NIWA
Taihoro Nukurangi

Instream habitat and minimum flow and allocation requirements in the Waiapu River

Prepared for Gisborne District Council

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Executive summary

The purpose of this study is to recommend a minimum flow and to suggest a total allocation (the sum of all maximum allowable rates of abstraction) for the Waiapu River. There is currently no minimum flow for or total allocation for abstractions from the river. The Gisborne District Council (GDC) wish to put defensible minimum flows and allocations in place in preparation for any abstraction applications. To assess potential effects of abstractions and provide advice regarding minimum flow setting and allocations we used physical habitat modelling to assess the effects of changes in flows on instream physical habitat and aquatic biota. These models predict how physical habitat availability will vary in response to flow changes for a particular species by calculating the change in weighted useable area (WUA). WUA is the wetted area of a stream weighted by its suitability for use by an aquatic species. The aquatic species examined in this study were: diatoms, short filamentous algae, long filamentous algae, food producing habitat, *Deleatidium* mayfly nymphs, common bully, inanga feeding, koaro, smelt, torrent fish, small and large (>300 mm long) longfin and shortfin eels, rainbow trout fingerlings and adult rainbow trout feeding habitat. These species are either present in the Waiapu River or have been recorded in the catchment. Many of these species are diadromous, i.e., they will have to migrate along the main stem of the Waiapu River to complete their lifecycle.

Instream habitat was surveyed and modelled for different discharges for a study reach on the Waiapu River where the adjacent flood plain could potentially be irrigated and abstractions could occur. The study reach was upstream of any significant tributary inflows The study reach consisted of 14 cross-sections and the instream hydraulic model was calibrated using measurements taken at two different flows (observed on two separate occasions), estimates of the stage at higher flows based on the rating curves of the Waiapu River at Rotokautuku and the stage for zero flow at each cross-section. The gauged flows were larger than the seven day mean annual low flow (7d-MALF), so the use of the rating curve point will have little effect on the suggested minimum flow which is normally less than the 7d-MALF. These data were used to determine how two hydraulic conditions (i.e., depth and velocity) varied with flow. Habitat suitability criteria from existing general habitat suitability curves developed from studies across numerous rivers were used to calculate the relationships between flow and WUA for selected target species. Application of these habitat suitability criteria is standard procedure.

For the study reach, hydraulic modelling indicated that as flow discharge increases, river width increases rapidly at low flows and then increases steadily within the modelled flow range. Steady increases in both water depth and velocity were also calculated as flow increases. This meant that weighted useable area (WUA) increased for all biota until a flow of 5 m^3/s to 10 m^3/s was reached when WUA for short filamentous algae and rainbow trout fingerlings started to decline. The WUA for *Deleatidium* (mayfly nymphs) and food producing habitat increased across the modelled flow range (0 to 30 m^3/s), whereas the WUA for native fish species peaked between 0.5 and 15 m^3/s. Very little useable habitat was available for adult rainbow trout although WUA for juvenile rainbow trout peaked at low modelled flows.

An appropriate minimum flow for the Waiapu River will depend on what level of protection is chosen for instream species versus the amount of water set aside for allocation. The report concludes that the optimum minimum flow is 5 m^3/s. An allocation of 1.5 m^3/s should be sufficient to irrigate a large proportion of the flood plain. While this allocation has a minor effect on the number and duration of events where the flow is at or below the minimum flow, the number of freshes responsible for maintaining the health and morphology of the river would be only marginally reduced.

1 Introduction

1.1 Study brief and background

Gisborne District Council (GDC), via an Envirolink Grant, contracted NIWA to carry out an instream habitat survey and analysis to provide advice on a minimum flow and flow allocation for the Waiapu River having regard to the potential effects of different minimum flows on instream ecology. While there is currently little demand for water from the river, GDC wish to put in place a minimum flow and total allocation so that if demand increases they are in a position to confidently grant allocations knowing that the river's instream values will be protected.

The scope and nature of the services was to conduct surveys of physical habitat and then model the response of physical habitat for a range of target species to changes in flow at the site. The target species were identified by interrogating the New Zealand freshwater fish database: (//www.niwa.co.nz/our-services/online-services/freshwater-fish-database). The specific aims of this study were:

- to assess the effects of variations in discharge on the amount of in-stream physical habitat available for species of interest in this project:
  - diatoms (i.e., thin algal films)
  - short filamentous algae
  - long filamentous algae
  - food producing habitat
  - *Deleatidium* mayfly nymphs
  - common bully
  - koaro
  - inanga
  - torrent fish
  - longfin eel
  - shortfin eel
  - rainbow trout
  - smelt
- to examine how changes in minimum residual flows would alter physical habitat for the above species and life stages at the specified field site.

This study describes the relationship between minimum flows and instream physical habitat in the Waiapu River in the vicinity of Ruatoria. Minimum flow requirements are examined for the specified periphyton species, stream macroinvertebrates and fish. The importance of floods and flushing flows is also considered.

This project focused on physical habitat as defined by the combination of depths, velocities and substrates found in the Waiapu River. The instream habitat modelling that was undertaken is a time intensive method for providing information for the environmental management of flow regimes and the results produced are site specific. Additional factors influencing habitat conditions such as geomorphological changes, water quality and temperature were not investigated within this project. The Waiapu River carries a very high suspended sediment load and this sediment load is likely to reduce the value of the habitat for most species. Fine sediment settles in periphyton and drapes over larger sediment particles reducing the opportunity for diatoms to flourish and provide food for macroinvertebrates. Thus, the amount of physical habitat found is likely to be an upper bound to the amount of habitat that is useful. This is because while the combination of depths and velocities might be suitable for fish the drape of sediment makes the habitat unsuitable for the periphyton and macroinvertebrates that the fish feed on. In the future the sediment sources might be bought under control and the river may have a chance to reach its habitat potential. Also, the river has a lot of big floods that may also limit the fish population.

2 Approach

2.1 General procedure

We followed procedures recommended by the Instream Flow Guidelines developed by the Ministry for Environment (MfE 1998, 2008). From faunal surveys that had previously been conducted and reported in NIWA's fish database, we identified the main instream values that could be affected by abstraction and set these as the values to be investigated by the study. Ecological values are not the only values that are important because aesthetic values, landscape values, Māori cultural and traditional values can also be influenced by flow changes (MfE 1998), but only instream values are examined in this report.

We used physical habitat modelling and related techniques to assess the effects of changes in flows on instream physical habitat for aquatic taxa. The analysis contained in this report quantifies the relationship between river flow and availability of suitable physical habitat for aquatic taxa. This report outlines how different minimum flows will negatively or positively influence physical habitat for particular species and the relative changes in availability of suitable physical habitat over a range of minimum flows.

2.2 Methods for determining instream flow requirements

Many factors influence the health of river ecosystems including temperature, oxygen, light, geomorphology and flow (Hynes 1970; Giller & Malmqvist 1998; Norris & Thoms 1999). All elements of a flow regime are important, including floods, average and low flows (Junk et al., 1989; Poff et al., 1997; Richter et al., 1997). A holistic approach must therefore be taken for the long-term management of river systems. Such an approach considers how human activities impact upon interactions between factors such as geology, sediment transport, channel structure, riparian conditions, water quality and biological habitat. However, apart from through dilution effects, flow rate (m^3/s) is only a surrogate variable; it is the water depth and velocity in a river, created by the interaction between flow rate and channel morphology, that provides physical habitat for plants, invertebrates and fish (Booker & Acreman 2006). Jowett (1992) found that the amount of physical habitat was an important determinant of trout abundance; Gore et al., (1998) found relationships between physical habitat (i.e., wetted area) and actual benthic community diversity; and Gallagher & Gard (1999) found a positive correlation between physical habitat and spawning density of salmon.

The direct relationship between physical habitat and flow provides a means for assessing the ecological impact of changing the flow regime of a river (Cavendish & Duncan 1986; Jowett 1990; Beecher et al., 1993). However, assessment of river flow management options often involves assessing scenarios that fall outside the range of observed conditions, and thus predictive models are required. The Physical Habitat Simulation (PHABSIM) system (Bovee 1982; Bovee et al., 1998) was the first systematic modelling framework to be developed and many models based on a similar concept have been produced including CASiMIR in Germany (Jorde 1996; Eisner et al., 2005), EVHA in France (Ginot 1995), RHYHABSIM in New Zealand (Jowett 1989) and RSS in Norway (Killingtviet & Harby 1994). Essentially these models quantify the relationship between physical habitat, defined in terms of the combination of depth, velocity and substrate/cover, and various flows (e.g. Johnson et al., 1993; Elliott et al., 1996). Criticisms of this approach include lack of biological realism (Orth 1986) and mechanisms (Mathur et al., 1985; Booker et al., 2004). Nevertheless, the models have been applied throughout the world (Dunbar & Acreman 2001), primarily to assess impacts of abstraction or river impoundment. However, the method has also been used to assess the effects of channel restoration and modification (Acreman & Elliott 1996; Booker & Dunbar 2004). PHABSIM in particular has become a legal requirement for many impact studies in the USA (Reiser et al., 1989) and a standard tool employed by the Environment Agency of England and Wales to define the sensitivity of rivers to abstraction (Booker & Acreman 2006). RHYHABSIM has been applied to many rivers in New Zealand (Lamouroux & Jowett 2005) for a variety of reasons. Jowett and Biggs (2006) reviewed the results from six rivers in which habitat-based methods had been applied to flow setting. They found that in five of these cases the biological response and the retention of desired instream values was achieved.

The instream flow incremental methodology (IFIM; Bovee 1982; Bovee et al., 1998) is an example of an interdisciplinary framework that can be used in a holistic way to determine an appropriate flow regime by considering the effects of flow changes on instream values, river morphology, physical habitat, water temperature, water quality, and sediment processes (Figure 2-A). This report uses the IFIM approach to examine the effect of flow on instream physical habitat only. The approach used did not investigate potential changes in water temperature, water quality or sediment transport arising from changes in flow management.

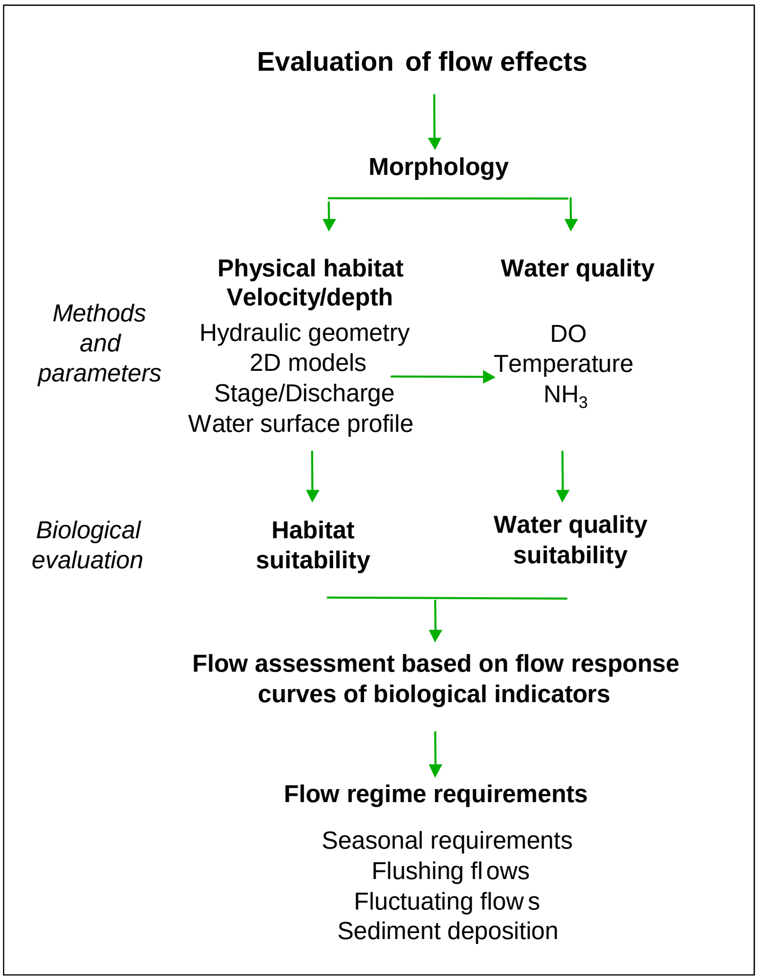


Figure 2-A: A framework for the consideration of flow requirements (Jowett & Biggs 2006).

A variety of approaches and frameworks to instream flow methods exist (Jowett 1997). In contrast with IFIM, other flow assessment frameworks are more closely aligned with the "natural flow paradigm" (Poff et al., 1997). The range of variability approach (RVA) and the associated indicators of hydrologic alteration (IHA) allow an appropriate range of variation, usually one standard deviation, in a set of 32 hydrologic parameters derived from the 'natural' flow record (Richter et al., 1997). The implicit assumption in this method is that the natural flow regime has intrinsic values or important ecological functions that will be maintained by retaining the key elements of the natural flow regime. Arthington et al., (1992) described a holistic method that considers not only the magnitude of low flows, but also the timing, duration and frequency of high flows. This concept was extended to the building block methodology (BBM), which "is essentially a prescriptive approach, designed to construct a flow regime for maintaining a river in a predetermined condition" (King et al., 2000). It is based on the concept that some flows within the complete hydrological regime are more important than others for the maintenance of the river ecosystem, and that these flows can be identified and described in terms of their magnitude, duration, timing, and frequency. More recently, Poff et al., (2010) proposed the ecological limits of hydrologic alteration (ELOHA) framework in which stakeholders and decision-makers explicitly evaluate acceptable risk as a balance between the perceived value of the ecological goals, the economic costs involved and the scientific uncertainties in functional relationships between ecological responses and flow alteration. Whilst there are many methods available for setting flows, all of which have pros and cons, physical habitat modelling and IFIM is the technique most commonly used throughout New Zealand at present. Therefore, this technique has been used to determine a minimum flow range for the Waiapu River and below we explain how physical habitat modelling and IFIM are conducted.

2.3 Physical habitat modelling

The approach adopted in many physical habitat studies is described by Johnson et al., (1995), Jowett (1997) and Clausen et al., (2004). This approach includes four main steps: identification of river sectors and species of interest; identification of habitats that exist within the sectors of interest; selection of cross-sections which represent replicates of each habitat type; and collection of model calibration data (water surface elevation, depth and velocity). These calibration data are used to determine the spatial distribution of depths and velocities across each cross-section (e.g., Figure 2-B) and the relationship between water levels at each cross-section and the quantity of water flowing in the river (e.g., Figure 2-C.

The calibration data are collected in order to simulate hydraulic conditions in the river for a range of flows which can then be combined with appropriate habitat suitability criteria (HSC). This allows prediction of useable physical habitat for the species / life stage of interest. Useable physical habitat is commonly expressed as Weighted Useable Area (WUA) in m^2 per m of river channel. WUA is an aggregate measure of physical habitat quality and quantity and will be specific to a particular discharge and species / life stage. Assessment of the changes in WUA which might occur as a result of any proposed changes in flow regime can then be made. In New Zealand habitat modelling has typically followed either one of two methods.

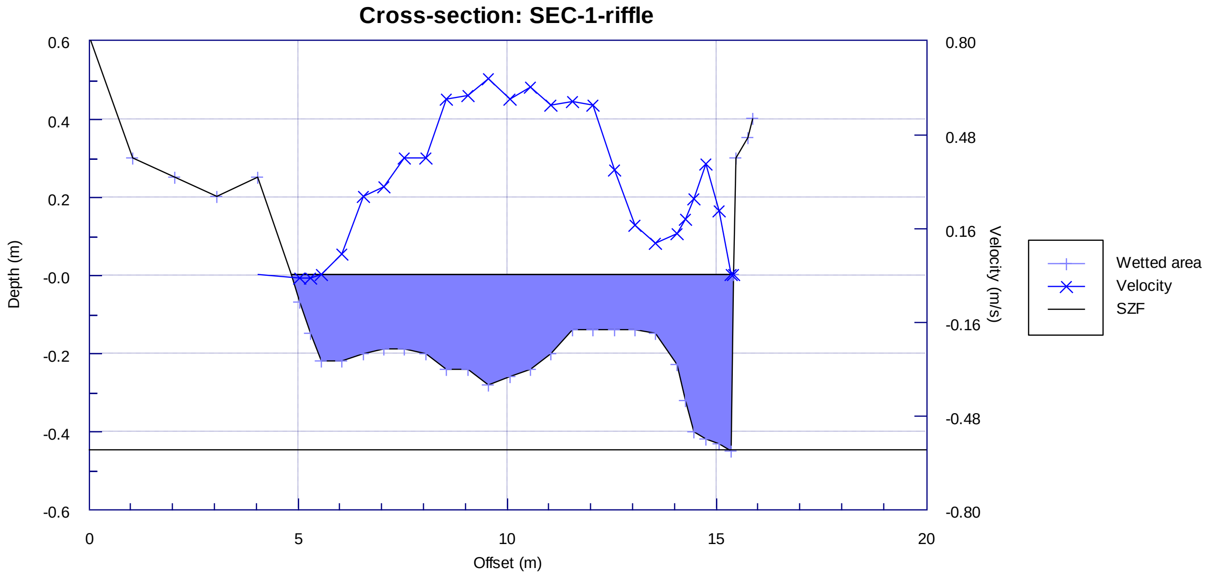


Figure 2-B: Example of velocities and depths measured for a cross-section. SZF = stage at zero flow.

