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Flow Requirements for Ecosystem Health in the Whenuakite River (Coromandel)

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NIWA Client Report: HAM2005-075
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Cover photo: Low tide at dawn (2-3-2005). Whenuakite River at the Te Kauanga Road Bridge.

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Executive Summary

The Whenuakite River flows into the upper Whitianga Harbour (Coromandel Peninsula) from native forest hill-country and pastoral lowlands. Abstraction pressure on the Whenuakite River is increasing with demand for irrigation of kiwifruit and other horticulture. Existing and proposed consents are spread throughout the lower catchment (downstream of Boat Harbour Road). Reduced flows from abstraction can affect stream ecosystems. Potential issues raised for the Whenuakite catchment include fish and invertebrate habitat, growth of nuisance aquatic plants, water quality and whitebait spawning, with the relative importance of each issue expected to vary along the length of the river. Environment Waikato asked NIWA to investigate the flow requirements for these specific issues. The river was divided up into reaches that have common issues and appropriate methods were chosen to investigate each issue, including WAIORA for oxygen modelling and RHYHABSIM for habitat and temperature modelling.

The reaches assessed and issues investigated are summarised in Table 1. Natural low flow conditions were found to maintain adequate habitat and water quality in the lowland and upland reaches. However, dissolved oxygen levels in the tidal reach drop below acute limits during natural low flow conditions because of oxygen depletion by aquatic plants. Abstracting water will further reduce dissolved oxygen concentrations during low flow conditions and extend the time that the river experiences low oxygen concentrations. This suggests the critical issue for setting allocation limits from the Whenuakite is oxygen depletion in the tidal reach.

A minimum flow of 0.205 m^3/s is recommended for the tidal reach (based on the moderate impairment oxygen standard of 4 g/m^3). This is considered adequate to maintain the resident aquatic ecosystem, which is likely to be impaired by existing low oxygen conditions. To achieve regional plan objectives for a net improvement in water quality, it is recommended that allocations be made subject to mitigation (e.g., avoid abstraction during times of daily oxygen minima). In addition to the resident fish, the tidal reach is also the migratory pathway for all diadromous native fish living in the greater Whenuakite catchment. These migrating fish will include more sensitive species that inhabit the forested tributaries. Therefore, a higher minimum flow of 0.26 m^3/s is recommended during the whitebait migration season (1 August to 30 November).

Table 1: Flow requirements for the issues that were investigated in each reach of the Whenuakite River. Some of the issues not found to have high flow requirements are simply indicated as "Not critical". Otherwise, flow requirements are specified (m^3/s) and the standards used to derive them are given in the footnotes. Natural flow estimates are also provided for each reach (median flow, MALF, Q_5).

m^3/s	Brackish reach	Tidal reach	Lowland reach	Midland Reach	Upland reach
Whitebait spawning	Not critical				
Oxygen depletion		0.205 to 0.26 [A]	0.062 [B]		
Temperature		Not critical	Not critical		(see section 3.4)
Nutrients		0.08 [C]			
Fish habitat			0.075 [D]	0.075 [E]	0.015 [F]
Invertebrate habitat					0.014 [G]
Nuisance aquatic plants		>1 [H]	>1 [H]		
Median Flow		0.84	0.520	0.465	0.067
MALF [I]		0.21	0.130	0.115	0.023
Q_5 [J]		0.16	0.100	0.090	0.017

A. A flow of 0.205 m^3/s is required to exceed the dissolved oxygen moderate impairment standard for adult native fish (4 g/m^3); 0.24 m^3/s is required to exceed the slight impairment standard for adult native fish of (5 g/m^3); 0.26 m^3/s is required to exceed the slight impairment standard for early life stages (5.5 g/m^3).
B. Flow required to maintain slight impairment standard for adult native fish (5 g/m^3 dissolved oxygen).
C. Flow required to maintain ANZECC nutrient threshold for NH_4-N.
D. Flow required to maintain 85% of maximum habitat for inanga.
E. Flow required to maintain 85% of maximum habitat for shortfin eel.
F. Flow required to maintain 85% of habitat available at MALF for redfin bully.
G. Flow required to maintain 85% of riffle habitat available at MALF.
H. Flow required to produce velocities that would reduce the biomass of aquatic plants. Not used for flow recommendations because it is well in excess of natural baseflows.
I. MALF is the 7-day mean annual low flow.
J. Q_5 is the one in 5-year 7-day low flow.

1. Introduction

1.1 Study Brief and Background

The Whenuakite River flows into the upper Whitianga Harbour. The top of the catchment borders the Tairua Harbour catchment, with other tributaries flowing in from behind Hot Water Beach and Boat Harbour Bay. Abstraction pressure on the Whenuakite River is increasing with demand for irrigation of kiwifruit and other horticulture in the catchment. Existing and proposed consents are spread throughout the lower catchment (downstream of Boat Harbour Road).

Reduced flows can affect stream ecosystems. Potential issues raised for the Whenuakite catchment include fish and invertebrate habitat, growth of nuisance and beneficial macrophytes, water quality and whitebait spawning. Environment Waikato asked NIWA to investigate the flow requirements for these specific issues. The relative importance of each issue is expected to vary along the length of the river. The river was divided up into reaches that have common issues, based on a pre-survey site visit (9-12-2004).

