 50% of a given sample) can tolerate for a prolonged period (seven days is the usual standard) but beyond which fish cannot tolerate for an indefinite period (Elliott 1994). The ultimate lethal temperature is that which fish cannot tolerate for even a short period (10 minutes is the usual standard).

than the incipient lethal temperature. For example, brown trout cease feeding at temperatures above 19°C. Trout deaths have been reported in New Zealand rivers when water temperatures have equalled or exceeded 26°C (Jowett 1997). However, mortality is likely to increase as water temperature rises above the growth optima (14°C – 17°C for brown trout), and population productivity is likely to suffer (Hokanson *et al.* 1977). As temperature increases fish are likely to seek refuge, in cooler tributaries, deeper water, or where cool groundwater up-wellings occur, for example (Nielsen *et al.* 1994; Mathews & Berg 1997; Ebersole *et al.* 2001; Barid & Krueger 2003; Hay 2004).

Salmonids are also more sensitive to low dissolved oxygen than most other freshwater fishes, including New Zealand native fish species (Dean & Richardson 1999), and (on the basis of what little information is available) guideline levels of DO that will protect fish are also likely to protect invertebrates (ANZECC 2000). A minimum oxygen concentration of 5.0–5.5 mg/L can be tolerated by free swimming brown trout but should be at least 80% saturation (Mills 1971 cited in Elliott 1994). The incipient lethal level of dissolved oxygen concentration for free swimming brown and rainbow trout is about 3 mg/L (Raleigh *et al.* 1984, 1986). Dean & Richardson (1999) recorded no mortality for several species of native fish, as well as juvenile rainbow trout, at DO levels of 5 mg/L over a 48 hour exposure period. However, long-term exposure to dissolved oxygen levels of even 6 mg/L can chronically impair the growth of salmon, by up to 20% depending on the water temperature (BCME 1997). Following the BCME (1997) guidelines, 8 mg/L is an appropriate long-term (*e.g.* 30 day mean) level for best protection of salmonids and other aquatic life. ANZECC (1992) water quality guidelines suggest a minimum of 6 mg/L or 80% saturation to protect aquatic life, and the 80% saturation guideline is also included in the RMA (1991). The more recent ANZECC guidelines (2000) suggest that the long-term average or median DO should be 98-105% saturation in lowland rivers.

Figure 13 shows the DO and water temperature data recorded at the Pukio site over the period 12 January to 30 April 2007, compared with flow recorded at the Waihenga gauge site (approximately 10 km upstream, Figure 1).

This figure suggests that high flow events have a strong influence on both water temperature and dissolved oxygen patterns, but that low flows *per se.* do not have such an influence. High flow events were associated with a relatively short-term reduction in water temperatures and a reduction in the amplitude of diurnal DO fluctuations (Figure 13). The water temperature generally appeared to return to pre-flood levels within a matter of days. However, the diurnal fluctuations in dissolved oxygen increased more gradually, over a matter of weeks, presumably as periphyton biomass, sloughed off during the flood event, gradually accrued during the flow recession. It appears that the amplitude of diurnal DO fluctuations (and consequently the magnitude of the early morning DO low points) was influenced by the length of time since the last flood event, rather than the magnitude of low flow at the time, as would be expected with periphyton accrual.
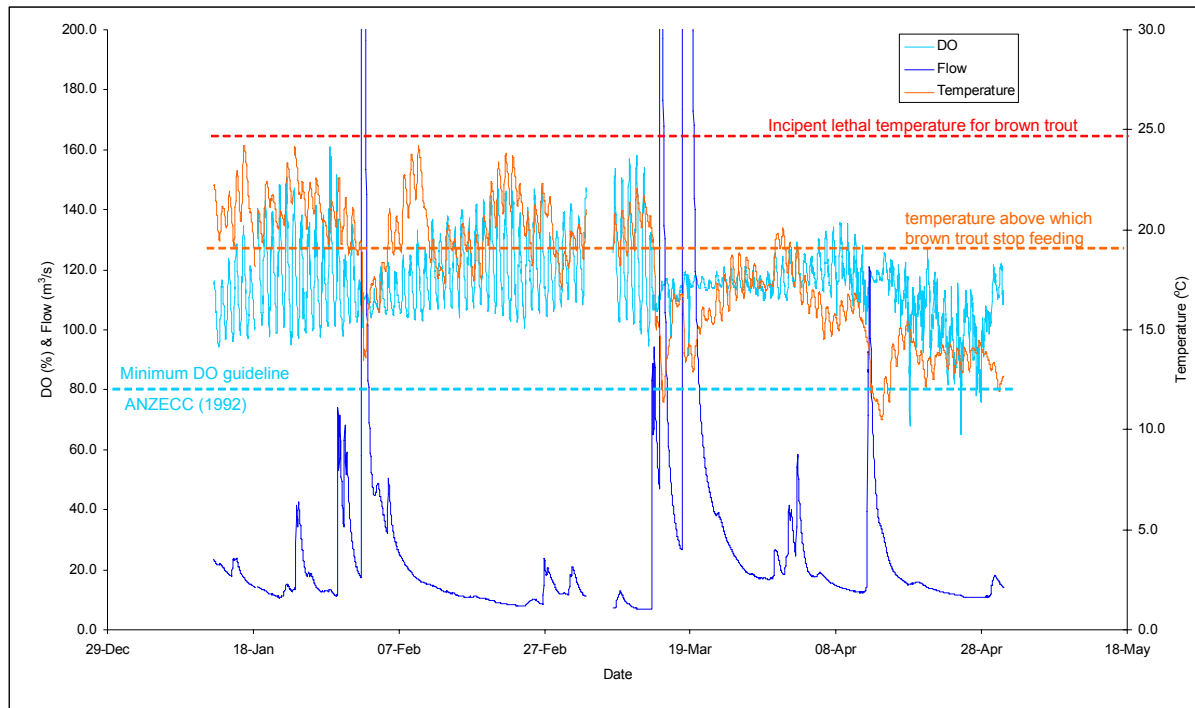
Figure 13. Time series of dissolved oxygen (DO) saturation, water temperature, and flow in the Ruamahanga River during summer 2007, at GWRC's Pukio monitoring site.