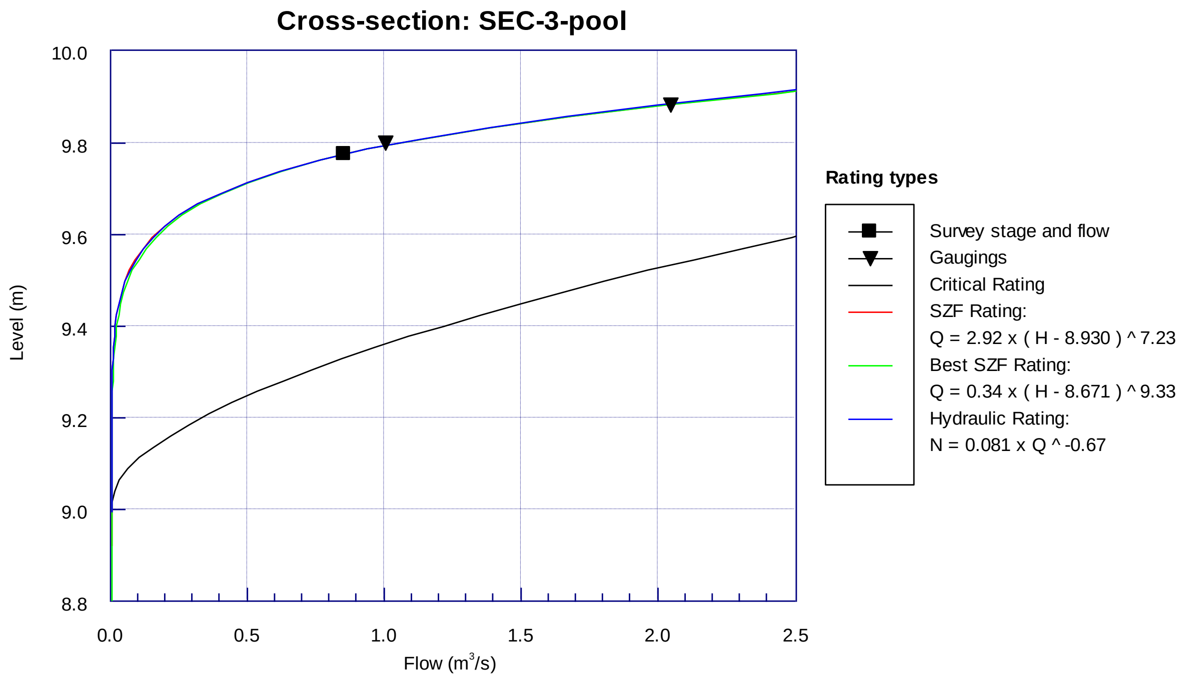


Figure 2-C Example of a water level-discharge relationship at a cross-section.

The first method is known as the "habitat mapping" method. The number and distribution of habitat types within the reach of interest are identified using habitat mapping techniques. Stage-discharge relationships are applied to simulate hydraulic conditions at isolated cross-sections placed throughout the reach of interest. Identification of the habitat type and several observations of water surface level and discharge are required at each cross-section. Modelled conditions at these cross-sections are then used in conjunction with results from the habitat mapping to weight each cross-section and therefore represent conditions in the reach of interest. The advantage of the habitat mapping method is that it does not require the selection of a representative reach from within the length of river that is of interest.

The second method is known as the "representative reach" method. One-dimensional hydraulic modelling approaches are applied to a series of cross-sections located contiguously along the river to form a study site within the length of river that is of interest. The habitat types of each cross-section may be identified and can be used to assess the representativeness of the modelled reach. The advantage of the representative reach approach is that it allows more physically-based methods to be used in hydraulic simulation. This can be advantageous in rivers with particularly complex hydraulic characteristics caused by low width-to-depth ratios, the presence of in-channel vegetation or frequent groundwater-surface water interactions.

Both the "habitat mapping" and the "representative reach" methods may involve identification of habitat types (e.g., Table 2-1) .Methods for identification of physical habitat types have been developed and applied over many years on different river types for research and river management purposes internationally (Jowett 1993; Maddock 1999; Maddock et al., 2004). These methods aim to identify the types and spatial configuration of geomorphic and hydraulic units. Habitat identification and mapping is often used in conjunction with physical habitat studies when 'upscaling' results from discrete sections to provide catchment wide assessments, or make river management recommendations. Information on the application and testing of habitat mapping approaches is described in the literature (e.g. Bisson et al., 1982; Hawkins et al., 1993; Jowett 1993; Roper & Scarnecchia 1995; Poole et al., 1997; Vadas Jr. & Orth 1998; Bjorkland et al., 2001; Parasiewicz 2001; Parasiewicz & Dunbar 2001; Roper et al., 2002; Dauwalter et al., 2006). Physical habitat units have been defined and classified by many authors, leading to an array of terms in use to describe the physical environment utilised by the instream biota. The terms used to describe these units differ between authors and include 'channel geomorphic units' (CGU's) (e.g. Hawkins et al., 1993), 'mesohabitats' (e.g. Tickner et al., 2000), 'physical biotopes' (e.g. Padmore 1997) and 'hydraulic biotopes' (e.g. Wadeson 1994). Newson & Newson (2000) provided a review of the use of some of these terms and the differences between them.

2.4 Flow setting

The National Policy Statement for Freshwater Management (NPSFM) states that, for flowing water, water quantity limits (i.e., environment flows as defined in MfE 2013) must comprise at least a minimum flow and an allocation rate. In situations where a regional council has not set minimum flows for a catchment, proposed interim limits for ecological flows for rivers with mean flows greater than or equal to 5 m^3/s were proposed by the Ministry of the Environment (MfE 2008). These proposed limits are for a minimum flow of 80% of the mean annual low flow as calculated by the regional council and a total allocation of 50% of MALF. (MfE 2013) suggests that this default minimum flow would be superseded following any more detailed study, such as a physical habitat modelling study.

Table 2-1: Habitat type definitions used in this study (after Hawkins et al., 1993 and Maddock 1999).

Channel Geomorphic Unit (CGU)	Hydraulic character	Brief Description
Fall (Fa)	Turbulent and very fast	Vertical drops of water over the full span of the channel, commonly found in bedrock and step-pool stream reaches
Cascade (Ca)	Turbulent and very fast	Highly turbulent series of short falls and small scour basins, frequently characterised by very large substrate and a stepped profile
Chute (Ch)	Turbulent and very fast	Narrow steep slots or slides in bedrock
Rapid (Ra)	Turbulent and fast	Moderately steep channel units with coarse substrate, unlike cascades possess planar profile
Riffle (Ri)	Turbulent and moderately fast	Most common type of turbulent fast water mesohabitat in low gradient alluvial channels. Substrate is finer than other fast turbulent mesohabitats. Less white water, with some substrate breaking the surface
Run (Ru)	Non-turbulent and moderately fast	Moderately fast and shallow gradient with ripples on the water surface. Deeper than riffles with little, if any, substrate breaking the surface
Glide (Gl)	Non-turbulent and moderately slow	Smooth 'glass-like' surface, with visible flow movement along the surface. Relatively shallow compared to pools
Pool (Pl)	Non-turbulent and slow	Relatively deep and slow flowing (compared to glides), with fine substrate. Usually little surface water movement visible. Consists of transition from pool-head, mid-pool and pool-tail.
Ponded (Pd)	Non-turbulent and slow	Water ponded behind an obstruction – weir, sluice or other obstruction
Other (O)		To be used in unusual circumstances where feature does not fit any recognised type

Regardless of the method of data collection, simulated hydraulic conditions are then compared with the habitat suitability criteria in order to assess how the combined quality and quantity of physical habitat varies as flow changes. The habitat value at each point is calculated as a joint function of depth, velocity and substrate type using the method shown in Figure 2-D. The area of useable physical habitat, or weighted useable area (WUA), is calculated by multiplying the area represented by each point by its joint habitat value. For example in Figure 2-D at a given point in the river (representing an area of reasonably uniform depth and velocity) where the depth is 0.1 m, depth suitability is only 65% optimal, according to knowledge of the depth requirements of the fish. Similarly, the velocity recorded at the point is 0.25 m/s, which is optimal (suitability weighting of 1), and the substrate is fine gravel (sub-optimal, with a weighting of 0.4) and cobbles (optimal with a weighting of 1). Multiplying these weighting factors together we get a joint habitat suitability weighting of 0.455 for that point in the river for the selected fish species. If the depth had been 0.2 m and there had been no fine gravel, then that point in the river would have been optimal (i.e., 1 for depth × 1 for velocity × 1 for substrate = 1). This exercise is repeated within the habitat assessment model for the depth/velocity/substrate characteristics in every grid square across the river, and the area covered by each square is multiplied by the point suitability. These areas, which have been weighted by their respective point suitability values, are then summed to give a measure of total area of suitable physical habitat for the given species at the given flow. This process is then repeated for a series of other flows with the depths, velocities, and habitat values being modelled for the new flows as described above. The total area of suitable physical habitat is then plotted as a function of flow to show how the area of suitable physical habitat for a given species changes with flow. Variations in the amount of suitable habitat with flow are then used to assess the effect of different flows for target organisms.

Where habitat modelling has been conducted, various approaches to setting levels of protection provided by a minimum flow can be used. For example, for maintaining a maximum amount of habitat, a percentage of habitat at median flow, or using a breakpoint (or “inflection point”) on the habitat/flow relationship (Jowett 1997). The latter has possibly been the most common procedure used where minimum flow requirements have been assessed using habitat methods. While there is no percentage or absolute value associated with a breakpoint, it is a point of diminishing return, where proportionately more habitat is lost with decreasing the flow than is gained by increasing the flow.

Habitat methods can also incorporate flow regime requirements, in terms of both seasonal variation and flow fluctuations. Flow fluctuations are an important component of the habitat of most naturally flowing streams. Such fluctuations remove excess accumulations of silt and accumulated organic matter (e.g., from algal slimes) and rejuvenate stream habitats. Extended periods without a flow disturbance can result in a shift in benthic community composition such as a reduction in diversity and an increase in density and biomass of snails and other species (Suren et al., 2003).

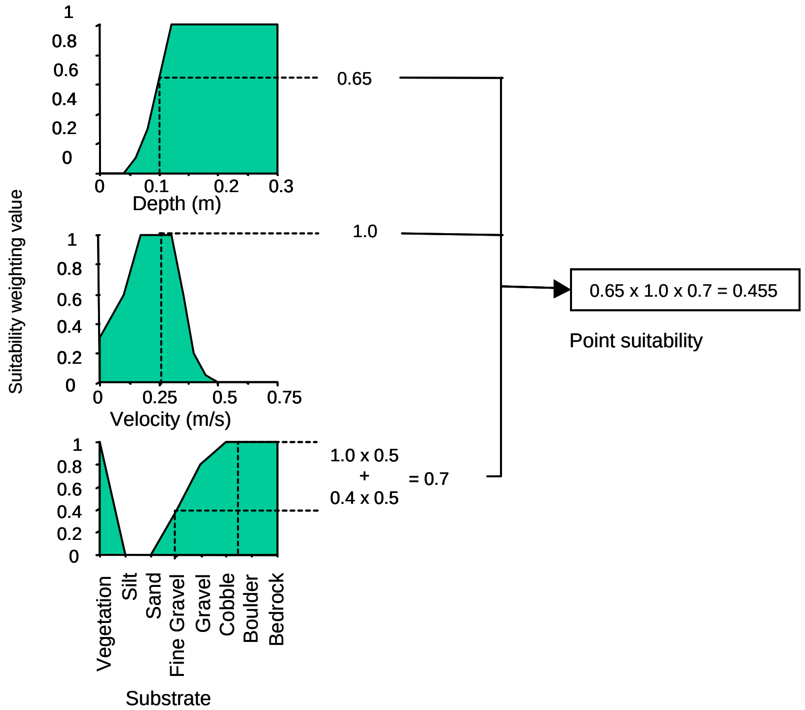


Figure 2-D: Calculation of habitat suitability for a fish species. This example is for a fish species at a point with a depth of 0.1 m, velocity of 0.25 m/s, and substrate comprising 50% fine gravel and 50% cobble. The individual suitability weighting values for depth (0.65), velocity (1.0), and substrate (0.7) are multiplied together to give a combined point suitability of 0.455.

3 Data collection

3.1 Site location

The Waiapu River is located near East Cape and drains the northern part of the eastern side of the Raukumara Range. It is formed when the Tapuaeroa and Mata Rivers join about 22 km from the sea. The Waiapu River is a 6th-order stream with a catchment area of 1378 km² at the Rotokautuku Bridge and approximately 1730 km² at the sea.

This study concentrated on the reach in the vicinity of Ruatoria where the first demands for water from the Waiapu River are likely to occur. This reach between the Mata and Mangaoparo Rivers is regarded as ecologically critical as more water is added to the river from the Mangaoparo River and other tributaries further downstream. The study reach was located in the upper reach of the Waiapu River approximately 22 km from the sea. The upstream end of the study reach was located at 2068468E, 579414N (NZTM) and the reach extended for 1300 m to the downstream cross-section at 2069148E, 5795883N (NZTM). The Waiapu River is predominately a single channel cobble and gravel bed stream and is characterised by runs and with only occasional pool habitats present (Figure 3-A). During the study it was observed that the coarse sediment of slow flowing stream margins were often covered in thick drape of fine sediment.

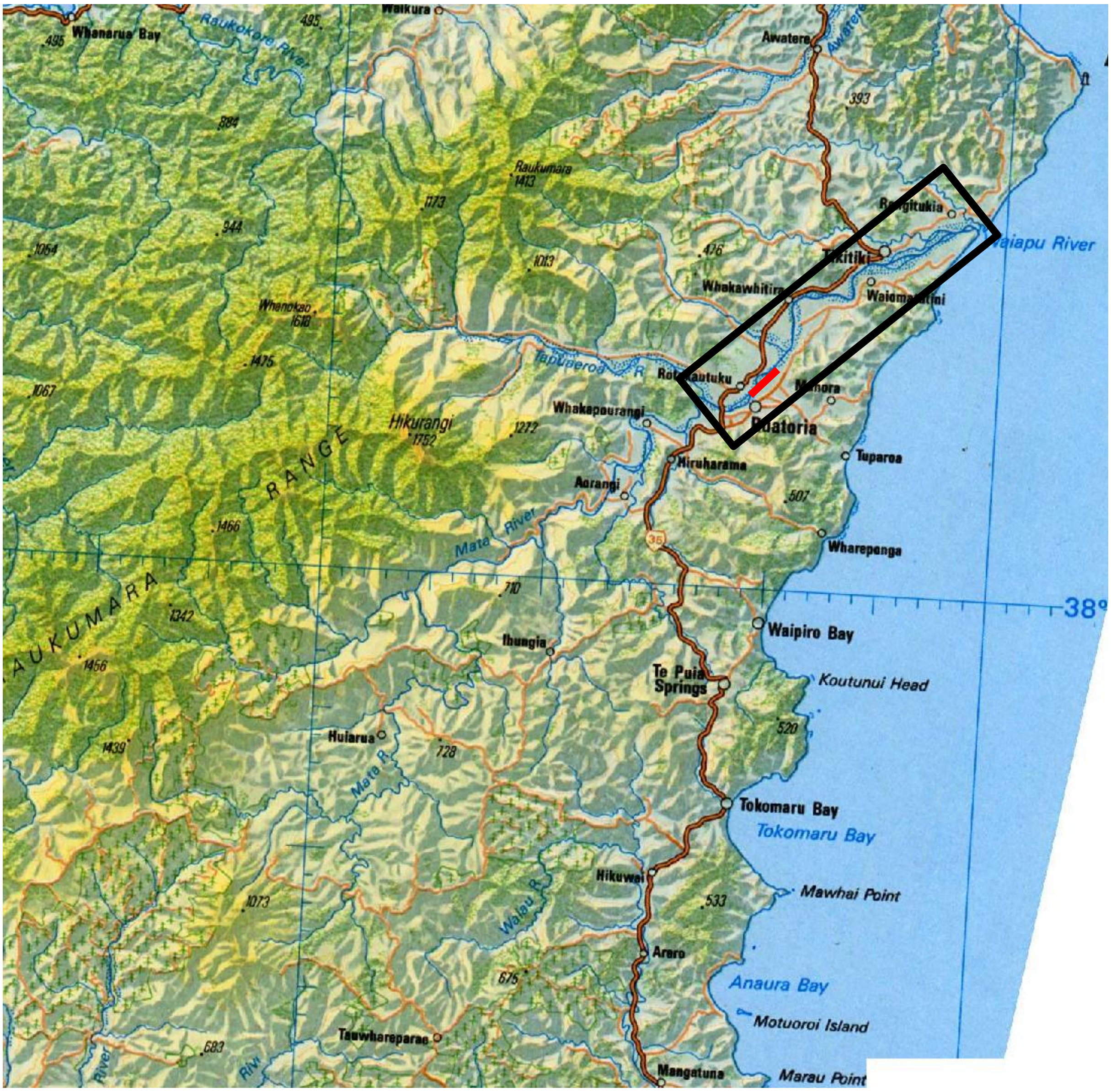


Figure 3-A: Specific location of the study reach (block rectangle) relative to the length of Waiapu River that was habitat mapped (red line).