1.2 Framework for determining flow requirements

The Ministry for the Environment (MfE) developed a standardised framework for determining instream flow requirements (MfE 1998). These flow guidelines advocate the development of clear management objectives for the instream values that are to be sustained (e.g., fish habitat, water quality). Technical assessment methods can then be applied to the issues most likely to be critical. This report examines potential instream ecological effects associated with water abstraction, so only implements the components of the MfE framework that are relevant to this task.

The Proposed Waikato Regional Plan offers guidance in identifying instream values and objectives for the Whenuakite River (January 2004 version). Policy in the plan is based on a stream classification system, with policies and standards selected depending on the values of each stream class. All streams in the Waikato region are included in the surface water class. The Whenuakite River is also nominated as an indigenous Fishery Class waterbody. The Natural State water class only applies to selected tributaries in the catchment where abstraction pressure is not currently an issue. The key objective relating to this report is to maintain existing aquatic life (Section 3.2.3, Policy 3). More specific standards provided for rivers of this classification include requirements for sufficient flow to maintain fish habitat (Section

3.2.4.4 a.), and that changes in dissolved oxygen are not allowed to have significant adverse effects on existing aquatic ecosystems (Section 3.2.4.1 a.). The plan does not go as far as setting quantitative standards for habitat or oxygen levels, so it is necessary for this report to provide recommendations and options.

Following the MfE flow guidelines (MfE 1998), the next step is to identify potentially critical issues for the Whenuakite River. The character and habitat type varies over the catchment, from small forested cobble-streams in the headwaters, to a deep, slow-flowing river in the lowland section. The issues most likely to be critical were expected to vary with stream type. Different methods were therefore chosen for each reach to best target the critical issues. There are no in-river impoundments proposed for the Whenuakite River, so the magnitude of flood flows are unlikely to be affected by the proposed abstractions (abstractions are typically a fraction of baseflows, which in turn represent a fraction of flood flows). Issues relating to flow regime requirements (flushing flows etc.) are therefore not considered a critical issue for the Whenuakite River. The mouth of the Whenuakite River is not closed-off from the sea by sand or gravel accumulation, so access for fish from the sea (e.g., whitebait) is not expected to be a critical issue for setting flow requirements. The Whenuakite is not known to support trout populations or trout spawning. Providing adequate habitat conditions for native fish in the lower catchment is expected to require greater flows than that required for fish passage and migration, hence depth requirements for fish passage were not investigated. Native fish communities are likely to have significant flow requirements for habitat and water quality. Flow requirements for stream invertebrates and issues relating to aquatic plant growth are also potentially critical issues for the Whenuakite River.

The technical assessment methods chosen to investigate the effects of reduced flows on aquatic ecosystems include WAIORA for oxygen modelling and RHYHABSIM for habitat and temperature modelling. Basic mass-flow calculations were used to investigate nutrient issues. Whitebait spawning was investigated by obtaining a better understanding of tidal patterns near the river mouth. The methods used are further described below and in Section 2.

1.3 Introduction to Instream Habitat Modelling

1.3.1 Flow Assessment Methods

There has been considerable debate and discussion of flow assessment methods without any real resolution as to the best method (e.g., Stalnaker & Arnette 1976;

Wesche & Rechard 1980; Schuytema 1982; Trihey & Stalnaker 1985; Estes & Orsborn 1986; Morhardt & Altouney 1986; Richardson 1986; Karim et al. 1995, Hudson et al. 2003), possibly because the environmental goals of the methods are different (Jowett 1997). Quantitative instream flow methods are generally divided into three major categories: (i) historic flow regime; (ii) hydraulic; and (iii) habitat. Although all three categories aim to maintain an appropriate stream environment, they focus on different aspects of the stream, such as flow, wetted perimeter or physical habitat, and these measures are used to specify a level of environmental protection (e.g., the proportion of flow, wetted perimeter or physical habitat that is retained by a minimum flow). There is an implicit assumption that the proportion of flow, wetted perimeter or physical habitat specified as a level of protection will reflect the condition of the stream environment, and that there is some cut-off level or minimum flow below which aquatic life will not be adequately sustained. However, responses of habitat variables and associated organisms to different levels of flow are generally gradual, and decisions need to be made as to when an acceptable level of environmental protection has been achieved.

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

The ecological goal of habitat methods is to provide or retain a suitable physical environment for aquatic organisms that live in a river. The consequences of loss of habitat are well known; the environmental bottom-line is that if there is no suitable habitat for a species it will cease to exist. Habitat methods tailor the flow assessment to the resource needs and can potentially result in improved allocation of resources. However, it is essential to consider all aspects such as food, shelter, and living space and to select appropriate habitat suitability curves (Orth 1987; Jowett 1997; Biggs 1996; MfE 1998).

1.3.2 Habitat preferences and suitability curves

The terms habitat-suitability and habitat-preference are often used interchangeably to refer to the range of habitat conditions where an organism prefers to live. For example, if we look at the temperature requirements of people, most would prefer to live in areas/habitats where temperatures range from 22–28^{o}C. Then, all else being equal, we would expect to see lower densities of people in areas/habitats that were progressively colder or hotter than the optimal range.

Of course, not all else is equal and people are widely distributed. But when looking at the potential effects of water abstraction on stream ecosystems, the only aspect being manipulated is the baseflow, and therefore most other habitat parameters tend to remain constant. Riparian vegetation is unlikely to change, and likewise for the stream substrate[1], stream gradient, flood disturbance, distance to the sea, and other determinants of fish diversity and abundance. By understanding the preferences of stream organisms for parameters that do change with flow (primarily depth and velocity), we can predict the change in habitat suitability with flow.