During the period depicted in Figure 13 there were a few brief periods when DO dropped below the 80% saturation guideline suggested by ANZECC (1992) and in the RMA (1991). The cause of these low DO spikes is not clear. However, these events were not associated with particularly low flows. Conversely, the periods of lowest flow, in late February and early March, when flows were in the order of 7-8 m^3/s (similar to or lower than the proposed minimum flows for the two modelled reaches) DO levels were consistently supersaturated. Even during the short-term breaches of the DO saturation guideline the level of oxygen in the water, in terms of mass per volume, never dropped below 6 mg/L, and the 30 day average was always above 10 mg/L.

The timing of flushing events is beyond the control of water managers, unless a substantial water storage dam was constructed in the catchment. The dissolved oxygen levels experienced in the lower Ruamahanga are not able to be controlled by altering the permitted minimum flow, and reducing flow from the naturalised MALF to the proposed minimum flow would have no discernable effect on DO.

Although the water temperature was above 19°C for much of the time it did not reach the incipient lethal temperature for brown trout (24.7°C). Aside from the relatively short-term sags in water temperature associated with floods, the temperature regime did not appear to be strongly related to flow. As with DO, the proposed minimum flow would have no discernable effect on water temperature.

5. SUMMARY AND RECOMMENDATIONS

This report describes the application of habitat modelling to assess instream flow requirements for the lower reaches of the Ruamahanga River. Two sections of the lower river were assessed separately. The sections addressed were:

1. The highly sinuous part of the river between the Waiohine confluence and "Bentley's Beach" (Figure 1), where the channel is less confined by stop-banks than it is further downstream, and large gravel/cobble beaches are common (represented by the Morrisons Bush reach),

2. The section between "Bentley's Beach" and Tuhitarata Bridge, where the channel is more confined by stop-banks, with gravel beaches occurring only infrequently down its length (represented by the Pahautea reach).

The method used to determine minimum flows was based on habitat (WUA) versus flow relationships derived from instream habitat modelling within the environmental flow assessment framework of the IFIM. Interpretation of the habitat versus flow relationships to identify a minimum flow for each reach was based on the following rationale:

1. Minimum flow was determined for a critical value (*i.e.* a species or life-stage that has both the highest fishery, or conservation, value and highest flow requirement); with the assumption that this minimum flow will also provide for lesser instream values, with lower flow requirements:

    - Adult brown trout were identified as the critical value in these reaches of the Ruamahanga River. Habitat suitability criteria developed for adult brown trout feeding habitat by Hayes & Jowett (1994) and by Bovee (1995) are the most appropriate of the habitat suitability criteria available for habitat modelling in these reaches.

2. The minimum flow for the critical values were referenced to the MALF or flow at which habitat is optimal, whichever was lowest.

3. A level of habitat retention was chosen which is thought likely to sustain the critical value:

    - A 90% habitat retention level for adult brown trout in these reaches is conservative and perhaps appropriate given the relatively high value of the trout fishery in the Ruamahanga mainstem, as evidenced by the level of angler use.

Table 5 contains recommended minimum flows for the two reaches assessed, based on retention of 90% of habitat at the naturalised one day MALFs (10.7 m^3/s in the Morrisons Bush reach, and 11.8 m^3/s in the Pahautea reach). Alternative minimum flows are provided in Table 4 based on 80% habitat retention in recognition that the choice of retention level is somewhat arbitrary – based on risk versus value. These alternative minimum flows may serve as a basis for negotiation over what is ultimately an appropriate minimum flow, based on the relative instream values and out-of-stream water uses.

Table 5. Suggested minimum flows for the Morrisons Bush and Pahautea reaches of the Ruamahanga River, based on retention of 90% of adult brown trout feeding habitat at the naturalised MALF.

Reach	MALF (m³/s)	Habitat Suitability Criteria	Suggested minimum flow (m³/s)
Morrisons Bush	10.7	Brown trout adult (Bovee 1995) no substrate	8.5
Pahautea	11.8	Brown trout adult (Bovee 1995) no substrate	7.5

It is important that maintenance of ecologically relevant flow variability be considered when applying these minimum flows, to help control periphyton, and sustain invertebrate productivity and fish feeding opportunities. This could be achieved using the method previously applied by Horizons Regional Council (*e.g.* Roygard & Carlyon 2004; Hurndell *et al.* 2007), which quantifies the expected change in the frequency and duration of occurrence of the minimum flow, in response to different total allocation volume scenarios, perhaps adapted to include community consultation on the level of change deemed acceptable.

Hydraulic modelling predictions indicate that implementing these suggested minimum flows would not have a significant adverse effect on fish or boat passage. A possible exception may be passage for native fish through the Morrisons Bush reach. However, passage is still likely to be possible at the minimum flow, notwithstanding the modelling predictions, and any obstruction to passage would be temporary and probably relatively brief (depending on the allocation limit adopted which will affect the duration of minimum flow).