The specific location of the study reach is shown in Figure 3-B.

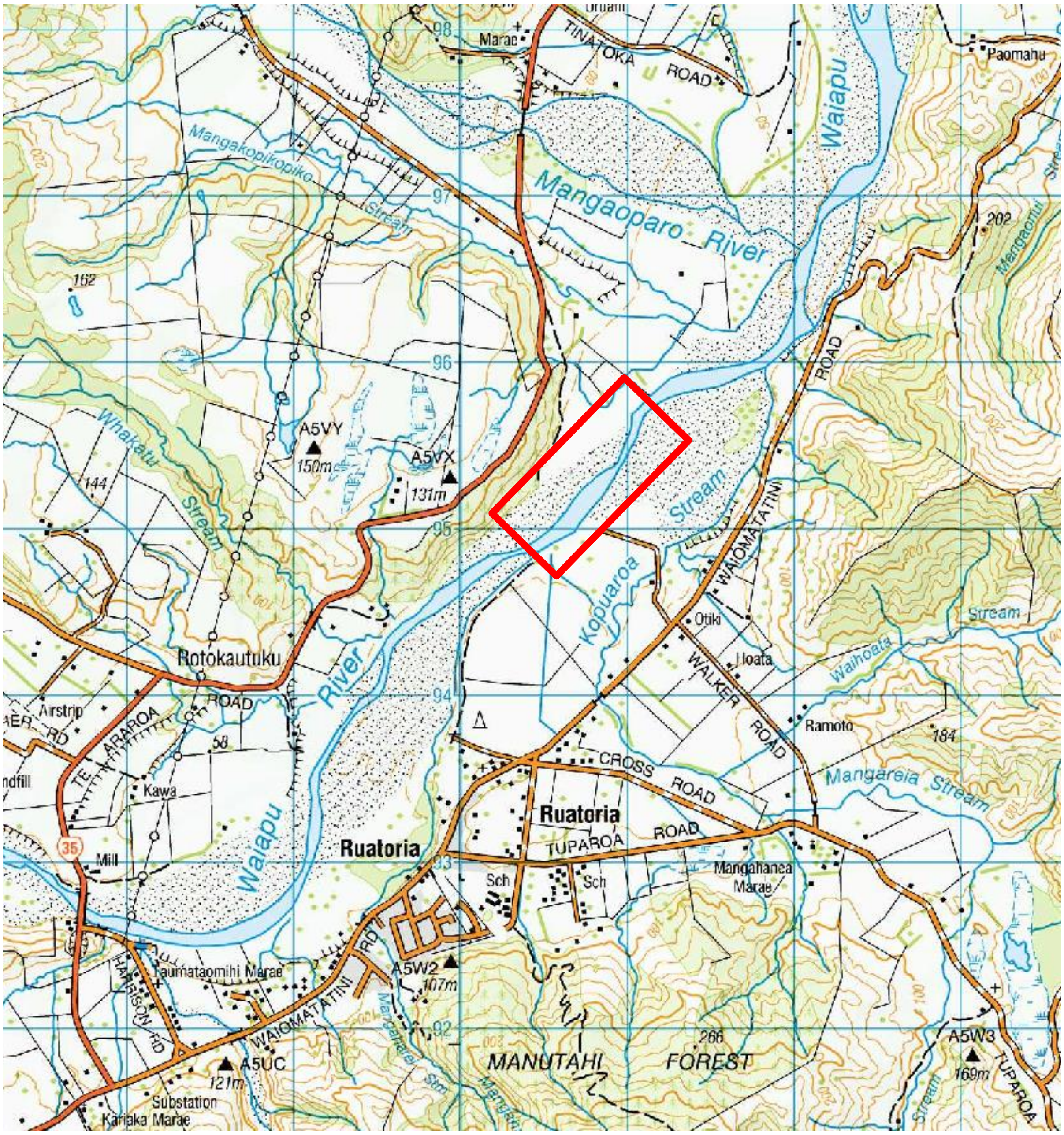


Figure 3-B: Specific location of the study reach (red rectangle).

3.2 Hydrology

Continuous flow data has been collected at the Rotokautuku Bridge since 1975. The flow summary statistics (for period 1975-2013) for that site are shown in Table 3-1.

GDC advise that the gravel bed river is unstable at the recorder site and that the stage to discharge ratings for the Waiapu River may not capture all the rating changes and so there is some uncertainty about the accuracy of the 7d-MALF.

Table 3-1: Flow summary statistics (m^3/s) for Waiapu River at Rotokautuku Bridge (1975-2013.).

Mean	Median	7D MALF	Upper Quartile	Lower Quartile	95%
97.0	38.8	6.398	98.4	16.7	370

3.3 Instream habitat survey and analysis

To determine the proportions of different habitat types in the survey reach, the habitat was 'mapped' for 1300 m of Waiapu River (see Figure 3-A). The survey site was contained within this length and comprised 14 cross-sections with at least two cross-sections per habitat type. Appendix B contains a photograph of each cross-section. Each cross-section was therefore placed to represent the contiguous pattern of habitat conditions (Table 3-2). One survey peg on each bank was used to mark, relocate and resurvey each cross-section. Water velocities, depths, and substrate composition were recorded at a spacing of 3 m, or less, at each cross-section at one discharge. Water levels and discharge values were then measured at a further discharge Table (3-3). Immediately after the survey and calibration gauging the river was subject to a flood caused by cyclone Pam that would most likely have caused changes to the cross-sections and swept away the low level pegs, thus making further calibration gaugings unreliable. The flood peaked at the Waiapu River at Rotokautuku Bridge at approximately 2000 m^3/s and the mean annual flood peak is 2600 m^3/s (Figure 3-C). Instead the change level at the water level recorder, where the river morphology is similar to the study site, between the calibration flow and 30 m^3/s was used.

Table 3-2: Cross-sectional characteristics. Habitat type definitions given. Cross-section 1 is the downstream end of the reach.

Cross-section	Habitat type	Distance (m)	Weight (%)	Number of points: Instream	Number of points: All	Average point spacing (m): Instream	Average point spacing (m): All
1	Run	0	4	20	85	2.8	6.2
2	Glide/pool	100	9	25	83	2.8	6.1
3	Glide	228	9	23	73	2.2	6.9
4	Riffle	354	14	25	77	2.7	6.7
5	Riffle	590	11	22	88	2.8	5.5
6	Glide	652	4	26	74	2.9	5.8
7	Glide	708	4	17	67	2.6	6.2
8	Riffle	764	6	31	92	3.3	4.3
9	Run	862	8	29	84	2.9	4.9
10	Glide	961	6	22	81	2.9	4.7
11	Glide	1034	6	26	78	2.9	4.8
12	Pool	1127	7	22	67	2.9	5.4
13	Pool	1214	8	37	91	1.5	10.9
14	Run	1330	4	36	66	1.2	4.5

[1] 'Instream' spacing refers to the average distance between survey points in the stream channel.

[2] 'All' spacing refers to the average distance between survey points across the entire cross-section.

Table 3-3: Calibration flows (m³/s).

Date	Discharge	Velocity measured at which cross-sections?
10/03/15	11.08	11
12/03/15	11.8	11
	30	

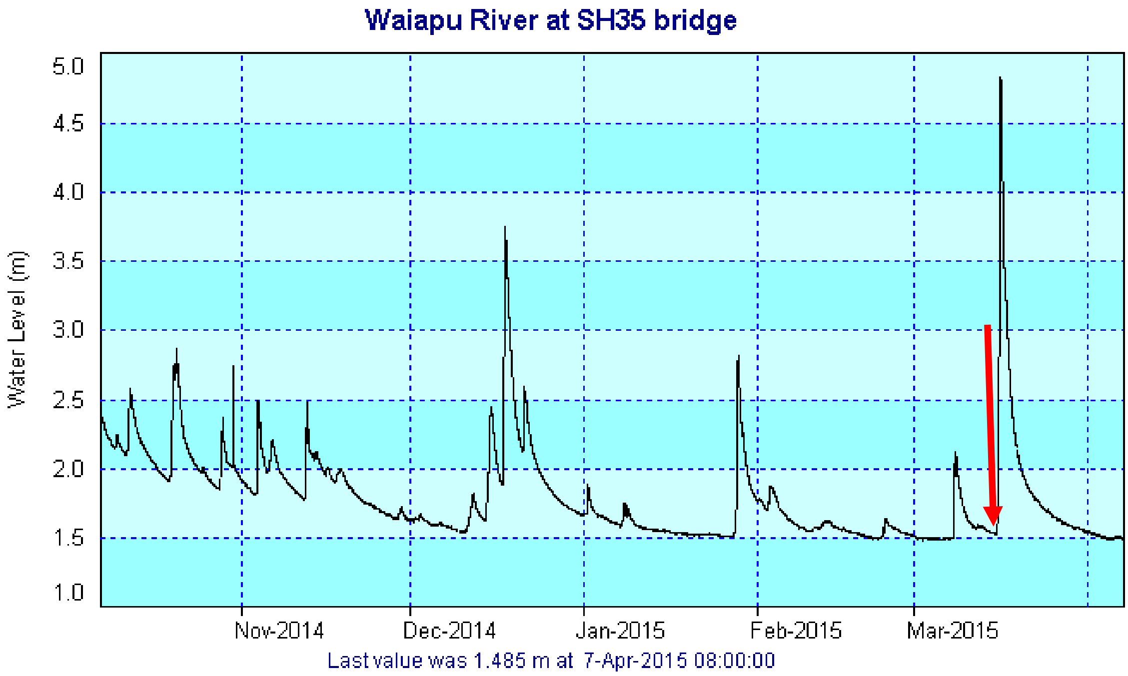


Figure 3-C: Timing of the survey and calibration flow (red arrows) relative to other flows. Note the size of the flood immediately after the survey.

Cross-sectional topography was measured using a Trimble R10 GNSS differential GPS. Water surface levels and the locations of survey pegs were measured using the differential GPS on 10/03/15 and 12/03/15.

Mean water column velocities were measured using a Marsh-McBirney Flo-mate 2000 electromagnetic current meter or a Gurley current meter placed at 0.4 of the depth for at least 20 seconds. Velocities and depths in sections 13 and 14 were measured with a 1200 kHz Rio Grande Acoustic Doppler Current Profiler (APCP) manufactured by Teledyne RD Instruments. Cross-section 13 was gauged using a combination of ADCP and conventional methods. Depths for other sections were measured using a wading rod. On 10/03/15 velocities, depths and substrate compositions were measured across all cross-sections. Substrate composition was recorded using an eight class substrate classification as determined by the habitat suitability criteria (Appendix A) of: vegetation, silt (<0.06 mm), sand (0.06−2 mm), fine gravel (2−8 mm), gravel (8−64 mm), cobble (64−256 mm), boulder (>256 mm) and bedrock. On 12/03/15 velocities and depths were measured across cross-section 11 which had relatively uniform depths and velocities to allow best calculation of discharge.

The habitat analysis proceeded as follows:

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

2. A stage-discharge relationship was developed for each cross-section using a least squares fit to the logarithms of the measured flows and stages (water levels) including an estimated stage at zero flow and estimated stage at 30 m^3/s.

3. Water depths were computed at each measurement point across each cross-section for a range of simulated flows using measured bed topography data and calculated stage-discharge relationships. Velocities were computed for each cell at each flow using the flow conveyance method to disaggregate velocity across each cross-section based on the measured pattern of velocity distribution (Jowett et al., 2008).

4. Habitat suitability was evaluated at each measurement point from habitat suitability criteria for each target species.

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

6. WUA was plotted against flow and the resulting relationships were examined to determine flow requirements.

3.4 Habitat suitability criteria

The habitat suitability criteria chosen for a study must be appropriate for the species known to occur, or likely to occur, in the study river (all HSC used in this study are shown in Appendix A). The habitat suitability criteria used in this study are listed in Table 3-4.

Table 3-4: Aquatic species and habitat suitability indices.

Taxa group/Species	HSC name	HSC source
Periphyton	diatoms	unpublished NIWA data
	short filamentous	unpublished NIWA data
	long filamentous	unpublished NIWA data
Stream invertebrates	food producing	Waters (1976)
	Deleatidium mayfly nymphs	Jowett et al., (1991)
Fish	Koaro	Jowett & Richardson (2008)
	Smelt	Jowett & Richardson (2008)
	Inanga	Jowett & Richardson (2008)
	Torrent fish	Jowett & Richardson (2008)
	Common bully	Jowett & Richardson (2008)
	Rainbow trout (< 100 mm)	Jowett & Richardson (2008)
	Rainbow trout feeding	Thomas & Bovee (1993)
	longfin eel < 300 mm	Jowett & Richardson (2008)
	longfin eel > 300 mm	Jowett & Richardson (2008)
	Short fin eel < 300 mm	Jowett & Richardson (2008)
	Short fin eel > 300 mm	Jowett & Richardson (2008)

Figure 3-4 shows the locations of all fish species that had been recorded in the catchment. Few of the fish species have been recorded in the Waiapu River. Most of the fish species from the catchment are diadromous and must use the Waiapu River to reach the sea as part of their life cycle.

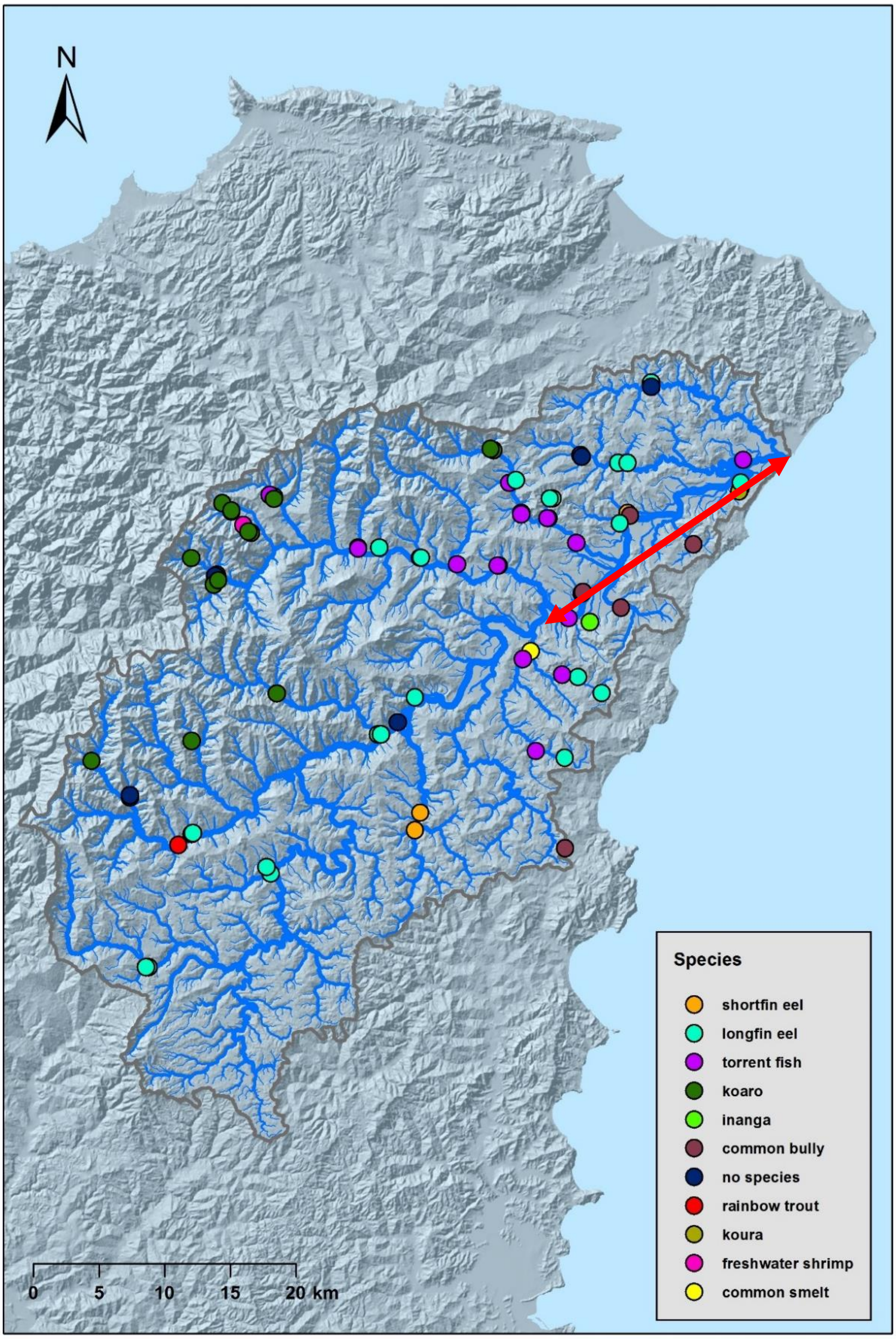


Figure 3-4: The Waiapu River and its tributaries showing the species and location of fish recorded in the Freshwater Fish Database. . The red line shows the extent of the Waiapu River.