Suitability curves for a range of stream organisms have been defined, based on extensive research, for instream flow assessment methods such as PHABSIM (Milhous et al. 1989) and RHYHABSIM. Such suitability curves can be derived directly by surveying habitats over a range of depths, velocities etc. and plotting the abundance of organisms against habitat measures to show where they are most abundant (i.e., where they prefer to live).

Generally, native fish are found in similar habitats over a wide range of rivers. McDowall (1990) has classified these habitats in descriptive terms. The quantitative approach taken in New Zealand has been to develop general habitat suitability criteria for species of interest by using data collected from multiple rivers. To date, general habitat suitability curves have been developed for several native fish species (e.g., Figure 1.1), some of it published (e.g., Jowett & Richardson 1995; McCullough 1998) and some of it unpublished.

[1] Substrate can be affected by impoundments and dams that capture entire flood events. High flow events are important for flushing periphyton and fine sediment build up. Simple abstractions that do not involve in-river impoundments, such as the type considered here, are rarely capable of affecting the flood regime.

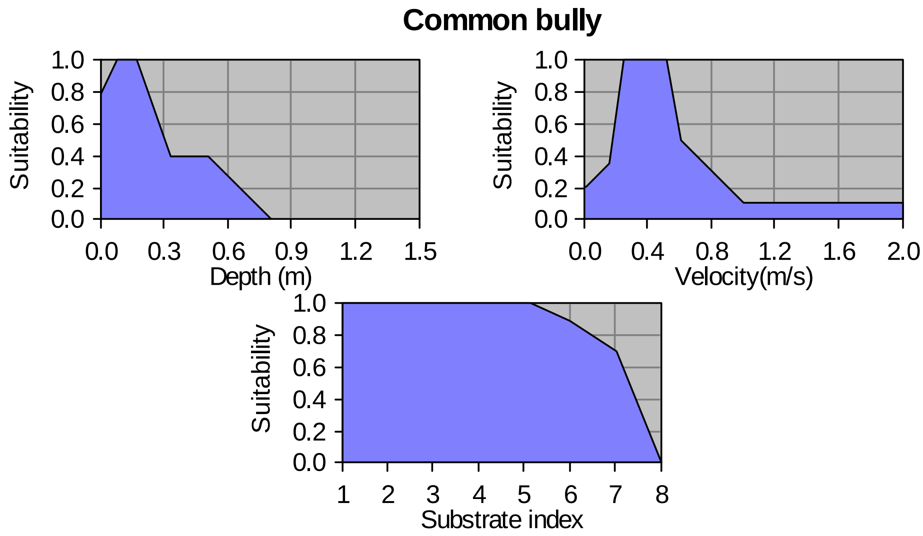

Figure 1.1: Habitat suitability curves for common bully, where suitability ranges from 0 (unsuitable) to 1 (optimal). Substrate index: 1=vegetation, 2=silt, 3=sand, 4=fine gravel, 5=gravel, 6=cobble, 7=boulder, 8=bedrock (Jowett & Richardson 1995).

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

A stratified random survey approach, called habitat mapping, was used in this study for the upland reach. Habitat mapping is undertaken over the segment of river under study so that the proportions of different habitats (e.g., pool, riffle, run, etc.) can be calculated. Cross-section locations are then selected to represent each of the habitat types. In the other reaches habitat was more uniform, and cross-sections were spaced regularly to represent the diversity of depths and velocities present.

At each cross-section, depths, water velocities, and substrate composition are recorded at sufficient intervals to describe the cross-section (Jowett 1989). Flow and water level are recorded for each cross-section and repeated at two other flows to establish a relationship between depth and flow (a rating curve). Water velocities and depths over each cross-section can then be predicted for a range of flows, using the rating curve and channel geometry.

1.3.4 Procedure for Calculating Instream Habitat

The procedure for an instream habitat analysis is to select appropriate habitat suitability curves or criteria (e.g., Figure 1.1), and then to model the effects of a range of flows on the selected habitat variables in relation to these criteria. The area of suitable habitat, or weighted usable area (WUA), is calculated as a joint function of depth, velocity and substrate type for different flows, as shown in Figure 1.2. Instream habitat can be expressed either as the total area of suitable habitat or as the percentage of the stream area that is suitable habitat. WUA (m^2/m) is the measure of total area of suitable habitat per metre of stream length. WUA (%) is the percentage of suitable habitat within the wetted area. Both WUA (m^2/m) and WUA (%) can be used to assess minimum flow requirements for fish. In streams where the flow is confined between defined banks, the two measures will produce similar results.

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

1.2.5 Assessing Flow Requirements

There are two decisions to be made when assessing flow requirements based on habitat modelling results; firstly, which species are to be protected, and secondly the level of habitat protection afforded to the nominated species. Jowett & Richardson (1995) suggested that flow recommendations for native fish be based on redfin bully and common bully habitat, because these fish represent a habitat guild with preferences that were intermediate between the fish that prefer slow, shallow water and those that prefer deeper, swift water. The Environment Bay of Plenty method recommends basing minimum flows on the species with the highest flow requirement (Wilding 2002).