Continuous monitoring over the summer of 2007 suggests that dissolved oxygen and water temperature are not directly influenced by the magnitude of low flow. The length of the period between flushing events did appear to influence the magnitude of diurnal DO fluctuations, but the control of the timing of flushing flood flows is not in the hands of flow managers in this catchment. Implementing the suggested minimum flows would have no discernable effect on dissolved oxygen levels or water temperature in the lower Ruamahanga River.

6. ACKNOWLEDGEMENTS

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8.   APPENDICES

Appendix 1. Habitat suitability criteria used in this report

N.B. Where no citation is given for native fish suitability criteria they are assumed to be based on Jowett & Richardson (1995).

Brown trout adult (Hayes & Jowett 1994)
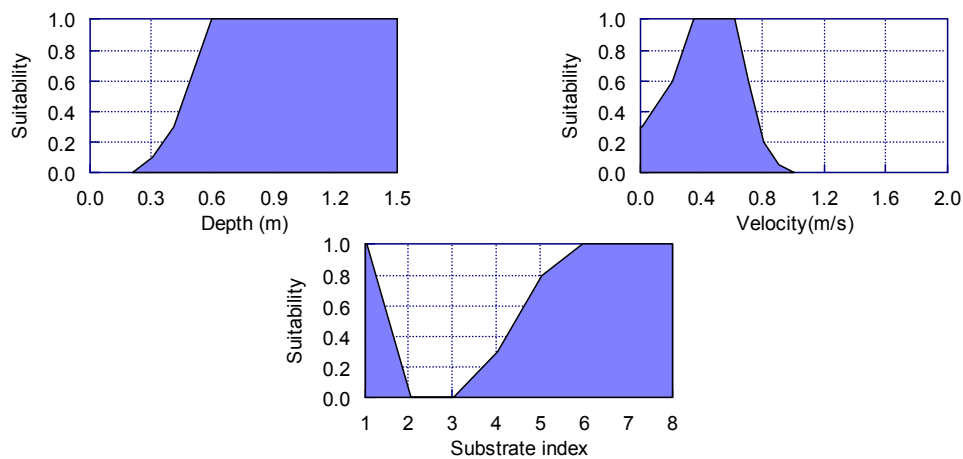
Brown trout adult (Bovee 1995) no substrate
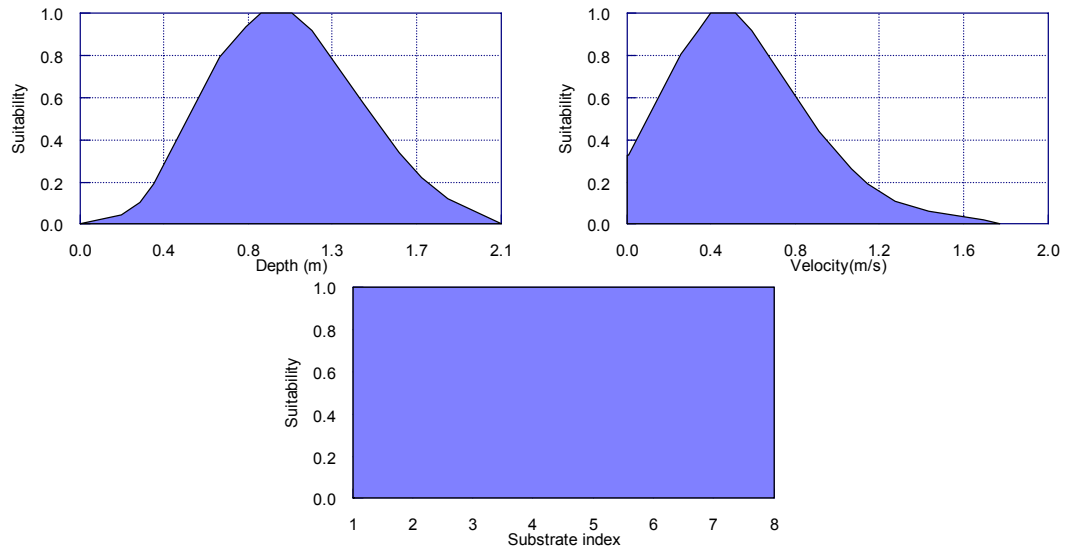
Brown trout adult (Raleigh et al. 1986)
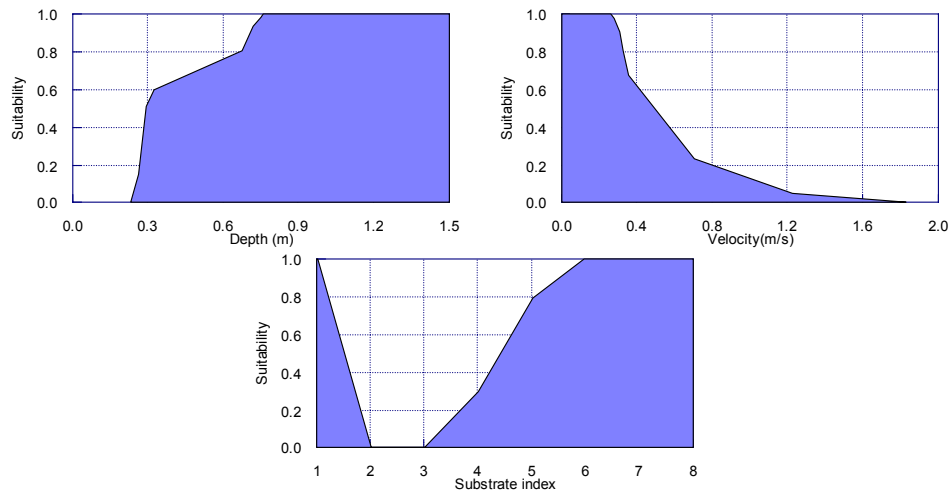
Brown trout juvenile (Bovee 1995) no substrate
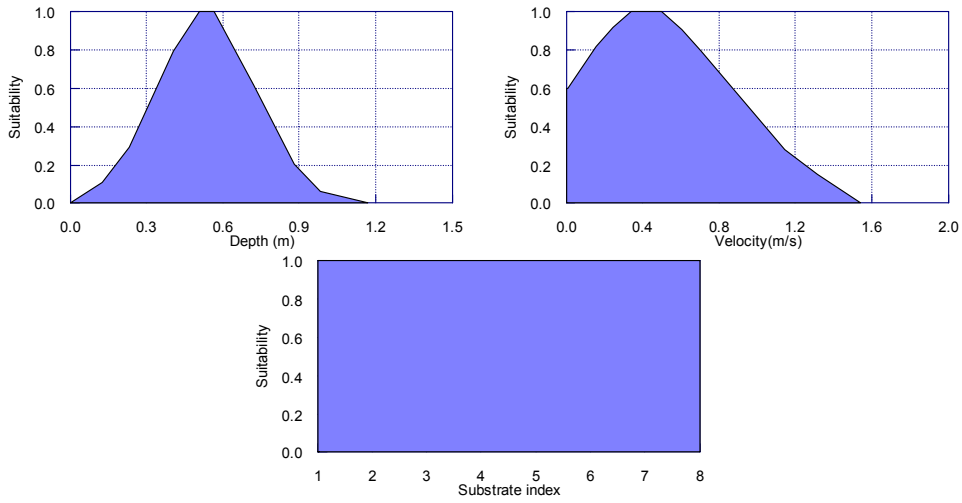