3.5 Data analysis

3.5.1 Weighted useable area

To compare how WUA varied across all species at flows ranging from 1 to 30 m^3/s, the percentage of maximum WUA was calculated for the 16 habitat suitability curves that had been modelled (see Table 4-1). The percentage of maximum WUA was calculated by dividing the WUA at a particular flow by the maximum WUA. For example, if WUA peaks at 4 m^2/m for a particular fish species at a flow of 1.0 m^3/s but at a flow of 0.5 m^3/s WUA is 2 m^2/m, then WUA at 0.5 m^3/s would be 50% of maximum WUA for that fish species.

In the summary analyses, these percentage of maximum WUA values were averaged across all 16 aquatic responses to assess which flow provided the most habitat (in terms of percentage of maximum WUA). This may bias the average values in favour of both eel species and rainbow trout where two life stages each are among the 16 aquatic responses

3.5.2 Flow allocation

There is currently no flow allocation from the Waiapu River. We assume that the most likely demand for water will be for irrigation of the river flats adjacent to the Waiapu River from its confluence with the Mata River to the sea. An allocation was calculated from the area of the flats, assuming peak demand of 5 mm/day. The average monthly peak Penman potential evapotranspiration over a 20 years at Gisborne aerodrome was 5.1 mm/day (NIWA data).

3.5.3 Recreation

No formal analysis on recreational values was undertaken, Instead observations were made at the time of the survey, when the flow was about twice the 7d-MALF, of the suitability of depths and velocities for bathing, rafting, kayaking, and jet-boating.

3.5.4 Flow variability

Flow variability is important for providing flushing flows for river health, i.e., flushing periphyton from the river bed, removing any drapes of fine sediment from larger bed material, transporting bed load, maintaining river morphology and nourishing beaches.

One way of estimating the flushing flow capacity of a river is to count the number of flows greater than a threshold. In New Zealand it is common to use the frequency of events (floods per year) exceeding three times the long-term median flow (FRE3) (Clausen and Biggs 1997) for this purpose. Here FRE3 was calculated from the flow record from the Waiapu River from 1 January 1975 to 4 December 2013, using the average daily flow, a threshold of three times the median flow of 38.8 m^3/s and a window of 7 days where events over the threshold occurring within the window are counted as one. FRE3 values were calculated for the natural flow and the natural flow less 2 m^3/s.

3.5.5 Hydrograph flat-lining

When the flow recedes to less than the minimum flow plus the consented allocation and the consents are fully exercised, then the residual flow will fall below the minimum flow. To prevent that happening, abstractions are restricted and the residual hydrograph will be maintained at the minimum flow or be “flat lined” until the natural flow recedes below the minimum flow. Flat-lining is considered undesirable.

To compare the effect of different allocations on flat-lining with the natural flows, we calculated a number of statistics from the 38 year record:

- The number of times the flow was at or below a threshold such as the minimum flow or mean annual low flow.
- The average number of days per year the flow was at or below a threshold.
- The average number days for each below threshold event.
- The length of the longest below threshold event in the record.

4 Results

4.1 Physical characteristics

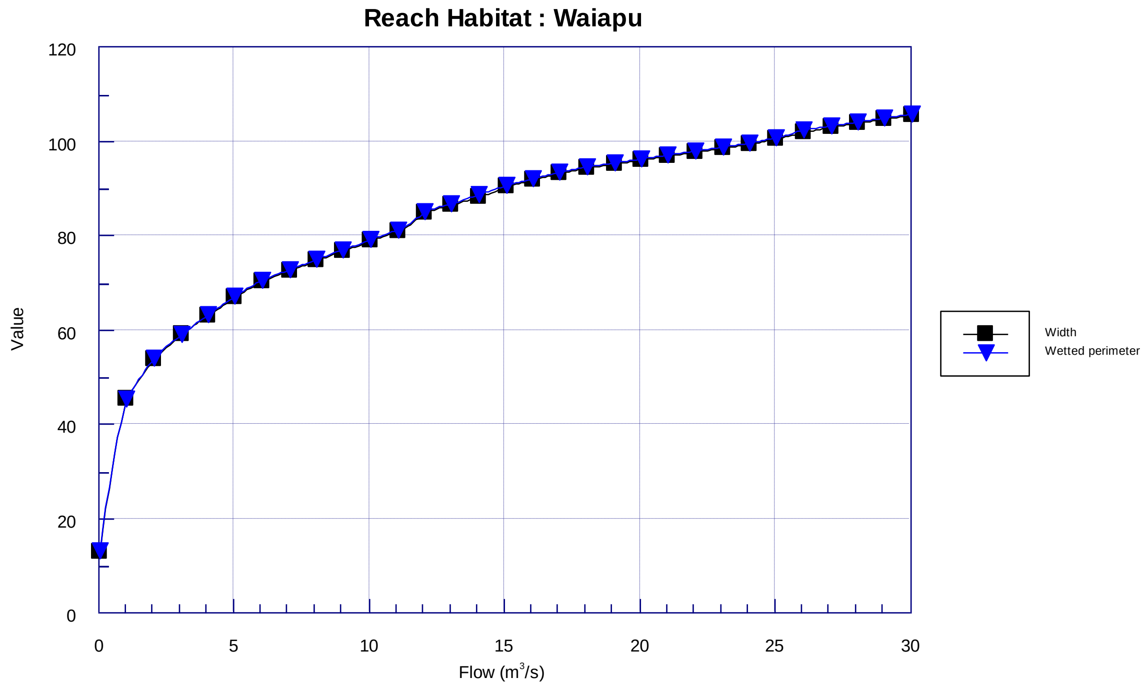
The site where habitat measurements were conducted in the Waiapu River was in the vicinity of the most likely upstream intake site. In this study reach of the Waiapu River the substrate consisted mainly of cobble, gravel and fine gravel in varying proportions with interstitial spaces filled with sand and silt. Where the water velocity was very low larger substrates were covered with a thick drape of silt. The site contained no instream macrophytes and there were only at a couple of cross-sections with overhanging willow in places (Figure 4-4) Some slow flowing shallow areas had a dense covering of long green filamentous algae (Figure 4-2) and other areas had shorter more sparse filamentous algae. All algal growths contained deposits of silt. For this study reach, hydraulic modelling predicted that as discharge increases, width increases slowly at very low flows and then steadily increases with changing flows as the river spreads over the wide, relatively unconfined river bed (Figure 4-3, 4-4, 4-5). Predicted depth and velocity show a similar trajectory as flow increases (Figure 4-6).

Figure 4-1: Pool near section 13 showing overhanging willow.

Figure 4-2: Long filamentous algae in slow flowing water.

Figure 4-3: View of the Waiapu River survey reach looking upstream from Section 8.

Figure **4-4: View of the Waiapu River survey reach looking downstream from section 8.**



4-5: Mean width and wetted perimeter against discharge for the Waiapu River survey reach. The Y-axis units are metres.

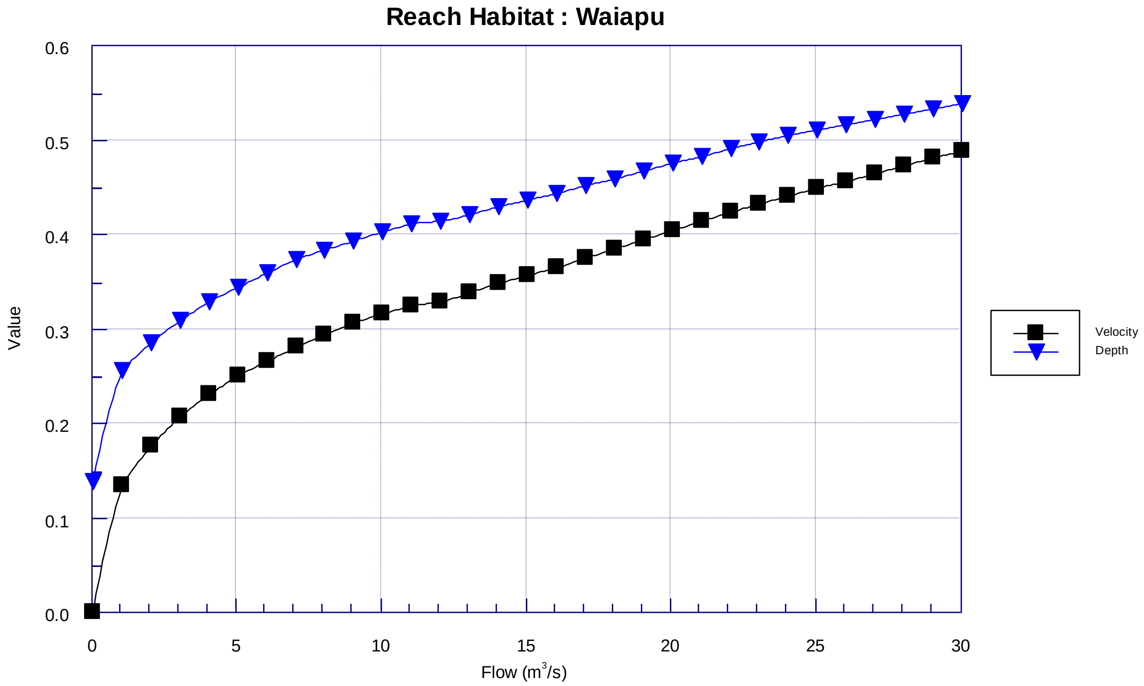


Figure 4-6: Mean velocity and depth against discharge for the Waiapu River survey reach. The Y-axis units are m/s for velocity and m for depth.

4.2 Instream habitat

WUA (m^2/m) can be used to assess flow requirements in relation to physical habitat. WUA is an aggregate measure of physical habitat quality and quantity. WUA was calculated using the habitat suitability criteria in Jowett & Richardson (2008). In this study, WUA was modelled for flows between 0 and 30 m^3/s since this was the flow range of most interest.

4.2.1 Periphyton

Thin films of diatoms prefer any depths (given clear water) and fast velocities (Appendix A). These conditions generally occur at flows above 5 m^3/s in the survey reach as indicated by the increase in WUA as discharge increases (Figure 4-7). Short filamentous algae prefer moderately deep depths and moderately fast velocities (Appendix A). This combination of conditions increases with flow so WUA for short filamentous algae peaks at 10-13 m^3/s (figure 4-7). Long filamentous algae, generally considered nuisance algae, prefer shallow and slow flowing water and these conditions occur at the edges of pools and glides. These slow flowing areas move sideways as flows increase and remain relatively constant in area in this wide river bed. In the survey reach, WUA for long filamentous algae is predicted to remain relatively constant at flows greater than 1 m^3/s (Figure 4-7).

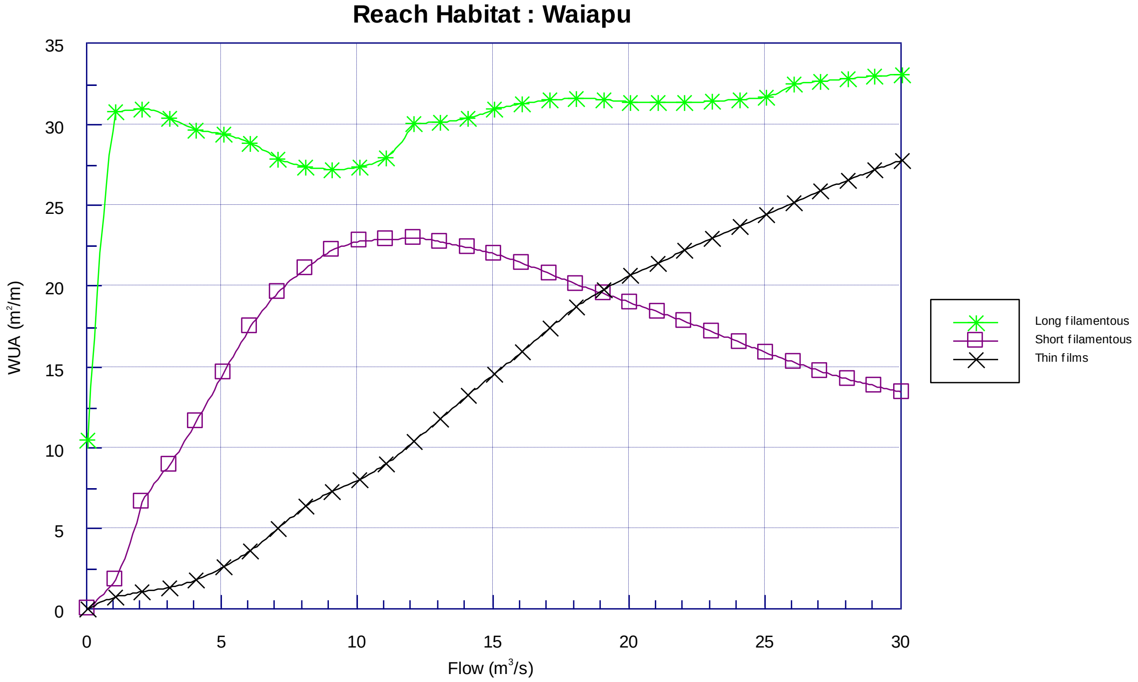


Figure 4-7: Variation of weighted useable area (WUA m2/m) with flow for the three main types of periphyton communities.

4.2.2 Stream invertebrates

Food producing habitat (Waters 1976) is optimised at depths between 20–80 cm, water velocities around 0.75 m/s and on cobble substrate (Appendix A). Given this combination of physical factors, food producing habitat increases with discharge for flows from 0 to 20 m^3/s (Figure 4-8).

Compared to food producing habitat, there is predicted to be more useable habitat for *Deleatidium* at all discharges (Figure 4-8). Whilst depth and substrate suitability is similar for both *Deleatidium* and food producing habitat, this particular mayfly has a broader range of optimal water velocities (0.41–1.25 m/s) which results in the predicted higher WUA across all flows.

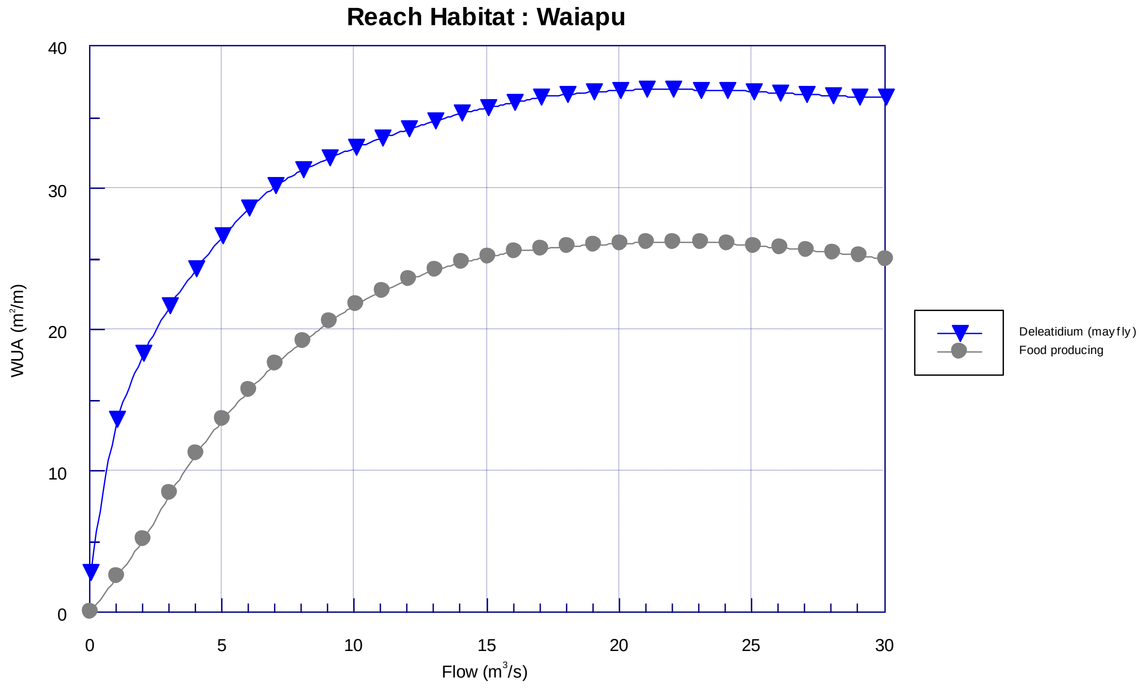


Figure 4-8: Variation of weighted useable area (WUA m^2/m) with flow for *Deleatidium* and food producing habitat.

4.2.3 Fish

WUA for common bully increases rapidly from 1 m^3/s to peak at 4 m^3/s, then falls to a relatively constant value at flows greater than 13 m^3/s as its channel edge habitat moves, but remains constant in area as flows increase Figure 4-9). Torrent fish WUA peaks at 13 m^3/s. While Koaro prefer slower flowing water and there is not a lot of suitable habitat for them; their WUA peaks at 9 m^3/s and declines hereafter. Inanga feed at very slow velocities and WUA declines rapidly at flows greater than 1 m^3/s. Smelt WUA is >80% of maximum between 3 and 9 m^3/s (Figure 4-9).