Various approaches to setting habitat protection levels have been used, from maintaining a maximum amount of habitat, to calculating a percentage of habitat at median flow, or using an inflection-point or breakpoint of the habitat/flow relationship (Jowett 1997). Nominating the flow that provides maximum habitat as the minimum flow is generally avoided because this reduces the chance of fish actually experiencing that optimum (i.e., it is better to allow optimum flows, rather than set a limit intended to discourage reaching that point).

Using an inflection point is possibly the most common procedure for assessing minimum flow requirements using habitat methods. While there is no percentage or absolute value associated with an inflection point, it is a point of diminishing return, where proportionately more habitat is lost with decreasing the flow than is gained by increasing the flow. A clear inflection point is not always seen.

Environment Bay of Plenty developed a more prescriptive approach, leaving less to observer interpretation. This approach prescribes a percentage of habitat (termed the habitat protection level) that is scaled according to the significance of each fish species present (Wilding 2002). The intention of this method was to allow a consistent approach to setting minimum flows region-wide. More background and detail of this method is given in Appendix 1.

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., algal slimes), rejuvenating stream habitats (Jowett & Biggs 1997). Extended periods without flow disturbance usually result in a shift in benthic community composition, such as a reduction in diversity, and an increase in biomass of a few species within plant and animal communities (Biggs & Close 1989; Jowett & Duncan 1990). However, such flow regime requirements are normally only applicable below large impoundments that capture entire flood events (water pumps are rarely capable of abstracting a significant proportion of flood flows).

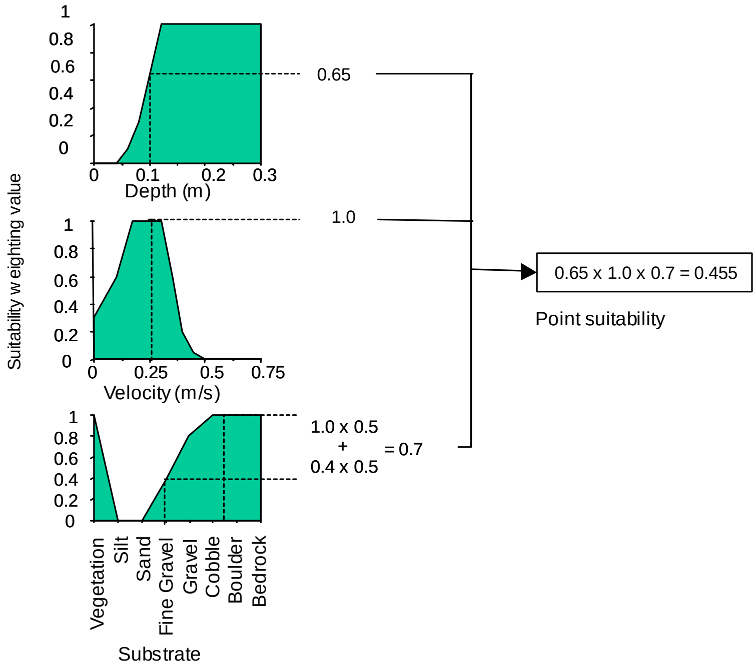

Figure 1.2: Calculation of habitat suitability for a fish species at a point with a depth of 0.1 m, velocity of 0.25 m/s, and substrate comprising 50% fine gravel and 50% cobble. The individual suitability weighting values for depth (0.65), velocity (1.0), and substrate (0.7) are multiplied together to give a combined point suitability of 0.455.

2. Sites and Methods

2.1 Study Reaches

The Whenuakite River flows into the Whitianga Harbour on the eastern side of the Coromandel Peninsula. The hills and ranges of the Whenuakite catchment are predominantly regenerating native forest (scrub) and exotic forest, with pasture extending across the valley floor (Figure 2.1 & 2.2). At Boat Harbour Road, the catchment is 69% native scrub, 12% plantation forest, and 18% pasture (from Landcover database information incorporated in the River Environment Classification database). At the river mouth, pasture and horticulture represent 42% of the total catchment area. Tributaries of note include the Parakau Stream, which drains a large forested catchment discharging to the lower tidal section of the Whenuakite River (Figure 2.1 and 2.2). The Huruhurutakimo Stream is a smaller tributary that empties into the lower river (Figure 2.2). This tributary drains a developed catchment (89% pasture and horticulture), including drained peat swamp, that is likely to represent a significant nutrient source.

Water takes for irrigation, both existing and proposed, are largely confined to the lower catchment. This study looked at the potential effects of water abstraction on aquatic ecosystems in the Whenuakite River. The river was divided into reaches based on river character and aquatic communities. The most likely critical issues were then determined for each reach and appropriate methods chosen accordingly.

The bottom reach of the river is brackish. Coffey (1997) found biological indicators of saltwater intrusion extending 1 km upstream of Te Kauanga Road bridge (Figure 2.2). The river-bed is gravel and sand at this point, with intertidal and riparian areas dominated by rushes and other wetland species (Figure 2.3 & cover photo). The effects of abstraction on whitebait spawning were investigated for this reach.