Brown trout 15-25cm (Raleigh et al. 1986)
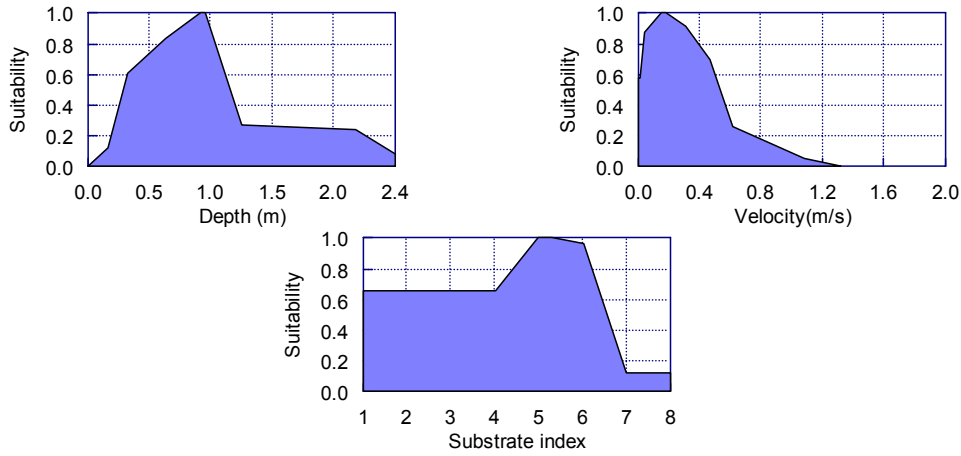
Food producing (Waters 1976)
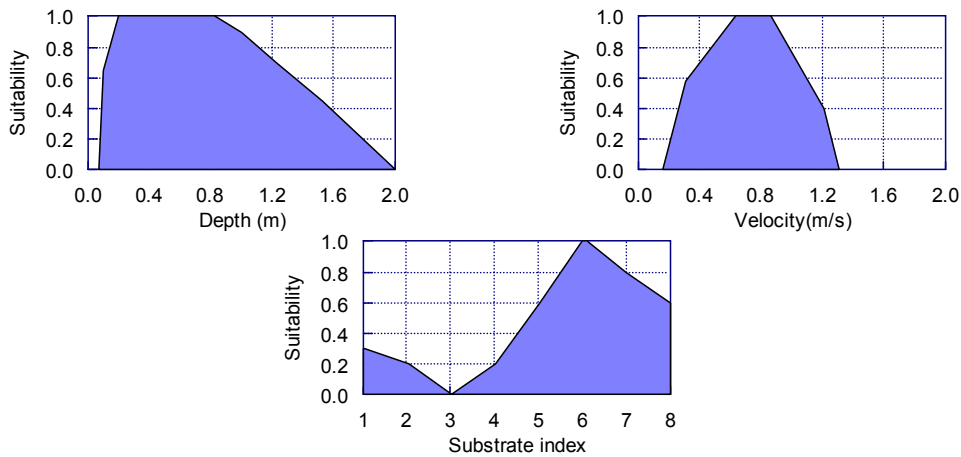
Longfin Eel > 300 mm (Jellyman et al. 2003)
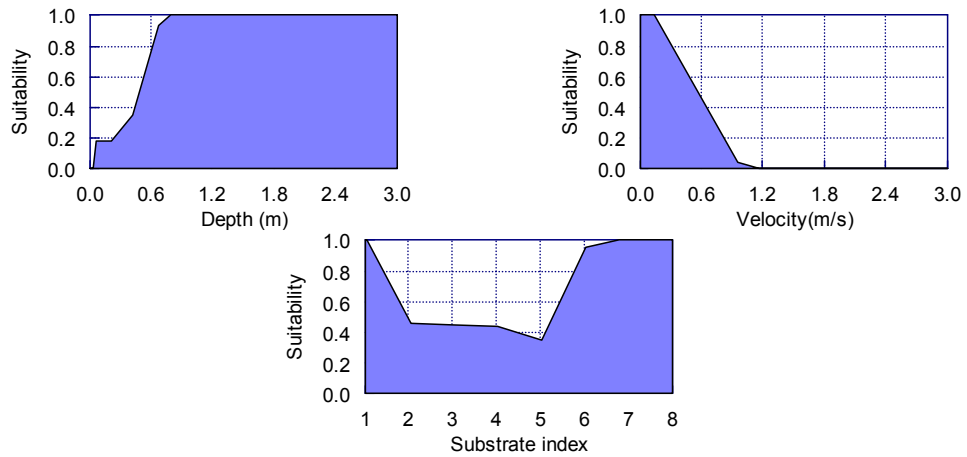
Longfin Eel < 300 mm (Jellyman et al. 2003)
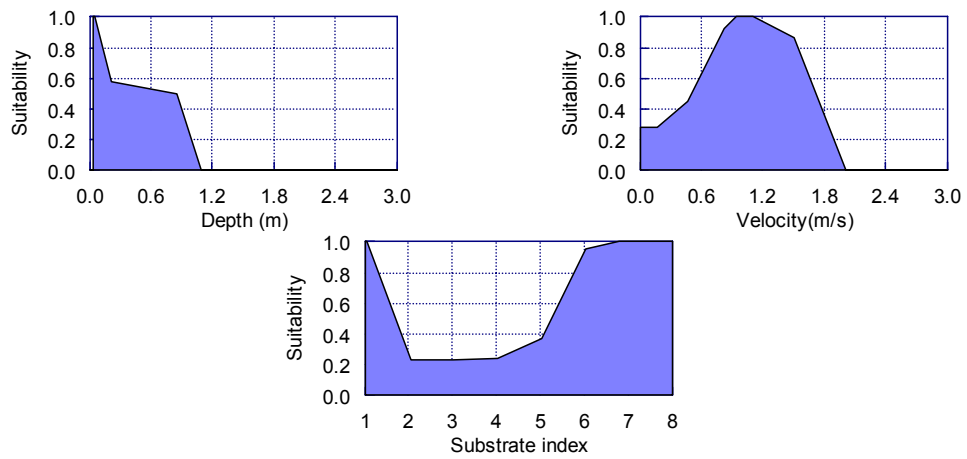
Shortfin eel (< 300mm)
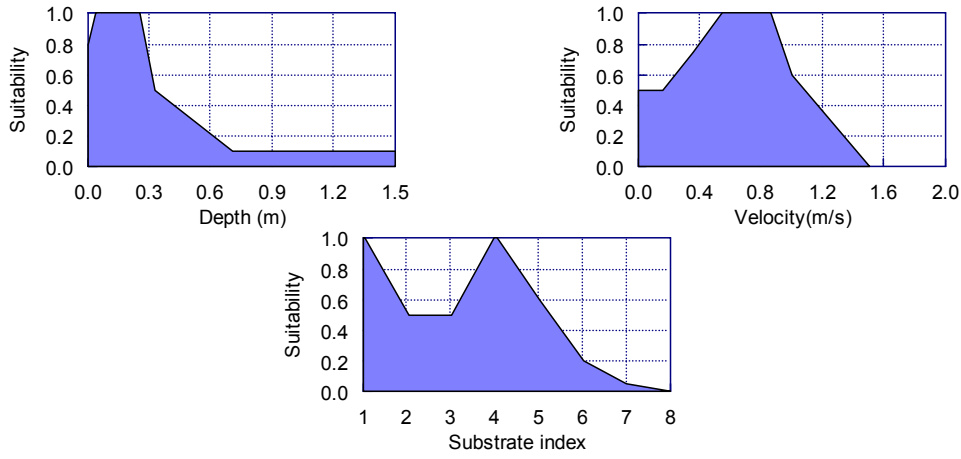
Torrentfish