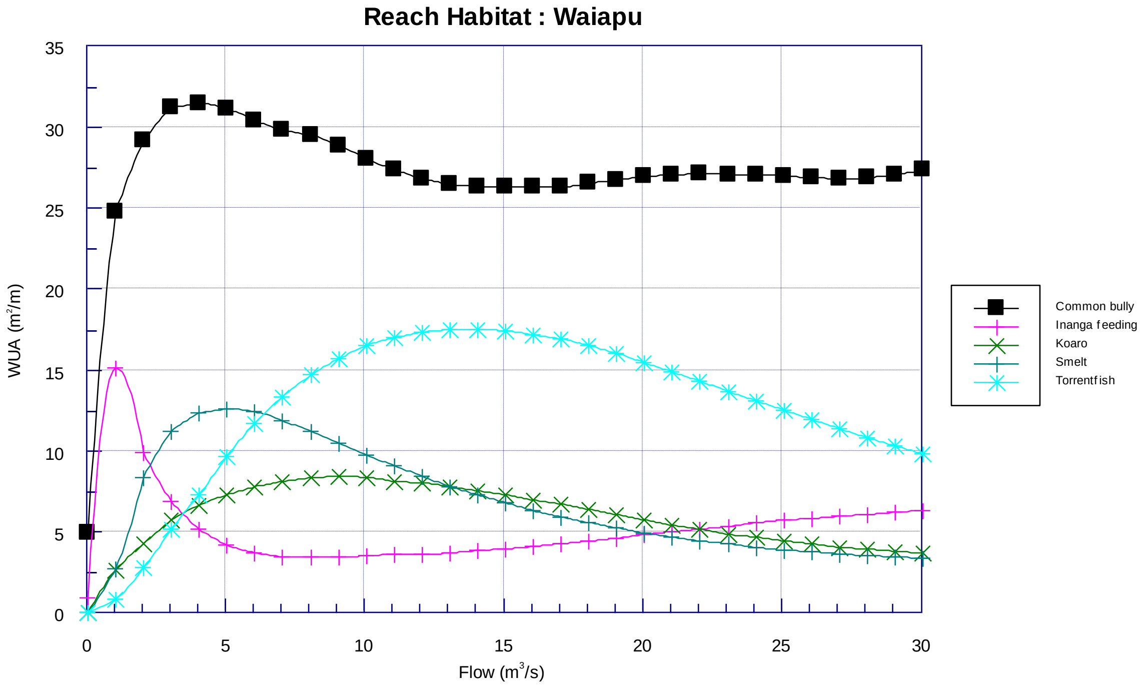


Figure 4-9: Variation of weighted useable area (WUA m²/m) with flow for four species of native fish.

Longfin eel WUA increases rapidly from low flows to peak at 8-9 m³/s and then falls slowly, so even at 30 m³/s more than 80% of their peak WUA is still available (Figure 4-10). There is less suitable habitat available for shortfin eels but it also increases rapidly from low flows and peaks at 6 m³/s. WUA for small shortfin eels rises rapidly then declines slowly to become < 80% of its maximum value at flows >16 m³/s. For large shortfin eels there is only a shallow decline in WUA as flows increase and almost 80% of maximum WUA is available up to 30 m³/s.

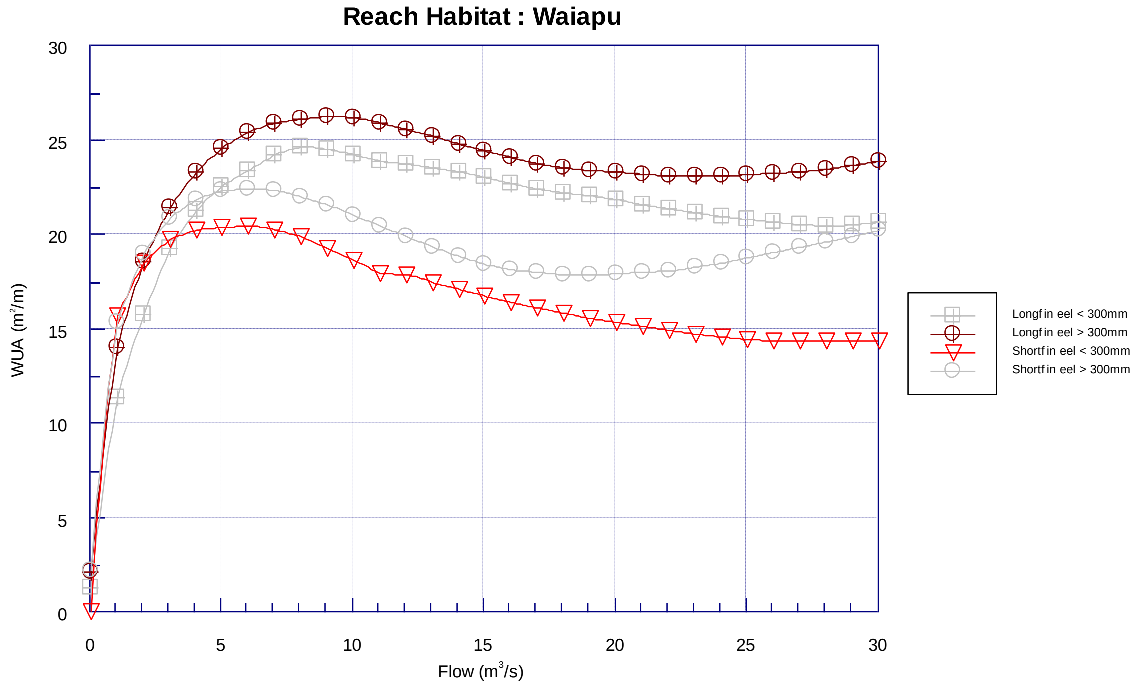


Figure 4-10: Variation of weighted useable area (WUA m²/m) with flow for large and small longfin and shortfin eels.

There is little WUA suitable for small rainbow trout, but what there is increases rapidly at low discharges and peaks at a flow of 3 m³/s and remains within 80 % of this value for flows < 10 m³/s (Figure 4-10). Rainbow trout adults prefer to feed in deep water of moderate velocity (Appendix A), so as water depths increase so does suitable habitat that appears to be reaching a peak at about 30 m³/s.

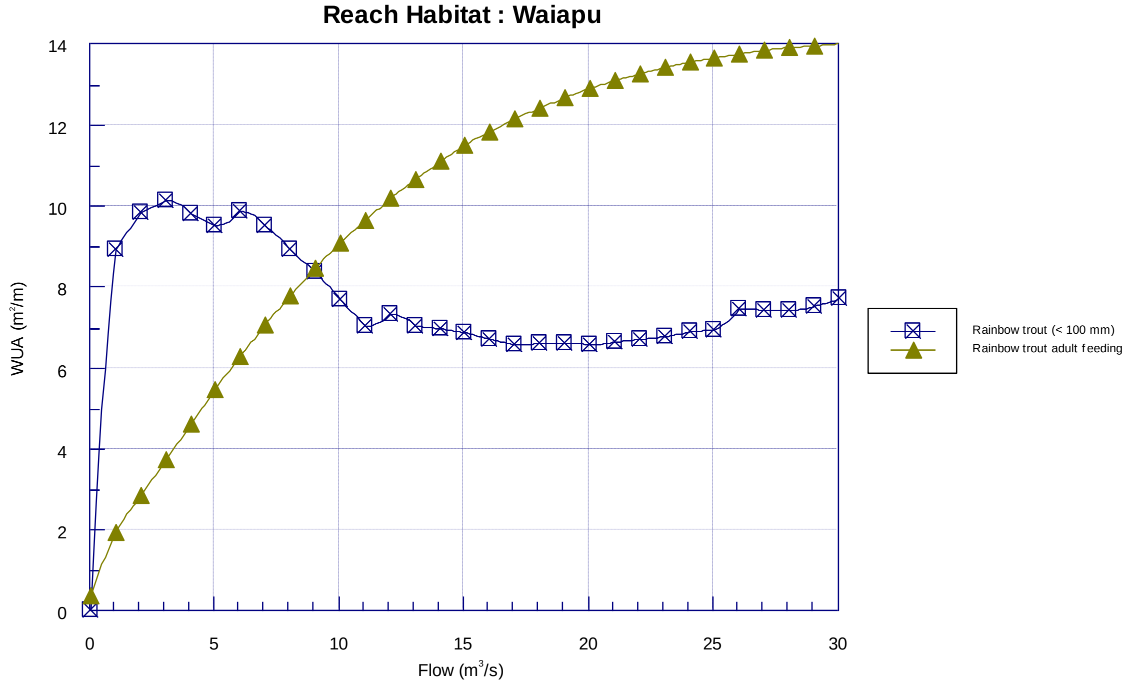


Figure 4-11: Variation of weighted useable area (WUA m²/m) with flow for rainbow trout fingerlings and rain bow trout adult feeding habitat.

When the percentage of maximum WUA is plotted against flow for all species (Figure 4-12, Table 4-1) it is apparent that at a minimum flow of 3 m^3/s at least 65% of the maximum WUA habitat would be available to all species (except diatoms). If flow was 4 m^3/s then at least 69% of the maximum WUA habitat would be available to all species (except diatoms) and if flow was 5 m^3/s then at least 73% of the maximum WUA habitat would be available to all species (except diatoms) (Figure 4-13). Results suggests that a minimum flow somewhere between 3 and 6 m^3/s would be optimal for native fish species as all four species have at least 90% of their maximum WUA available in this flow range.

Table 4-1: Change in the percentage (%) of maximum WUA at flows between 0 and 30 m^3/s for each of the aquatic groups or species examined. The average column is the mean % of maximum WUA for the 16 target species modelled.

Flow (m3/s)	Diatoms	Short filaments	Long filaments	*Deleatid-ium* (may fly)	Food Produc-ing	Common bully	Inanga feeding	Koaro	Smelt	Torrent-fish	Longfin eel < 300 mm	Longfin eel > 300 mm	Shortfin eel < 300 mm	Shortfin eel > 300 mm	Rain-bow < 100 mm	Rain-bow feeding	Aver-age
0	0.0	0.0	31.7	7.7	0.0	15.5	5.9	0.0	0.0	0.0	5.1	8.1	0.0	9.6	0.0	2.5	5.4
1	2.5	8.0	93.0	37.0	9.7	78.6	100.0	30.8	21.3	4.8	45.9	53.4	76.8	68.3	87.8	13.8	45.7
2	3.9	28.9	93.6	49.6	19.6	92.7	65.5	50.8	66.5	16.1	63.9	70.8	90.4	84.5	96.8	20.3	57.1
3	4.7	39.0	91.9	58.6	32.0	99.2	45.3	67.6	88.7	29.4	78.1	81.6	96.7	93.0	100.0	26.7	64.5
4	6.5	50.4	89.6	65.7	42.8	100.0	34.0	78.4	97.8	41.7	86.3	88.9	99.2	97.3	96.6	32.9	69.3
5	9.4	63.6	88.9	71.9	52.1	99.0	27.4	86.3	100.0	55.4	91.6	93.7	99.7	99.5	93.8	39.0	73.2
6	12.9	76.4	87.1	77.2	60.1	96.5	24.2	92.0	98.5	66.8	94.8	96.8	100.0	100.0	97.4	44.8	76.6
7	18.0	85.5	84.2	81.5	67.0	94.8	22.9	96.4	94.1	76.2	98.5	98.6	99.1	99.5	93.7	50.3	78.8
8	22.8	91.9	82.8	84.5	73.1	93.7	22.6	99.1	89.0	84.1	100.0	99.6	97.2	98.1	87.9	55.5	80.1
9	26.1	97.0	82.1	86.9	78.6	91.6	22.6	100.0	83.2	90.0	99.6	100.0	94.4	96.0	82.5	60.3	80.7
10	28.7	99.4	82.8	89.0	83.2	89.2	23.0	98.8	77.2	94.3	98.5	99.7	91.1	93.7	75.8	64.8	80.6
11	32.4	99.9	84.3	90.7	87.0	86.9	23.6	96.5	72.0	97.5	97.0	98.7	87.8	91.2	69.1	68.9	80.2
12	37.4	100.0	90.8	92.5	90.2	85.2	23.7	94.8	66.9	99.4	96.4	97.4	87.3	88.6	72.1	72.7	81.0
13	42.4	99.0	91.2	94.1	92.6	84.1	24.4	92.4	62.0	100.0	95.5	96.0	85.4	86.2	69.3	76.1	80.7
14	47.5	97.6	92.0	95.4	94.6	83.7	25.2	89.4	57.7	100.0	94.6	94.5	83.5	83.9	68.8	79.2	80.5
15	52.4	95.7	93.6	96.6	96.2	83.6	26.1	86.3	53.8	99.6	93.5	93.0	81.8	82.1	67.7	82.0	80.3
16	57.5	93.5	94.7	97.6	97.4	83.6	27.1	83.0	50.1	98.5	92.2	91.6	80.2	80.8	66.1	84.5	79.9
17	62.5	90.6	95.4	98.4	98.3	83.7	28.2	79.5	47.0	96.7	91.0	90.5	78.7	80.1	64.8	86.7	79.5
18	67.3	87.7	95.5	99.2	98.9	84.3	29.3	75.8	44.1	94.4	90.2	89.7	77.4	79.7	65.2	88.7	79.2
19	71.3	85.1	95.2	99.6	99.4	85.0	30.5	71.9	41.6	91.6	89.4	89.1	76.2	79.7	64.9	90.5	78.8
20	74.4	82.6	94.9	99.9	99.8	85.6	31.6	68.1	39.2	88.5	88.6	88.7	75.1	79.8	64.9	92.1	78.4
21	77.1	80.3	94.9	100.0	100.0	86.0	32.8	64.4	37.0	85.3	87.7	88.3	74.0	80.1	65.3	93.5	77.9
22	80.0	77.8	94.9	100.0	100.0	86.1	34.1	61.0	35.1	81.7	86.7	88.0	73.0	80.6	66.0	94.8	77.5
23	82.8	74.9	95.1	99.9	99.9	86.0	35.4	57.8	33.5	78.2	85.9	87.9	72.2	81.4	66.7	95.8	77.1
24	85.4	72.1	95.2	99.7	99.5	85.8	36.5	55.0	32.1	74.9	85.1	88.0	71.4	82.5	67.9	96.8	76.7

Flow (m3/s)	Diatoms	Short filaments	Long filaments	*Deleatid-ium* (may fly)	Food Produc-ing	Common bully	Inanga feeding	Koaro	Smelt	Torrent-fish	Longfin eel < 300 mm	Longfin eel > 300 mm	Shortfin eel < 300 mm	Shortfin eel > 300 mm	Rain-bow < 100 mm	Rain-bow feeding	Aver-age
25	87.9	69.2	95.9	99.5	99.1	85.6	37.6	52.5	30.8	71.6	84.4	88.2	70.7	83.6	68.2	97.6	76.4
26	90.5	66.5	98.4	99.2	98.5	85.4	38.5	50.1	29.7	68.3	83.8	88.5	70.4	84.8	73.3	98.3	76.5
27	93.1	64.1	98.8	98.9	97.9	85.2	39.3	48.0	28.8	65.1	83.3	88.9	70.2	86.1	73.1	98.8	76.2
28	95.6	62.0	99.2	98.7	97.1	85.5	40.1	46.3	27.9	62.0	83.1	89.4	70.1	87.5	73.1	99.3	76.1
29	98.0	60.2	99.7	98.6	96.4	86.0	40.9	44.8	27.2	59.1	83.4	90.0	70.2	88.8	74.0	99.7	76.1
30	100.0	58.5	100.0	98.5	95.5	87.0	41.6	43.5	26.6	56.3	83.9	90.8	70.4	90.1	75.9	100.0	76.2

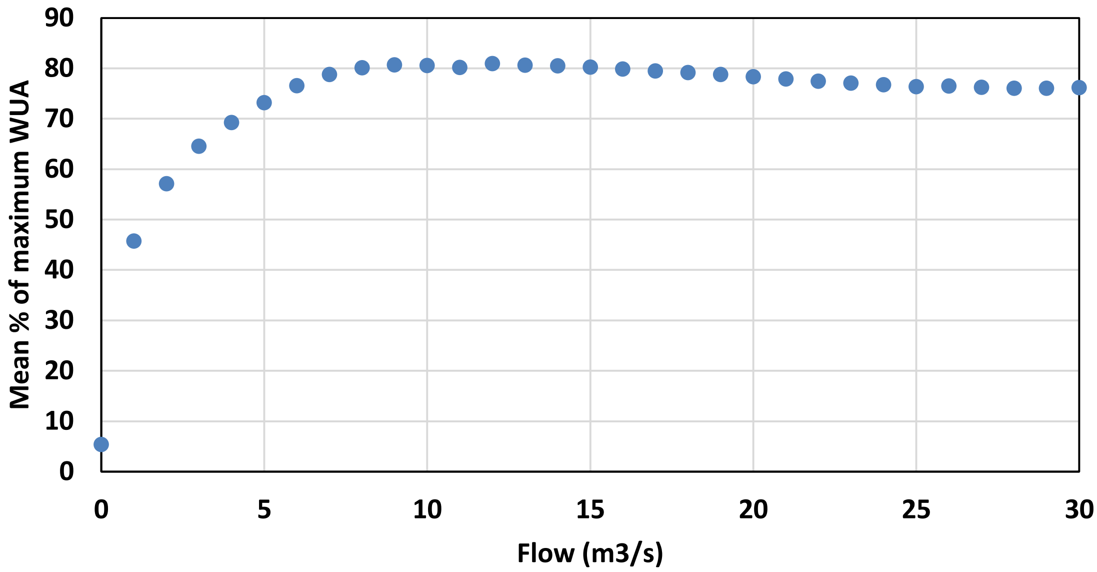


Figure 4-12: The average values for percentage (%) of maximum WUA for all modelled species (see Table 4 2) plotted against flows up to 1 m³/s. An explanation of how percentage of maximum WUA is calculated is provided in the text.