Moving further up the catchment, the tidal reach is slow flowing with abundant macrophyte communities (Figure 2.4 & 2.5). Macrophytes recorded by Coffey (1997) in this reach include natives and exotics (*Potamogeton ochreatus*, *Egeria densa*, *Myriophyllum propinquum*, *M. triphyllum*, *Nitella hookeri*, *Callitriche stagnalis*). These weed beds were most prolific upstream of the Parakau Stream confluence in March 2005 (Figure 2.5). Riparian vegetation includes some pasture, but is predominantly scrub (privet, flax, etc.). In assessing the flow requirements for this reach, water quality issues were the focus (nutrients, dissolved oxygen, temperature). Habitat surveys are generally unsuccessful in tidal reaches because water level is not a simple function of flow. The less dependent habitat is on flow, the less likely it will be a critical issue.

The lowland reach is a short section of river that lies between the tidal reach and the shallower midland reach. Macrophytes appeared less problematic in this reach (charophytes dominate), because of more complete shading from riparian vegetation (mostly kanuka and privet). Steep banks appeared to prevent stock access to the river here, which is deep and slow flowing (Figure 2.5). A habitat survey was conducted in this reach, along with water quality monitoring.

Half a kilometre upstream of Hot Water Beach Road, the river becomes shallower and faster flowing. This midland reach extends to within a kilometre of the Whenuakite Bridge on State Highway 25 (Figure 2.1). The habitat is predominantly sandy runs, with woody debris dams providing cover for fish and flow variability (Figure 2.7). There is moderate to good shade from riparian vegetation (predominantly privet). Occasional charophyte beds were also noted; these provide additional stable habitat. A habitat survey was carried out in this reach, as fish habitat is considered the most likely critical issue. Water quality was not considered a critical issue given the catchment is mostly forested. Moderate water velocities and shallow habitat with good shading are features unlikely to allow oxygen levels to drop significantly.

The upland reach starts within a kilometre of the State Highway 25 bridge. Substrate is predominantly cobble and boulder, with some sandy pools (Figure 2.8). The river divides into two tributaries just above State Highway 25, both draining forested catchments (regenerating native forest). Environment Waikato are bringing together habitat modelling work on a range of Coromandel streams, and a reach was included in the upland reach to expand the Coromandel dataset. This reach was located on the true right tributary, in farmland immediately downstream of the forest margin. Cattle have access to the stream, which receives some shade from kanuka and other trees.