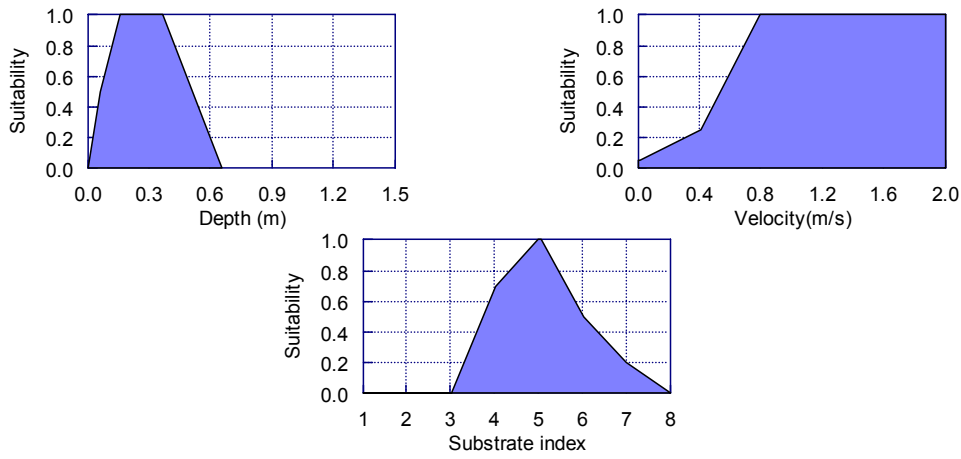
Bluegill bully
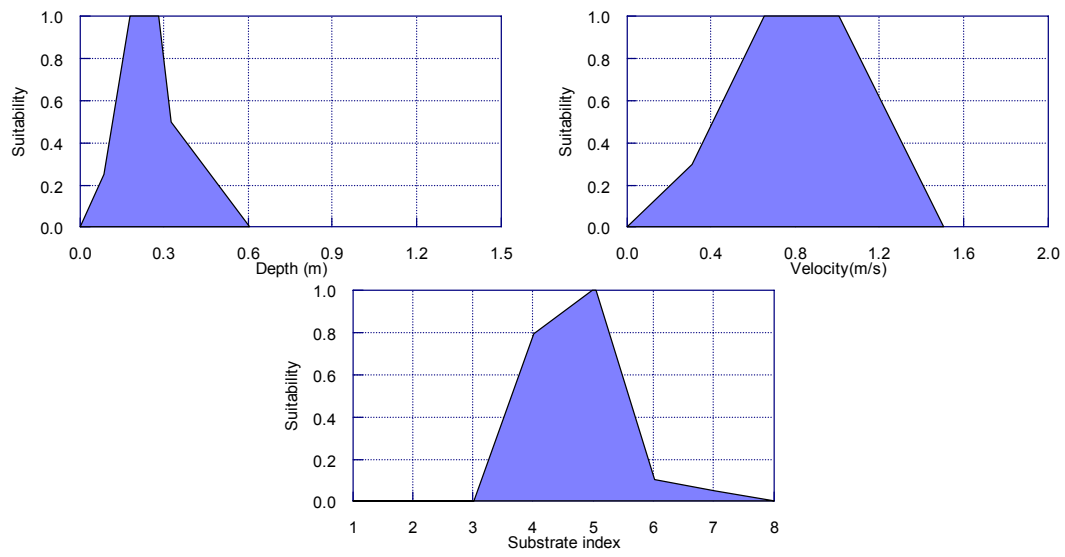
Common bully
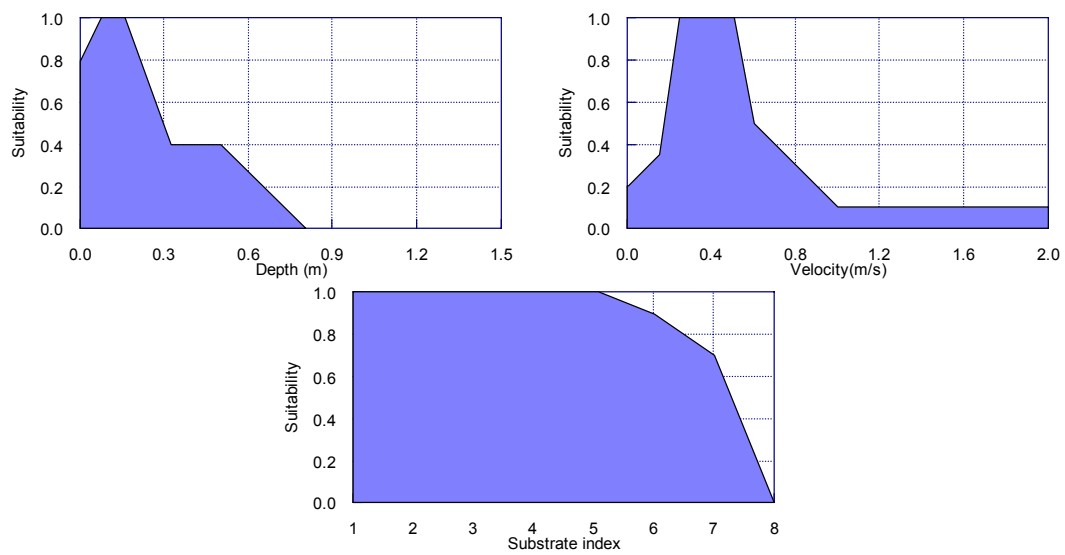
Crans bully
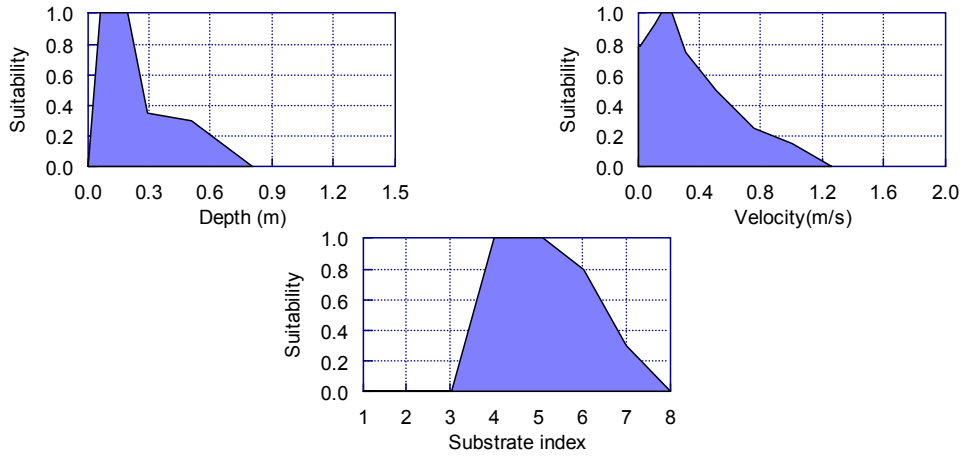
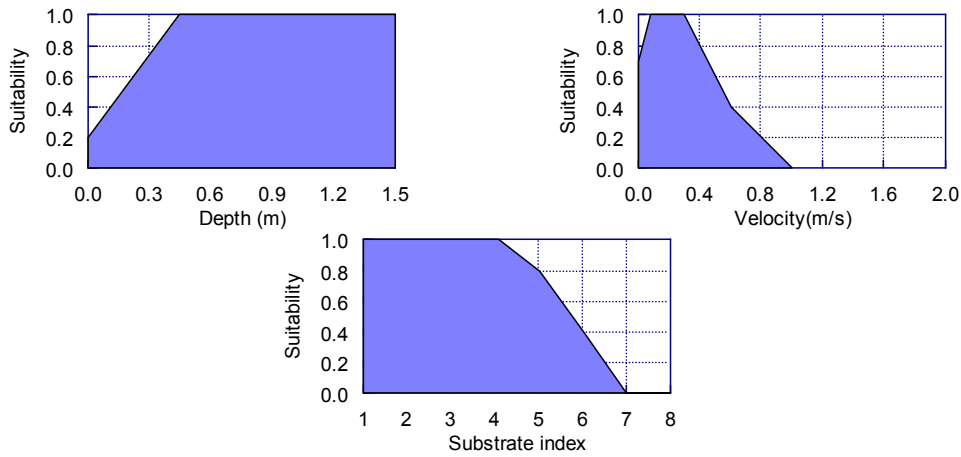## Redfin bully
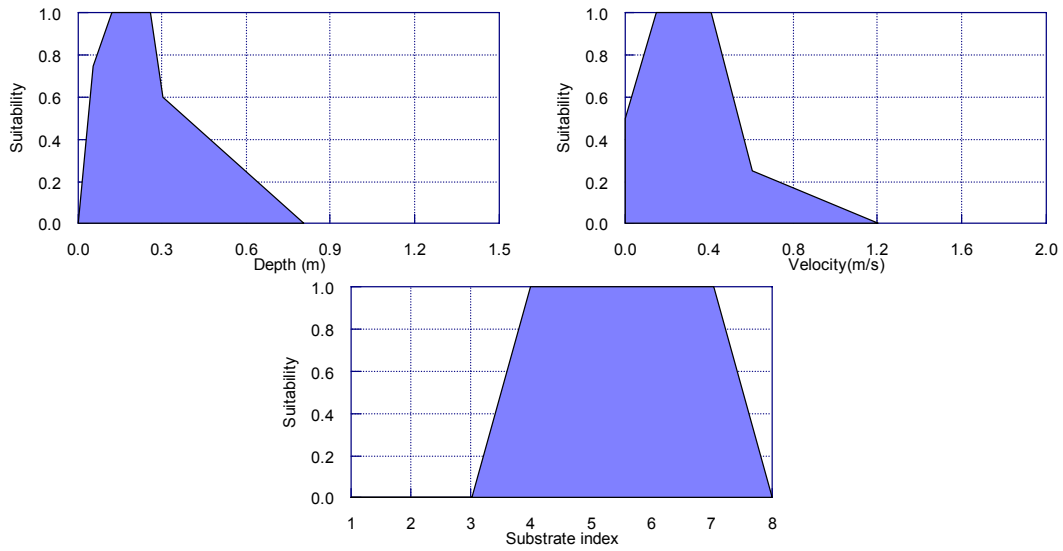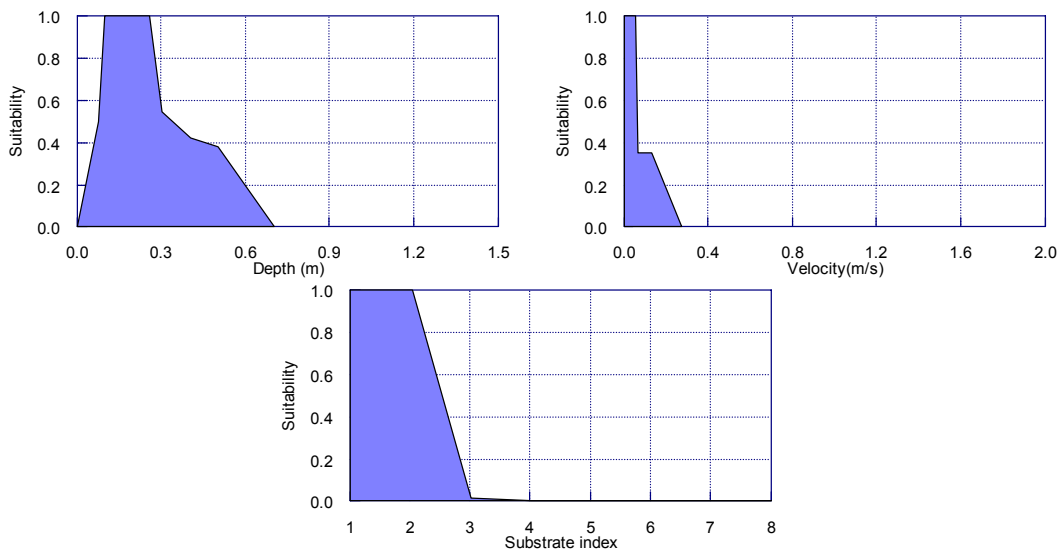
Upland bully
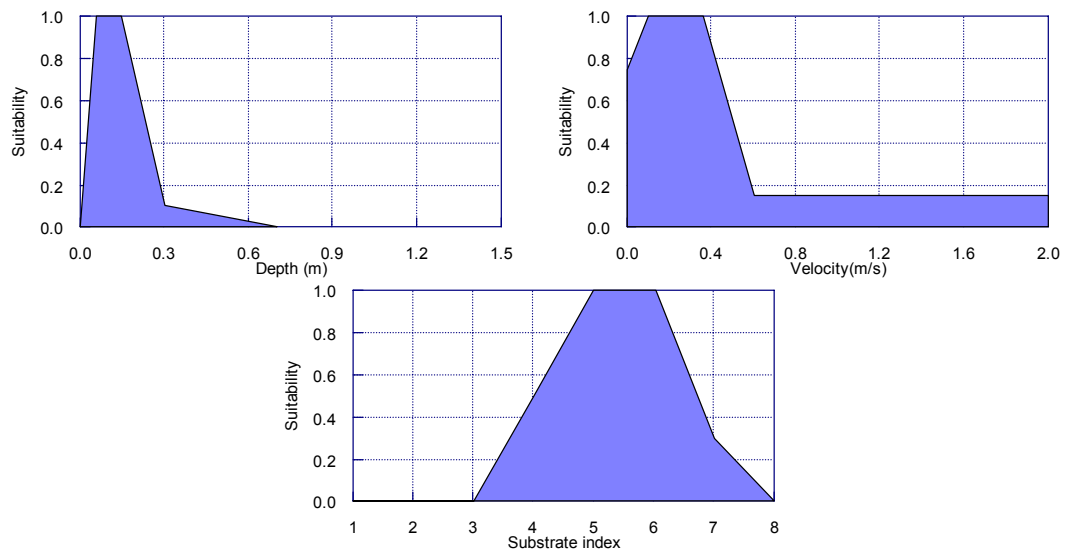