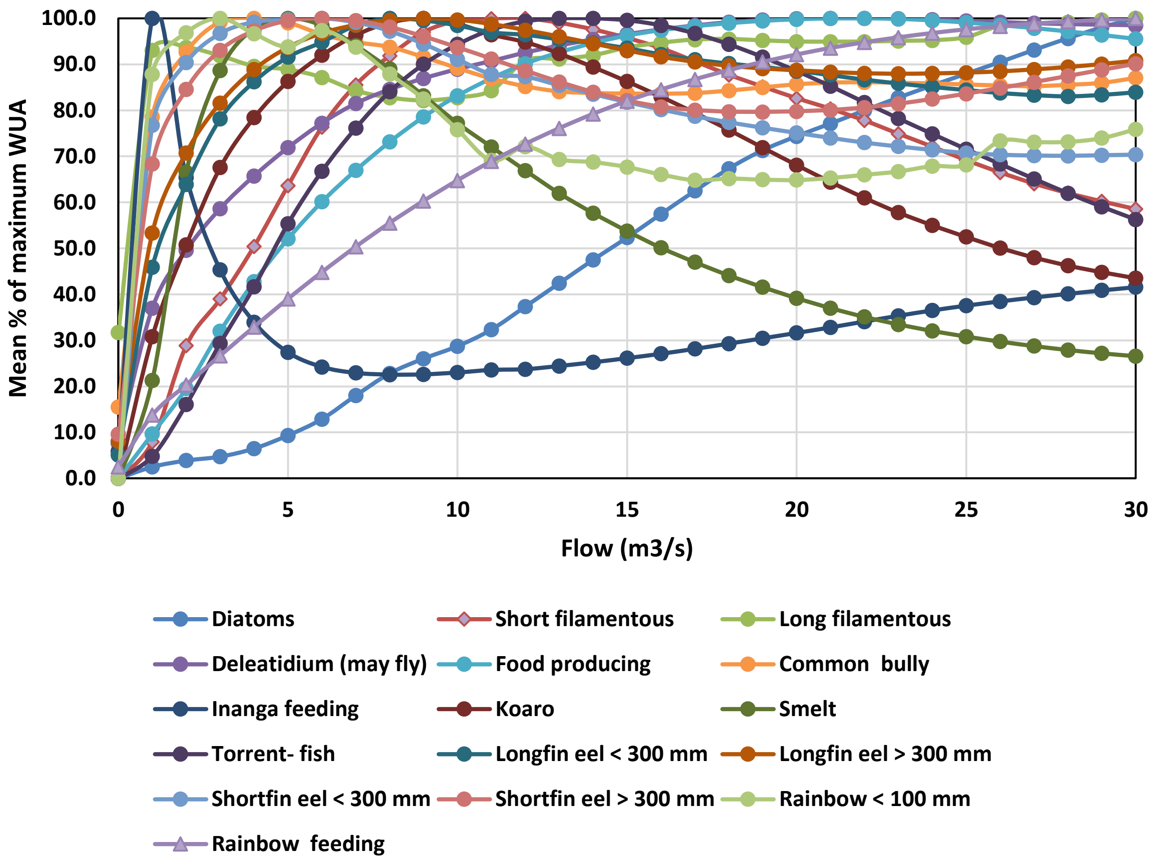


Figure 4-13-: Change in the percentage (%) of maximum WUA with flow for each species. Colours in this figure will be different from those used in previous species graphs.

4.2.4 Flow allocation

The area of flat land downstream of the Mata river confluence is ~49 km^2, of which ~ ⅓ is river bed. If approximately 80% of the remainder was to be irrigated with 5 mm per day then the peak water requirement would be 1.5 m^3/s. Similar logic was applied to the irrigation requirements of the Mata flood plain downstream of the Makarika Road Bridge to estimate a peak water requirement of 0.5 m^3/s. Given these allocations the total loss of flow from the river would be 2 m^3/s. During the irrigation season of 1 September to 30 April, and assuming a minimum flow of 5 m^3/s, an allocation of 2 m^3/s would have a 94% reliability of supply.

4.2.5 Recreation

The river would be suitable for bathing from a depth and velocity point of view at the flows during the survey. It would also be possible to raft, kayak or tube the river at the observed flows. However, given the low river slope, low velocities and bland landscape, the reach is unlikely to be attractive for these activities due to the lack of challenge offered by the river and its lack of scenic values compared to alternative venues. Jet boating at the observed flows would not be possible for recreational jet-boaters. We found it difficult to find water deep enough to launch the large NIWA jet boat and were only able to boat a few hundred meters before the river became too shallow.

4.2.6 Flow variability – flushing flows

There were 13.77 events/year when flow exceeded three times the median flow on the archived record and 13.72 events per year when a constant 2 m^3/s were assumed to be abstracted, so the number of flushing flows that are critical to river health and function is essentially unchanged.

4.2.7 Hydrograph flat-lining

Table 6-2 shows the effect on flat–lining of a minimum flow of 5 m^3/s with and without an abstraction of 2 m^3/s compared to the 7d-MALF. Clearly, with the abstraction the minimum flow would occur much more often and for a longer total time. The duration of the longest low flow period is unchanged.

Table 4-2: The number and duration of periods with flows less than the 7d-MALF and a minimum flow of 5 m^3/s with and without a constant abstraction of 2 m^3/s.

Flow threshold (m^3/s)	6.398	5.000	5.0 with 2.0 allocation
Lows/year < threshold	1.8	1.1	5.0
Low days /year	12.0	7.0	11.4
Days/low	6.6	6.5	2.3
Maximum duration (days)	42	40	40

In summary, an allocation of 2 m^3/s for the whole river would increase the number and duration of periods with flows at or below the minimum flow, but some of the periods would be quite short. However, the number of flushing flows that are critical to river health and function is essentially unchanged.

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5 Future work

It should be noted that calibration flows were collected over a narrow range (11m^3/s) and that these flows were much larger than the minimum flows discussed. Ideally, calibration flows would stretch over a broad range and include the minimum flows under consideration.

More electric fishing needs to be carried out in the Waiapu River to establish more precisely the species that live in the river and which would be affected by any abstraction.

6 Flow regime requirements

6.1 Introduction

The selection of minimum flows is a matter of judgement, where the habitat requirements and perceived values of the different species must be considered. Decisions need to be made about what an acceptable level of habitat protection is either on average across the species or for one or two key target species. For example, one option is to maintain 70% of habitat averaged across several species, or another option is to maintain 90% habitat for flow sensitive fish species. Minimum flow recommendations may be a compromise between species, and are usually made to prevent a sharp decline in habitat for most species or to retain a percentage of the maximum habitat, thus aiming to retain some habitat for all species that make up the aquatic community present in the study area. Higher levels of habitat protection may also be set for rarer species or for criteria viewed to be critical to the ecological functioning of the river such as production of food for fish or removal of nuisance algae.

6.2 Minimum flows

Low flows can limit the amount of available physical habitat and it is often assumed that frequently occurring low flows will limit fish populations. The mean annual low flow has been used as a measure of frequently occurring low flows for long-lived fish species (e.g., Jowett 1992). Alternatively, minimum flows are often selected so that they prevent a serious decline in habitat or the flow below which habitat declines sharply. However, effects on ecosystem health depends to some extent on the amount of time that the flow is likely to be at that minimum.

The length of river of most relevance for minimum flow in this case is the 8 km of the Waiapu River between the Mata River and the Poroporo River. The Poroporo and Mangaoparo Rivers are substantial tributaries that contribute downstream of the water-level recorder at the SH3 bridge. When interpreting how a change in flow will affect WUA for a species, it can be useful to convert WUA (m^2/m) to the area of useable stream habitat that will be gained/lost (Table 6-1). For example, if the minimum flow was set at 3 m^3/s, there is 28,459 m^2 of useable habitat for large Longfin eels at that flow, whereas if the minimum flow was set at 4 m^3/s there would be an extra 2543 m^2 of useable habitat available for this species at that flow in the 1350 m study reach (Table 6-1). Note that the availability of habitat does not directly correspond to an increase in fish numbers.

Evidence from physical habitat modelling suggests that below a minimum flow of 3 m^3/s there will be a marked decline in WUA for some aquatic species (Table 4-1: Change in the percentage (%) of maximum WUA at flows between 0 and 30 m3/s for each of the aquatic groups or species examined. The average column is the mean % of maximum WUA for the 16 target species modelled., Figure 4-9, Figure 4-10, Figure 4-11). The models also indicate that the weighted useable area for almost all aquatic species will be increased the higher the minimum flow is set. However, the incremental gains in useable habitat for aquatic species become smaller and smaller with increasing flow, particularly at flows higher than 5 m^3/s (Figure 4-9). The model outputs indicate that across a range of potential minimum flows, the WUA for most fish species will increase with more discharge. The only species recorded as being in the Waiapu River are large Longfin eels, torrent fish and common bully (Figure 3-4). Given the high WUA for larger Longfin eel at the various low flows in Table 4-2, and their cultural importance they should be considered of major importance for determining a minimum flow for the Waiapu River. A minimum flow of 4 m^3/s would mean that 88.9% of large Longfin eel habitat, and 75.5% of all fish habitat on average, would be retained (Table 4-1). A minimum flow between 3 to 6 m³/s would be optimal for common bully but torrent fish would only have 67% of optimum habitat at 6 m³/s (Table 4-1: Change in the percentage (%) of maximum WUA at flows between 0 and 30 m3/s for each of the aquatic groups or species examined. The average column is the mean % of maximum WUA for the 16 target species modelled.). A minimum flow of 5 m³/s provides all eels with at least 92%, common bullies with 99% and torrent fish 55%of their potential habitat.

Table 6-1: Changes in the total useable area (m²) of stream habitat at different minimum flows.

Flow (m³/s)	1	2	3	4	5	6
Diatoms	927	1,436	1,750	2,399	3,455	4,763
Short filaments	2,422	8,791	11,869	15,356	19,371	23,248
Long filaments	40,888	41,157	40,368	39,371	39,055	38,299
Deleatidium	18,165	24,336	28,787	32,270	35,286	37,904
Food	3,369	6,794	11,109	14,847	18,080	20,873
Common bully	32,840	38,724	41,456	41,789	41,383	40,319
Inanga	20,080	13,143	9,103	6,818	5,504	4,868
Koaro	3,441	5,666	7,542	8,754	9,633	10,266
Smelt	3,563	11,121	14,819	16,350	16,711	16,455
Torrent fish	1,120	3,727	6,811	9,664	12,840	15,484
Longfin eel < 300 mm	15,033	20,905	25,576	28,229	29,977	31,033
Longfin eel >300 mm	18,616	24,679	28,459	31,002	32,671	33,757
Shortfin eel < 300 mm	20,824	24,515	26,233	26,903	27,052	27,125
Shortfin eel >300 mm	20,368	25,193	27,731	28,990	29,647	29,803
Rainbow < 300 mm	11,834	13,046	13,472	13,019	12,640	13,115
Rainbow feeding	2,562	3,777	4,960	6,125	7,260	8,340

[1]Total useable area of stream habitat is calculated by multiplying the 1439 m study section by WUA for each species. The total area of stream habitat (m²) for the five different flows (m³/s) is: 65,018 (1), 77,274 (2), 84,816 (3), 90,478 (4), 96,143 (5) 100,919 (6).

6.3 Flow variation and flood flows

Section 4.2.4 suggested an allocation for consumptive use of 2 m³/s. An allocation of this size has essentially no effect on the number of flushing flows that are critical to river health and function (Section 4.2.6)

6.4 Flow variation and low flows

Section 4.2.7 shows the effect on flat–lining of a minimum flow of 5 m^3/s with and without an abstraction of 2 m^3/s. With the abstraction the minimum flow occurs much more often and for a longer total time. The duration of the longest low flow period is unchanged.

6.5 Methodological considerations

The response of several species to changes in flow were modelled and whilst all species were given an equal weighting in Table 4-1: Change in the percentage (%) of maximum WUA at flows between 0 and 30 m3/s for each of the aquatic groups or species examined. The average column is the mean % of maximum WUA for the 16 target species modelled., this may not be the best approach for setting a minimum flow. When determining an appropriate minimum flow it is also important to consider the species that currently occur in the reach, their abundance and protection level. For fish communities, longfin eels, common bullies and torrent fish have been observed in the Waiapu River. Whatever minimum flow is proposed should be weighted in favour of these species.

7 Conclusions

- Physical habitat modelling was used to assess the effects of changes in flows on instream physical habitat and aquatic species in the Waiapu River catchment.

- The habitat modelling results show how different minimum flows alter instream ecological values. The trade-off in habitat retention/loss for different ecological values is illustrated in Figure 4-13 and Table 4-1.

- The change in these instream ecological values with flow suggest that the minimum flow should be set somewhere between 3 and 6 m^3/s. Whilst the summary table outlines how different instream ecological values will be affected for a range of minimum flow options, the ultimate decision for setting a minimum flow has to balance up other instream and out-of-stream values.

- Specifically, a minimum flow of 4 m^3/s would mean that 88.9% of Longfin eel habitat, and 78% of all fish habitat on average, would be retained (Figure 4-13). At the estimated 7D MALF of 6 m^3/s, 83% of all fish habitat and 77% of the habitat of all species modelled would be retained.

  If a minimum flow was set at 5 m^3/s, then an average of 86% of the useable stream habitat for native fish species is provided for (see Table 4-1: **Change in the percentage (%) of maximum WUA at flows between 0 and 30 m3/s for each of the aquatic groups or species examined. The average column is the mean % of maximum WUA for the 16 target species modelled.**1). A minimum flow of 5 m^3/s or more would mean that, in addition to native fish values being maintained, at least 49% of the useable stream habitat was available for diatoms, short filamentous algae, *Deleatidium* (mayfly) and food producing habitat.

- An allocation of 1.5 m^3/s for the Waiapu River reach would be sufficient to efficiently irrigate the alluvial flats adjacent to the river. This, together with the irrigation abstraction of 0.5 m^3/s for the Mata River flats would increase the number and total duration of flows at or below the minimum flow, but would leave flushing flow frequency effectively unchanged. The increased total duration of low flows is unlikely to be harmful to the species recorded living in the reach.

- The Waiapu River carries a very high coarse and fine sediment load and this limits the availability of habitat, so the WUA values modelled probably represent an upper value for the amount of habit that is able to be used. The high sediment load possibly accounts for the fact that most fish species have been recorded in more stable tributary streams.

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9 References

Acreman, M.C., Elliott, C.R.N. (1996) Evaluation of the river Wey restoration project using the Physical HABitat SIMuation (PHABSIM) model. *Proceedings of the MAFF Conference of River and Coastal Engineers*, Keele, 3-5 July 1996.

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

Beecher, H.A., Johnson, T.H., Carleton, J.P. (1993) Predicting microdistributions of steelhead (*Oncorhynchus mykiss*) parr from depth and velocity preference criteria: test of an application of the Instream Flow Incremental Methodology. *Canadian Journal of Fisheries and Aquatic Sciences*, 50: 2380-2387.

Bisson, P.A., Nielsen, R.A., Palmason, R.A., Grive, L.E. (1982) A system of naming habitat types in small streams with examples of habitat utilization by salmonids during low streamflow. In Armantrout, N.B. (ed.) *Acquisition and Utilization of Aquatic Habitat Inventory Information.* American Fisheries Society, Western Division, Bethesda, Maryland. pp 62-73.

Bjorkland, J., Pringle, C.M., Newton, B. (2001) A Stream Visual Assessment Protocol (SVAP) for Riparian Landowners. *Environmental Monitoring and Assessment,* 68: 99-125.

Booker, D.J., Acreman, M.C. (2006) Generalisation of physical habitat-discharge relationships. *Hydrology and Earth System Sciences*, 11: 141-157.

Booker, D.J., Dunbar, M.J. (2004) Application of Physical HAbitat SIMulation (PHABSIM) modelling to modified urban river channels. *River Research and Applications,* 20: 167-183.

Booker, D.J., Dunbar, M.J., Ibbotson, A.T. (2004) Predicting juvenile salmonid drift-feeding habitat quality using a three-dimensional hydraulic-bioenergetic model, *Ecological Modelling,* 177: 157-177.

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

Bovee, K.D., Lamb, B.L., Bartholow, J.M., Stalnaker, C.B., Taylor, J., Henriksen, J. (1998) *Stream habitat analysis using the Instream Flow Incremental Methodology.* US Geological Survey, Biological Resources Division, Information and Technology Report USGS/BRD-1998-0004. 139 pp.