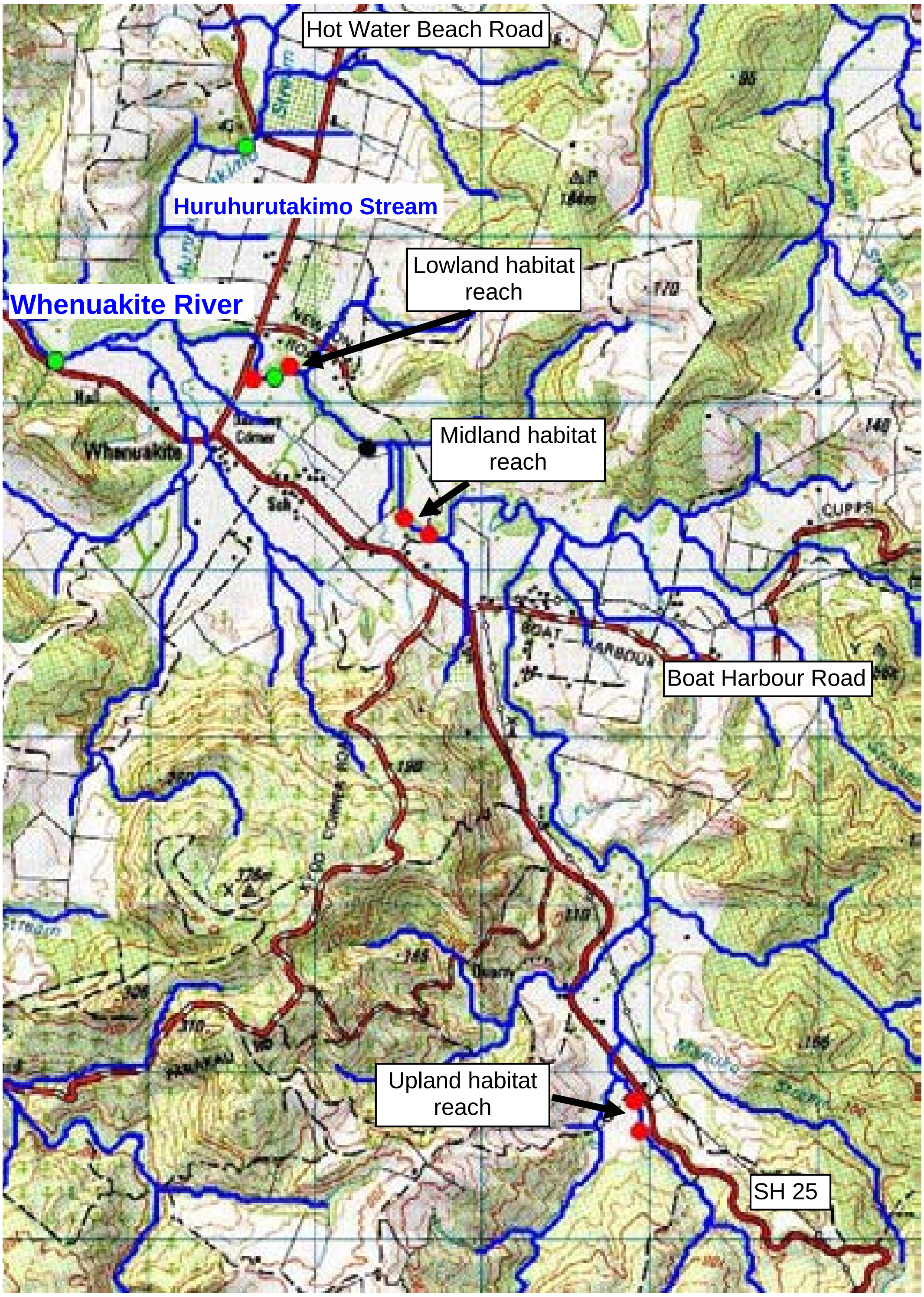

Figure 2.1: Study sites on the Whenuakite River, showing the location of habitat surveys (red dots mark cross-section at each end of the reach), water quality monitoring sites (green dots) and Black's Farm (black dot) were only flow was measured. (NZMS260 T11 © Sourced from Land Information New Zealand data. CROWN COPYRIGHT RESERVED.)

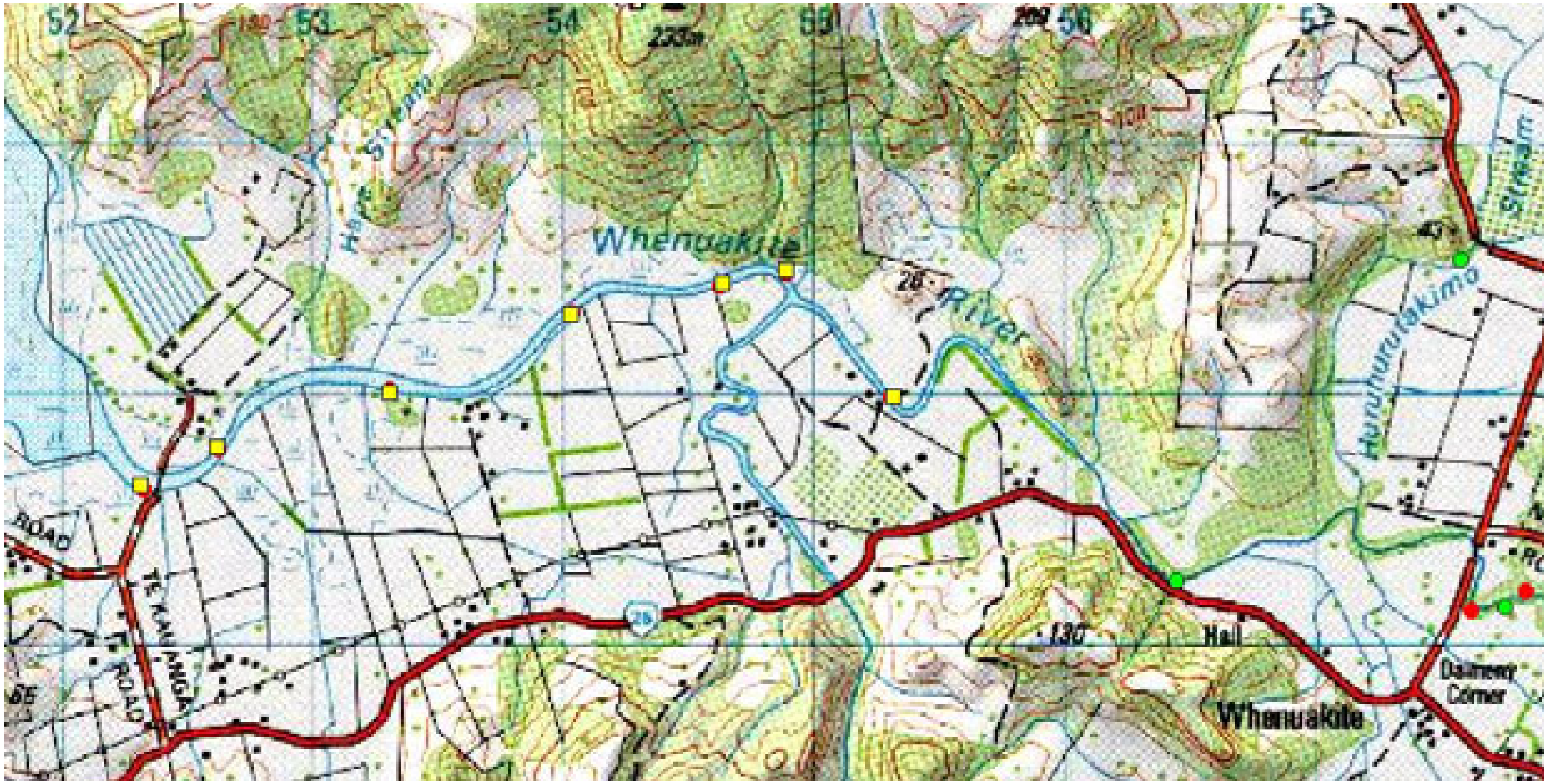

Figure 2.2 The lower Whenuakite River, showing the location of tidal survey points (yellow squares). The large tributary running south across State Highway 25 is the Parakau Stream. The map overlaps with Figure 2.1 at the green dot representing a water quality monitoring site, beside Whenuakite Hall. Tide influences water levels over this reach, with the tidal limit thought to be near the Huruhurutakimo Stream confluence. (NZMS260 T11 © Sourced from Land Information New Zealand data. CROWN COPYRIGHT RESERVED.)