Dwarf Galaxias
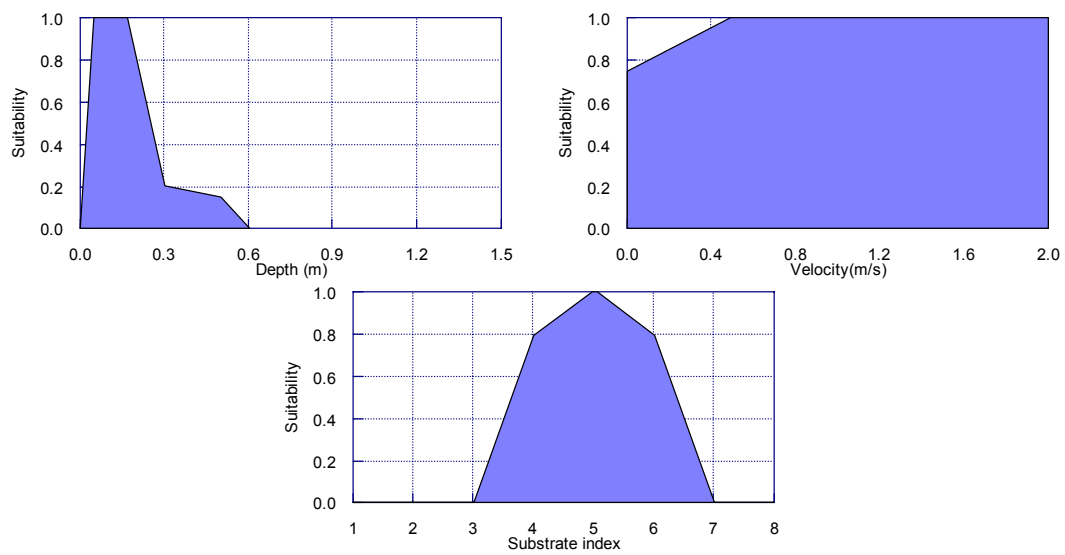
Inanga feeding (Jowett 2002)
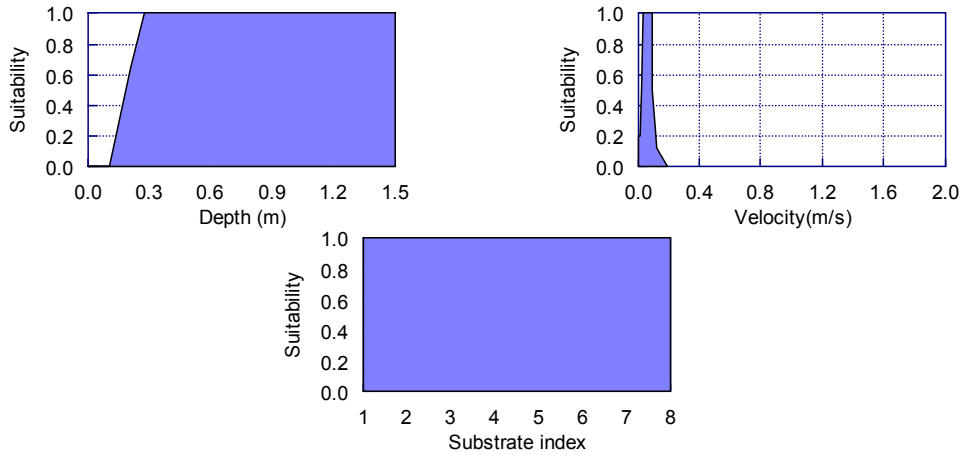
Common smelt

Juvenile lamprey (Glova & Jellyman 2001)

Appendix 2. Variation in predicted habitat quality (HSI) for trout and native fish in the Ruamahanga River, Morrisons Bush reach (a and b), Pahautea reach (c and d). Blue dashed line denotes MALF.