Cavendish, M.G., Duncan, M.I. (1986) Use of the instream flow incremental methodology; a tool for negotiation. *Environmental Impact Assessment Review*, 6: 347-363.

Clausen, B., Biggs, B, J.F (1997). Relationships between benthic biota and hydrological indices in New Zealand streams. *Freshwater biology*, *38*(2), 327-342.

Clausen, B., Jowett, I.G., Biggs, B.J.F. Moeslund, B. (2004) Stream ecology and flow management. In: L.M. Tallaksen and H.A.J. Van Lanen (eds) Developments in water science, 48, Elsevier, Amsterdam, pp 411-453.

Dauwalter, D.C., Fisher, W.L. Belt, K.C. (2006) Mapping Stream Habitats with a Global Positioning System: Accuracy, Precision, and Comparison with Traditional Methods. *Environmental Management*, 37: 271-280.

Dunbar, M.J., Acreman, M.C. (2001) Applied hydro-ecological science for the twenty-first century. In: Acreman, M.C. (ed) *Hydro-ecology: linking hydrology and aquatic ecology*. IAHS Pub. No. 266 1-18.

Eisner, A., Young, C., Schneider, M., Kpoecki, I. (2005) MesoCASiMiR - new mapping method and comparison with other current approaches, *COST 626 Proceedings from the final meeting in Silkeborg*, Denmark, 19-20 May 2005.

Elliott, C.R.N., Johnson, I.W., Sekulin, A.E., Dunbar, M.J., Acreman, M.C. (1996) *Guide to the use of the Physical Habitat Simulation System*. Report to National Rivers Authority. Institute of Hydrology, Wallingford, UK. 87 p.

Gallagher, S.P., Gard, M.F. (1999) Relationship between Chinook salmon (*Oncorhynchus tshawytscha*) redd density and PHABSIM-predicted habitat in the Merced and Lower American rivers, California. *Canadian Journal of Fisheries and Aquatic Sciences*. 56: 570-577.

Giller, P.S., Malmqvist, B. (1998) *The biology of streams and rivers*. Oxford University Press, Oxford.

Ginot, V. (1995) EVHA, Un logiciel d'evaluation de l'habitat du poisson sous Windows. *Bull. Fr. Peche Pisic***.** 337/338/339: 303-308.

Gore, J.A., Crawford, D.J., Addison, D.S. (1998) An analysis of artificial riffles and enhancement of benthic community diversity by physical habitat simulation (PHABSIM) and direct observation. *Regulated Rivers- Research and Management*, 14: 69-77.

Hawkins, C. P., Kershner, P., Bisson, A., Bryant, D., Decker, L. M., Gregory, S. V., McCullogh, D. A., Overton, C. K., Reeves, G. H., Steedman, R. J. and Young, M. K. (1993) A hierarchical approach to classifying stream habitat features. *Fisheries*, 18: 3-12.

Hayes, J.W. (1995) Spatial and temporal variation in the relative density and size of juvenile brown trout in the Kakanui River, North Otago, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 29: 393-408.

Hayes, J.W., Jowett, I.G. (1994) Microhabitat models of large drift-feeding brown trout in three New Zealand rivers. *North American Journal of Fisheries Management*, 14: 710-725.

Hynes, H.B.N. (1970) *The ecology of running waters*. University of Toronto Press.

Johnson, I.W., Elliott, C.R.N., Gustard, A., Armitage, P.D., Ladle, M., Dawson, F.H., Beaumont, W. (1993) Ecologically Acceptable Flows, *National Rivers Authority R&D Project Record 282/1/Wx,* Bristol, UK.

Johnson I.W., Elliott, C.R.N., Gustard, A. (1995) Modelling the effect of groundwater abstraction on salmonid habitat availability in the River Allen, Dorset, England, *Regulated Rivers: Research & Management*, 10: 229-238.

Jorde, K. (1996) Ecological evaluation of Instream Flow Regulations based on temporal and spatial variability of bottom shear stress and hydraulic habitat quality. In: *Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics*, M. Leclerc et al. (Eds.) Quebec City, Canada.

Jowett, I.G. (1989) *River hydraulic and habitat simulation, RHYHABSIM computer manual.* New Zealand fisheries miscellaneous Report 49. Ministry of Agriculture and Fisheries, Christchurch. New Zealand. 39 p.

Jowett, I.G. (1990) Factors related to the distribution and abundance of brown and rainbow trout in New Zealand clear-water rivers. *New Zealand Journal of Marine and Freshwater Research*, 24: 429-440.

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

Jowett, I. G. (1993) A method of objectively identifying pool, run and riffle habitats from physical measurements. *New Zealand Journal of Marine and Freshwater Research*, 27: 241-248.

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

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

Jowett, I.G., Hayes, J.W., Duncan, M.J. (2008) A guide to instream habitat survey methods and analysis. NIWA Science and Technology Series (No. 54). 121p.

Jowett, I.G., Richardson, J. (1989) Effects of a severe flood on instream habitat and trout populations in seven New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research*, *23*: 11-17.

Jowett, I.G.; Richardson, J. (2008) Habitat use by New Zealand fish and habitat suitability models. *NIWA science and technology series*, 132 p.

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

Junk, W.J., Bayley, P.B., Sparks R.E., (1989) The flood pulse concept in river-floodplain systems. *Canadian Journal of Fisheries and Aquatic Sciences*, 106: 110-127.

Killingtviet, Å., Harby, A. (1994) Multi Purpose Planning with the River System Simulator - a decision support system for water resources planning and operation. In: *Proceedings of* *the First International Symposium on Habitat Hydraulics*, Norwegian Institute of Technology, Trondheim.

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

Lamouroux, N, Jowett, I.G. (2005) Generalized instream habitat models. *Canadian Journal of Fisheries and Aquatic Sciences*, 62: 7-14.

Maddock, I.P. (1999) The Importance of Physical Habitat Assessment for Evaluating River Health, *Freshwater Biology*, 41: 373-391.

Maddock, I.P., Thoms, M., Jonson, K., Dyer, F., Lintermans, M. (2004) Identifying the influence of channel morphology on physical habitat availability for native fish: application to the Two-Spined Blackfish (*Gadopsis bispinosus)* in the Cotter River, Australia. *Marine and Freshwater Research*. 55: 173-184.

Mathur, D., Bason W.H., Purdy, E.J., Silver, C.A. (1985) A critique of the instream flow incremental methodology. *Canadian Journal of Fisheries and Aquatic Sciences*, 42: 825-831.

Ministry for Environment (1998) Flow guidelines for instream values. Volumes A and B. Ministry for Environment: 146 and 215 p.

Ministry for Environment (2008) Proposed National Environmental Standard on Ecological Flows and Water Levels: Discussion document. Ministry for Environment: 61p.

Ministry for Environment (2013) Proposed amendments to the National Policy Statement for Freshwater Management 2011: a discussion document. Wellington, New Zealand. Ministry for the Environment. ME 1130, 76 p.

Nehring, R.B., Miller, D.D. (1987) The influence of spring discharge levels on rainbow and brown trout recruitment and survival, Black Canyon of the Gunnison River, Colorado, as determined by IFIM / PHASIM models. Proceedings of the Western Association of Fish and Wildlife Agencies and the Western Division of American Fisheries Society, 67: 388-397.

Newson, M.D., Newson, C.L. (2000) Geomorphology, ecology and river channel habitat: mesoscale approaches to basin-scale challenges. *Progress in Physical Geography*, 24: 195-217.

Norris, R.H., Thoms, M.C. (1999) What is river health? *Freshwater Biology,* 41: 197-209.

Orth, D.J. (1986) In defense of the Instream Incremental Methodology. *Canadian Journal of Fisheries and Aquatic Sciences*, 43: 1092-1093.

Padmore, C.L. (1997) Biotopes and their hydraulics: a method for determining the physical component of freshwater habitat quality. In Boon, P.J. & Howell, D.L. (eds.), *Freshwater quality: defining the indefinable*. Edinburgh: HMSO. 251-257.

Parasiewicz, P. (2001) MesoHABSIM: A concept for application of instream flow models in river restoration planning. *Fisheries*, 26: 6-13.

Parasiewicz, P., Dunbar, M.J. (2001) Physical habitat modelling for fish - a developing approach. *Archiv fur Hydrobiologie Supplement*, 135/2-4: 1-30.

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

Poff, N.L., Richter, B.D., Arthington, A.H., Bunn, S.E., Naiman, R.J., Kendy, E., Acreman, M., Apse, C., Bledsoe, B.P., Freeman, M.C., Henriksen, J., Jacobson, R.B., Kennen, J.G., Merritt, D.M., O'Keefe, J.H., Olden, J.D., Rogers, K., Tharme, R.E., Warner, A. (2010) The Ecological Limits of Hydrologic Alteration (ELOHA): A new framework for developing regional environmental flow standards. *Freshwater Biology*, 55: 147-170.

Poole, G.C., Frissell, C.A., Ralph, S.C. (1997) Instream habitat unit classification: Inadequacies for monitoring and some consequences for management. *Journal of the American Water Resources Association*, 33: 879-896.

Reiser, D.W., Wesche, T.A., Estes, C. (1989) Status of instream flow legislation and practices in North-America. *Fisheries*, 14: 22-29.

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

Roper, B.B., Scarnecchia, D.L. (1995) Observer Variability in Classifying Habitat Types in Stream Surveys. *North American Journal of Fisheries Management*, 15: 49-53.

Roper, B.B., Kershner, J.L., Archer, E., Henderson, R. (2002) An evaluation of physical stream habitat attributes used to monitor streams. *Journal of the American Water Resources Association*, 38:1637-1646.

Scott, T., Butt, J., O'Brien, L. (2013) Kakapo Brook hydro-scheme: assessment of ecological effects. *Prepared for MainPower New Zealand Limited*. 65 p.

Suren, A.M., Biggs, B.J.F., Duncan, M.J., Bergey, L., Lambert, P. (2003) Benthic community dynamics during summer low-flows in two small rivers of contrasting enrichment 2. Invertebrates. *New Zealand Journal of Marine and Freshwater Research*, 37: 71-83.

Tickner, D., Armitage, P.D., Bickerton, M.A., Hall, K.A. (2000) Assessing stream quality using information on mesohabitat distribution and character. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 10: 179-196.

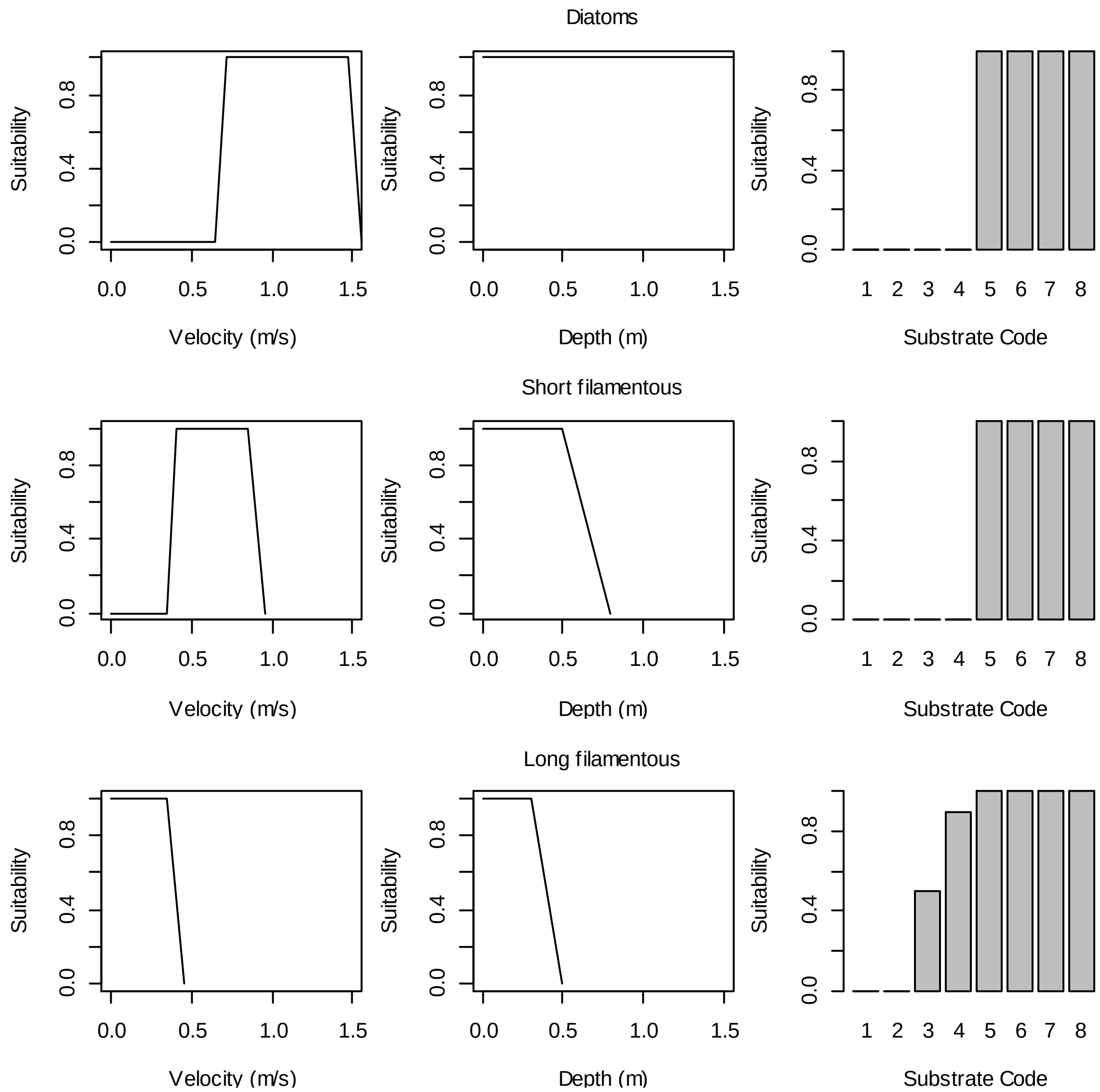
Vadas, R.L. Jr., Orth. D.J. (1998) Use of physical variables to discriminate visually determined mesohabitat types in North American streams. *Rivers* 6: 143-159.

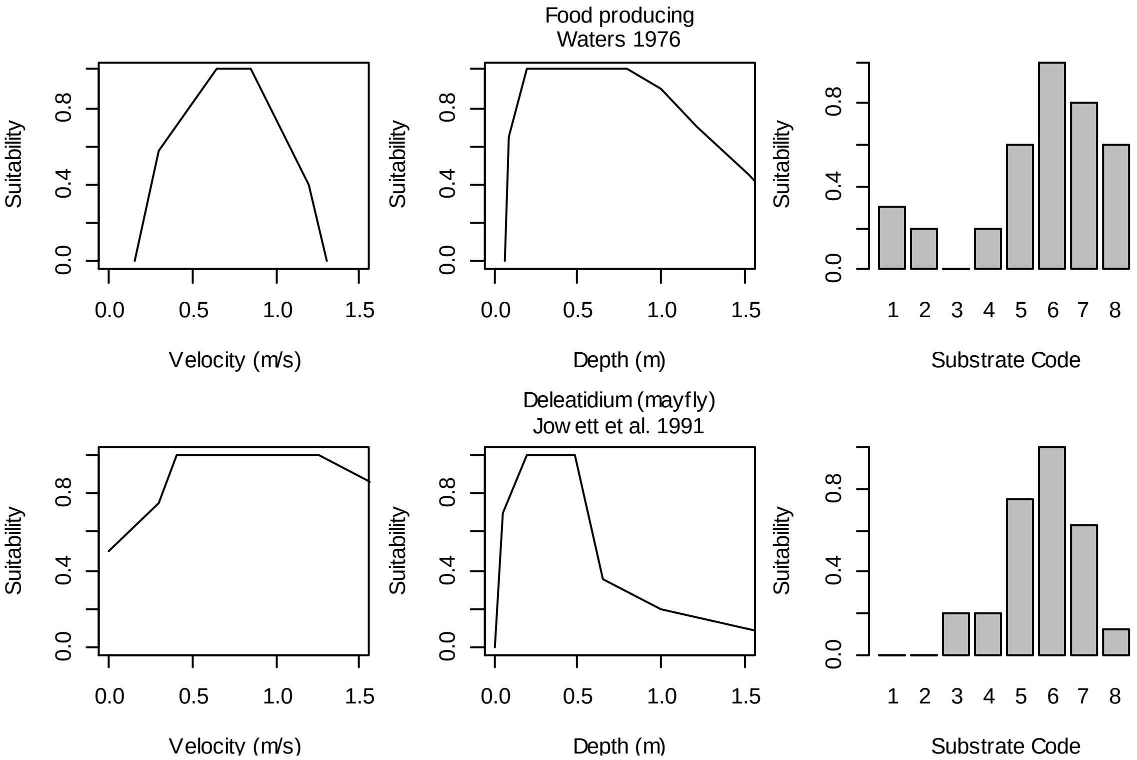
Veendrick, B. (2015) Glynn Wye Hydro and Irrigation Scheme – Hydrology Assessment. *Prepared for MainPower New Zealand Limited and Rooney's Holding Limited.* 45 p.