Figure 2.3: Whenuakite River viewed from Te Kauanga Road Bridge (9-12-2004). Inanga spawning (whitebait) is expected to occur on the margins of this brackish reach, which is tidal and at the limit of saltwater influence (Coffey 1997).

Figure 2.4: Whenuakite River tidal reach below the Parakau Stream confluence (2-3-2005). This reach is tidal, but without saltwater influence (Coffey 1997). Macrophytes are prolific, reaching the water surface along the margins.

Figure 2.5: Whenuakite River tidal reach at the water quality monitoring site close to Whenuakite Hall (9-12-2004). Macrophytes dominate the full width of the channel here.

Figure 2.6: The lowland reach is unaffected by the tide (3-3-2005). Beds of charophytes (native aquatic plants) grow in the shade of kanuka and privet.

Figure 2.7: The midland reach is well shaded with refuge for fish provided by woody debris and stable bank habitat. Macrophytes are limited to occasional charophyte beds (9-12-2004).

Figure 2.8: Boulder and cobble riffles differentiate the upland reach from the mid- and lowland reaches. (3-3-2005).

2.2 Fish Community

The three habitat-survey reaches were electric fished on 2 and 3 March 2005, using a Kainga backpack set. The lowland reach was too deep for effective electric fishing, so three fyke-nets were also deployed overnight. The New Zealand Freshwater Fish Database was searched for other fish records from the catchment.

2.3 Instream Habitat

RHYHABSIM was used to model habitat for fish and other biota in three study reaches, each representing a different habitat type (upland, midland and lowland). Habitat mapping was carried out for the upland reach to measure the percentage of riffle, pool and run habitat present. Cross-section locations were then selected, ensuring these represented the range of width, depth, and velocity characteristics for each habitat type. For example, run cross-sections included both deep and narrow, plus wide and shallow runs. Of the 15 cross-sections assessed, 7 were classed as runs, 5 as riffles and 3 as pools. Habitat mapping gave weightings for these habitat types of 36% pool, 24% riffle and 40% run.

For the lowland and midland reach, cross-sections were spaced evenly throughout the reach, as habitat types were less distinct. The lowland reach was all pool habitat of varying depth, and the midland reach was predominantly run habitat. The 15 cross-sections were expected to adequately represent the range of depth and velocity conditions in each reach (spaced every 15 m in the lowland reach and 10 m in the midland reach).

For both the upland and midland reach, water velocities, depths, and substrate composition were recorded for each cross-section. For the lowland reach, all but water velocity was measured. The sluggish water velocities (generally less than 0.05 m/s) are difficult to measure more accurately than can be estimated using RHYHABSIM, based on depth and flow. Velocity distribution factors were modified for cross-sections where the flow was confined to part of the channel (typically between weed beds).

Water level was measured for each cross-section and referenced against a temporary staff gauge. This was measured for the survey and for two other measured flows in order to establish the relationship between water level and flow (rating curve) at each cross-section.

The habitat analysis proceeded as follows:

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

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

3. Water depths and velocities were computed at individual measurement points for a range of simulated flows up to 2 m^3/s. Habitat suitability was evaluated from habitat suitability curves for each fish species (Appendix 2).

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

5. WUA was plotted against flow and the resulting curves were examined to determine flow requirements.

At step 2, some changes to the ratings curves were necessary to provide a more accurate representation of the change in water level with flow. These ratings crossed the critical rating (a rating assuming critical flow) or were steeper/flatter than expected given the stream type. Changes are detailed in Table 2.1. Water levels at the lowland reach dropped more than expected between gaugings, producing steep rating curves. Such problems were anticipated for this reach, given the soft bed and weed growth, which can cause water level to change while flow stays the same. Given this stream averaged 0.66 m deep at survey, with flows of less than 0.1 m^3/s, water levels are probably determined by downstream control-points rather than flow. Therefore, the relatively flat relationship between water level and flow that was predicted by the hydraulic rating was considered the most appropriate for this reach. The first gauging for the upland reach was an outlier on the rating curves and deviated from the rate of flow recession observed for the other sites. The flow was therefore changed from 0.028 m^3/s to 0.023 m^3/s (calculated as the same proportion of the catchment average for upland reach flows on the other two occasions).

Table 2.1: Changes to the default rating curves (as produced from the raw data) are detailed for each reach. The default rating is the least-squares fit to the logarithms of the measured flows and water levels, including an estimated SZF (stage at zero flow). Where a different rating curve was used, this is presented in the 'rating' column. Rating exponents normally fall within the range of 2.5 to 3.5 and were adjusted up or down where the ratings were otherwise unsatisfactory (see text).

Cross-section	Rating	Calculated exponent	Nominated exponent	Other changes
Upland Reach				
3		0.787	2.5	
4		5.181	3.5	
8				deleted second gauging
13				deleted second gauging
Midland Reach				
1				SZF deleted
2				SZF deleted
9		0.987	2.5	
10		0.895	2.5	
11				SZF deleted
12	hydraulic			
13		0.715	2.5	
14	hydraulic			
15	hydraulic			
Lowland Reach				
1	hydraulic			
2	hydraulic			
3	hydraulic			
4	hydraulic			
5	hydraulic			
6	hydraulic			
7	hydraulic			
8	hydraulic			
9	hydraulic			
10	hydraulic			
11	hydraulic			
12	hydraulic			
13	hydraulic			
14	hydraulic			
15	hydraulic			

Different approaches can be used to determine flow requirements from the plots of habitat (WUA) against flow, as discussed in section 1.2.5. Several approaches are presented for the Whenuakite River. The flow that provided maximum habitat and the flow at which habitat began to reduce sharply (inflection points) was determined for each species. In practice, inflection points are best determined by running a straight line horizontally across from the point of maximum habitat, then running a second line up from where the curve declines towards zero. The point at which the two lines intersect is the point of inflection.