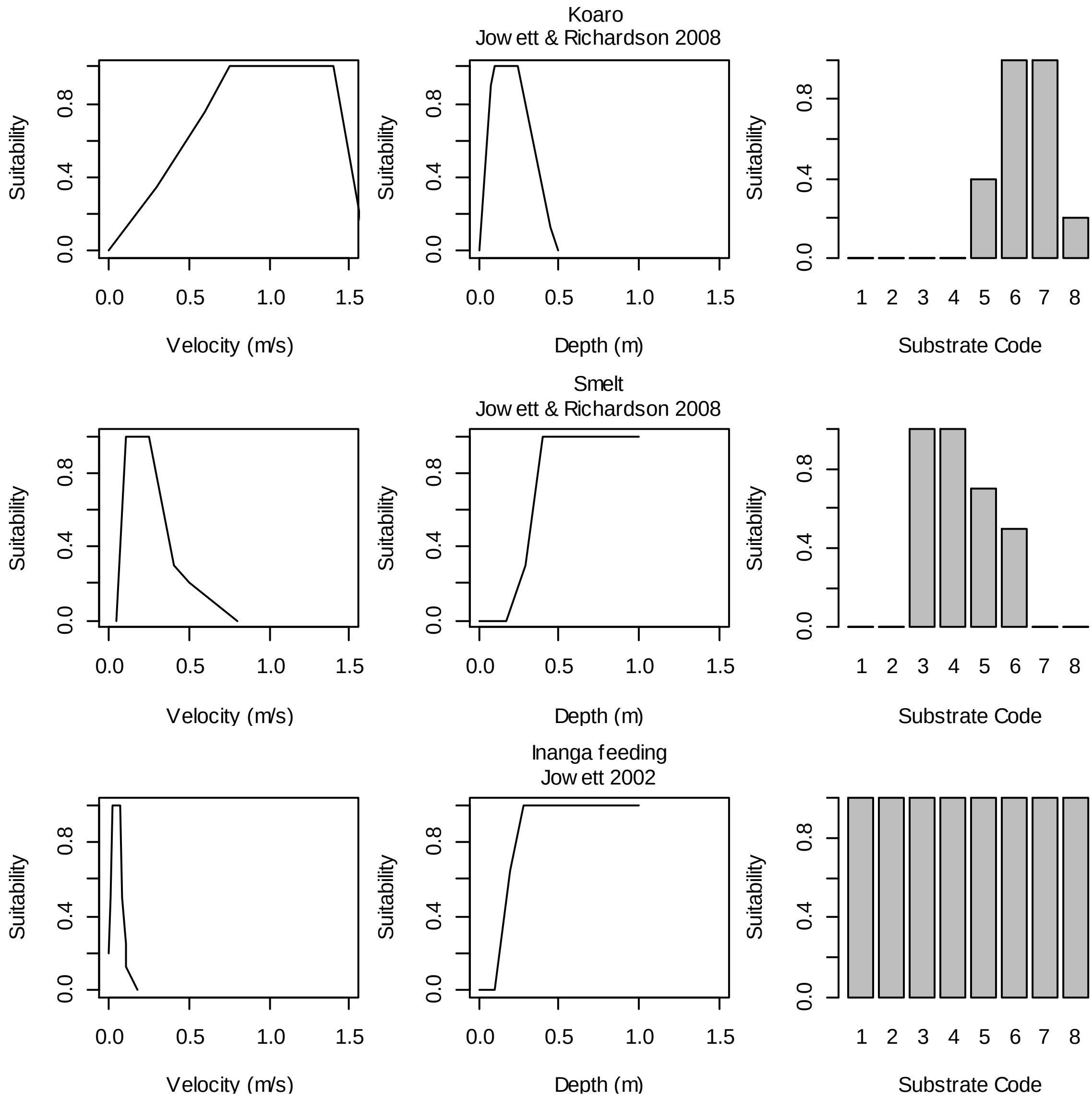
Wadeson, L.A. (1994) A geomorphological approach to the identification and classification of instream flow environments. *South African Journal of Aquatic Sciences*, 20: 1-24.

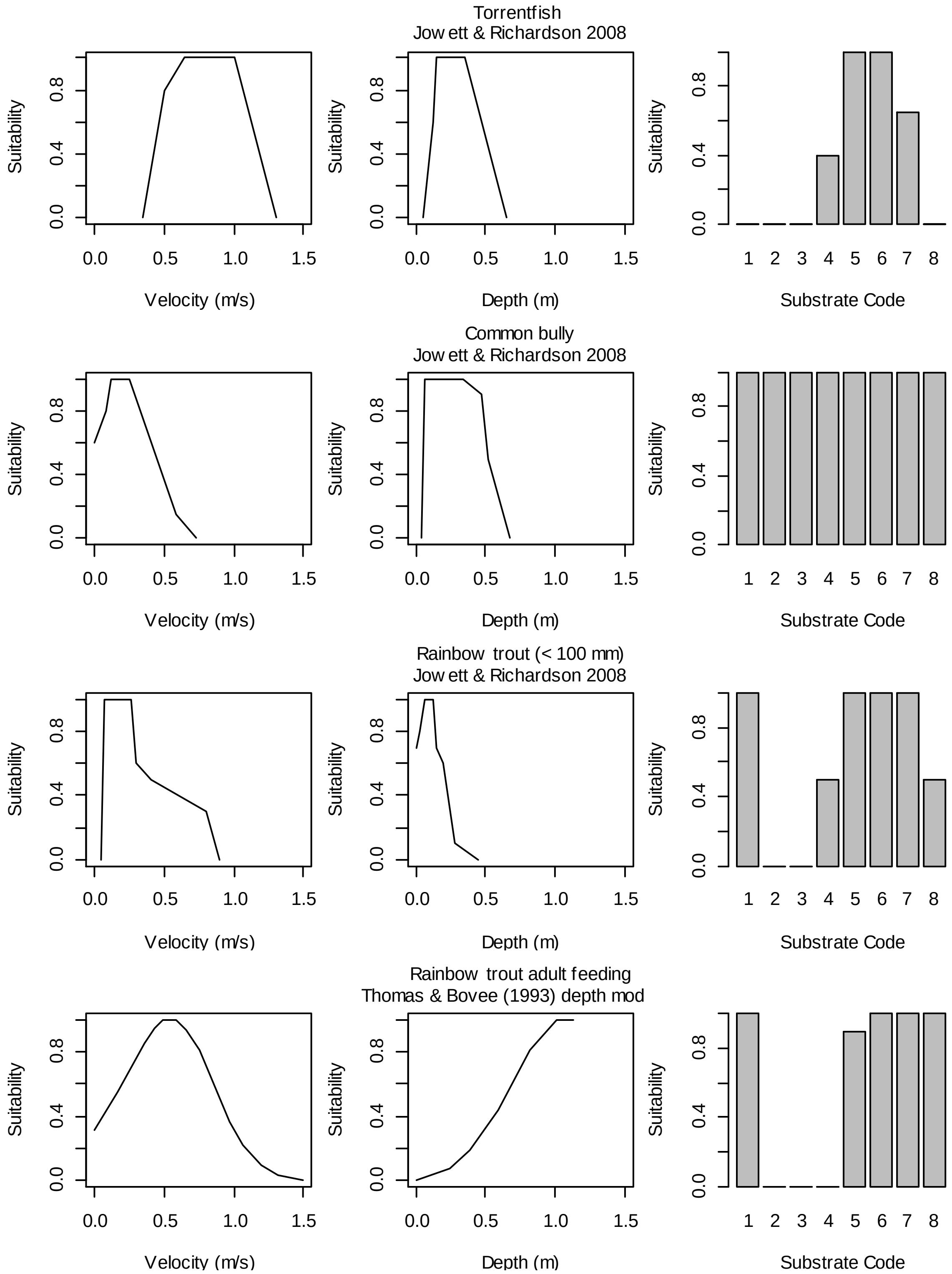
Waters, B.F. (1976) A methodology for evaluating the effects of different streamflows on salmonid habitat. *In*: Proceedings of the Symposium and Speciality Conference on Instream Flow Needs II. Orsborn, J.F. Allman, C.H. (Eds.). American Fisheries Society, Bethesda, Maryland. pp 224-234.

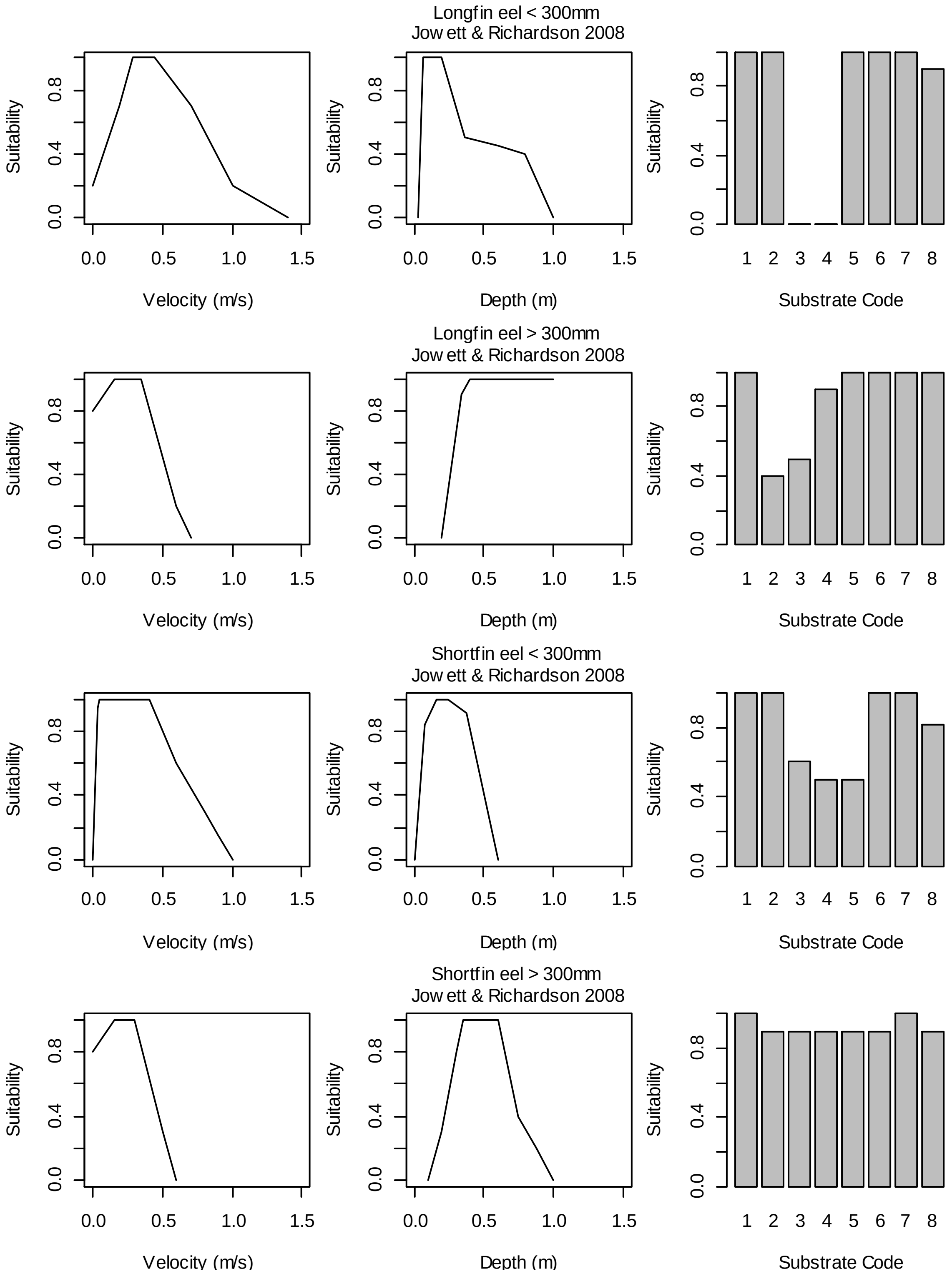
Appendix A Habitat suitability criteria


Diatoms
Suitability
0.0
0.4
0.8
0.0
0.5
1.0
1.5
Velocity (m/s)
Depth (m)
1 2 3 4 5 6 7 8
Substrate Code
Short filamentous
Long filamentous


Food producing
Waters 1976
Suitability
0.0
0.4
0.8
0.0
0.5
1.0
1.5
Velocity (m/s)
Depth (m)
1 2 3 4 5 6 7 8
Substrate Code
Deleatidium (mayfly)
Jow ett et al. 1991
Velocity (m/s)
Depth (m)
Substrate Code


Koaro
Jowett & Richardson 2008
Smelt
Jowett & Richardson 2008
Inanga feeding
Jowett 2002
Suitability
0.0
0.4
0.8
0.0
0.5
1.0
1.5
1 2 3 4 5 6 7 8
Velocity (m/s)
Depth (m)
Substrate Code


Torrentfish
Jowett & Richardson 2008
Common bully
Jowett & Richardson 2008
Rainbow trout (< 100 mm)
Jowett & Richardson 2008
Rainbow trout adult feeding
Thomas & Bovee (1993) depth mod
Suitability
0.0
0.4
0.8
Velocity (m/s)
0.0
0.5
1.0
1.5
Depth (m)
Substrate Code
1 2 3 4 5 6 7 8


Longfin eel < 300mm
Jowett & Richardson 2008
Longfin eel > 300mm
Jowett & Richardson 2008
Shortfin eel < 300mm
Jowett & Richardson 2008
Shortfin eel > 300mm
Jowett & Richardson 2008
Suitability
0.0
0.4
0.8
0.0
0.5
1.0
1.5
Velocity (m/s)
Depth (m)
1 2 3 4 5 6 7 8
Substrate Code

Appendix B Photographs of some cross-sections of the Waiapu River

Figure B-1: Cross-section 1.

Cross-section 2.


Cross-section 3.

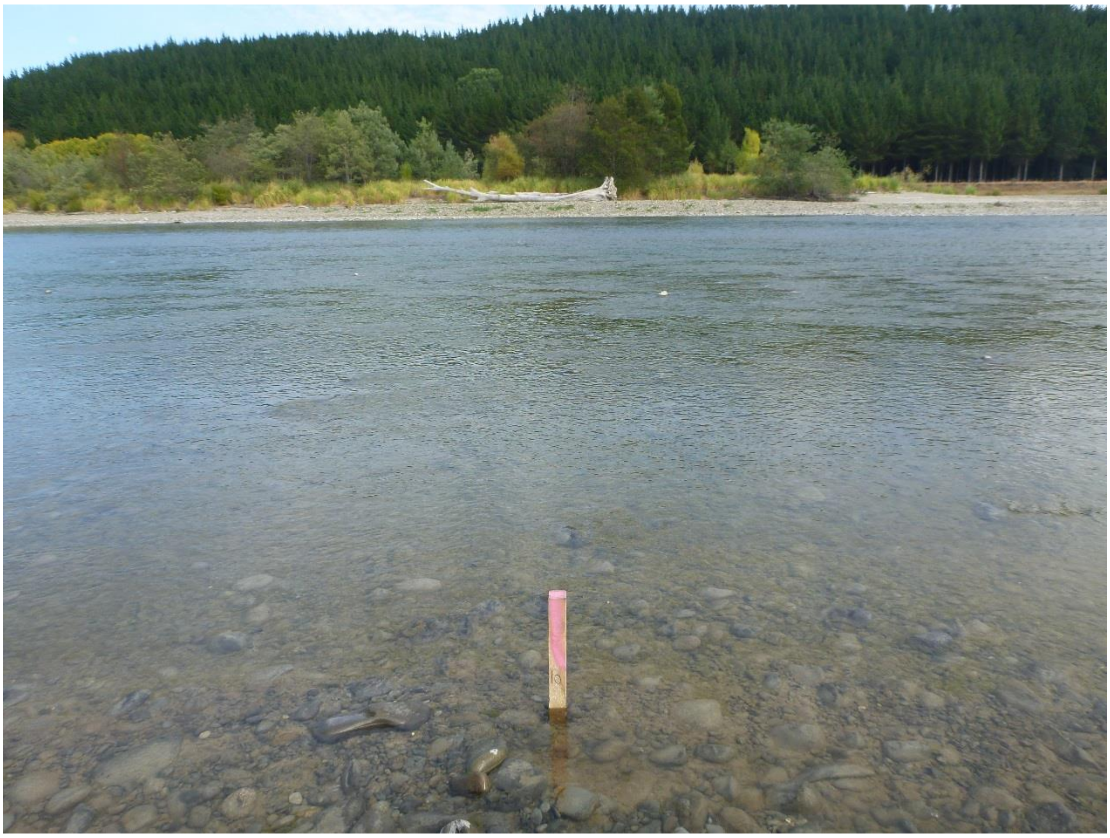

Cross-section 4 (Photo 35).

Cross-section 5 (photo38).

Cross-section 6.


Cross-section 7.


Cross-section 8 (Photo 50).



Cross-section 9 (Photo 53).

Cross-section 10 (Photo 57).

Cross-section 11.

Cross-section 12 (Photo 63)

Cross-section 13 (Photo 68).

Cross-section 14 (photo 70).