An alternative method of deriving minimum flows from habitat-flow response curves was developed by Environment Bay of Plenty (see Appendix 1 for a more detailed explanation and background). There are three steps to the method:

1. Identify the primary flow for each species. This is the flow where habitat is optimal, unless the optimum exceeds the natural flow (median flow) and is therefore unreasonable. In the latter case, the MALF is used as the primary flow.

2. Multiply habitat at the primary flow by the appropriate habitat protection level to obtain a minimum flow for each species (Appendix 1). Habitat protection levels are scaled according to population/ecosystem significance. (Environment Bay of Plenty's Criteria 6 (85%) is relevant for most species, except banded kokopu and koaro which are Category 2 species (95%)).

3. The species with the highest minimum flow determines the instream minimum flow requirement.

2.4 Water quality

The three sites monitored for nutrients and oxygen/temperature were the Huruhurutakimo Stream (at Purangi Road), the tidal reach of the Whenuakite River and the lowland reach (Figure 2.1). The tidal reach site was at the closest point to State Highway 25, and lowland site above Hot Water Beach Road. These reaches were considered the most susceptible to oxygen depletion (deep, slow flowing with extensive macrophyte beds). The Huruhurutakimo catchment drains a lot of pasture and horticulture, so maintaining adequate water quality in the Whenuakite River may require sufficient flow for dilution of this inflow.

Low oxygen levels and high stream temperatures are stressful to fish and other aquatic life, with reduced flows potentially exacerbating this situation. Data loggers were installed at all three sites to determine oxygen and temperature conditions. The loggers were set to record every 40 minutes from 1 to 17 March 2005. Flow measurements were taken at each site at the start and end of logger-deployment, with flow records from the Tairua River (Broken Hills) confirming a gradual recession of flows, without floods, over the monitoring period (Whenuakite River flows receded from 88% of MALF to 79% of MALF). The effect of reduced flows on dissolved oxygen levels was modelled using WAIORA (Version 2.0, Hill & Jowett 2004). The data-logger record and the lowland habitat-survey data provided the necessary information to model the relationship between flow and oxygen (average flow and temperature for the monitoring period; daily average and range of dissolved oxygen; time-lag between oxygen maxima and solar-noon). The data-logger parameters were averaged to produce a typical diurnal cycle for use in the model (representing summer low flow conditions). Oxygen was modelled at a specified temperature corresponding to the observed daily average (older versions of WAIORA require a calibrated temperature model to determine this temperature).

The effect of reduced flow on water temperature was modelled using RHYHABSIM. This model predicts the rate at which temperature increases as water flows downstream, and how this rate changes with flow. This modelling was applied to the upland and lowland reaches. The midland reach was not modelled because the extensive riparian canopy that shades this reach is expected to maintain cool water temperatures. For the lowland reach, the data-logger record from the habitat survey reach and from further downstream in the tidal reach provided excellent data for calibrating the model to the observed increase in temperature over this reach. Temperature data were not available for the upland reach. Therefore, the water temperature upstream of the study reach, plus riparian conditions upstream and downstream, were estimated.

Nutrient levels were monitored over the study period, with samples collected on three different occasions from each of three sites. Flows were also measured to enable calculation of mass flows. Nutrients that were measured include nitrogen and phosphorous, targeting the dissolved inorganic compounds that are readily available for macrophyte growth (NH_4-N, NO_3-N, DRP). The effect of reduced flows on dilution of these nutrients was then assessed using mass-flow calculations.

2.5 Tidal Survey

Previous studies determined the upstream limit of saltwater intrusion on the Whenuakite River (Coffey 1997). This study focussed on the tidal water-level range in the area identified by Coffey (1997). This was used to investigate the potential effects of abstraction on spawning of inanga (adult whitebait), which typically occurs at the salt/fresh water interface (Mitchell & Eldon 1991). Pegs were installed between the Te Kauanga Road boat ramp and an existing staff gauge 0.5 km upstream of the Parakau Stream confluence (Figure 2.2). Water levels were measured relative to each peg at both high and low tide, with cross-section profiles measured at two sites (Site 2 and 7). The NIWA tide forecaster provided tidal statistics for the Whitianga Harbour entrance (www.niwa.co.nz/services/tides), and indicated that a typical tidal range was captured during this study (high tide 0.76 m above mean sea level on 1/03/2005; low tide 0.68 m below on 2/03/2005; a range of 1.44 m, which represents the 49 percentile for March tides).

Tidal fluctuations make habitat surveys difficult, breaking the relationship between flow and water level (rating curve). To be sure the tide did not reach as far upstream as the lowland reach, water level measurements were taken at high and low tide for each cross-section in the lowland reach.

3. Results

3.1 Natural flow estimates

Estimates of the natural flow statistics are required for the minimum flow method used in this study. Estimates were also made for sites where abstractions are proposed. Flow was measured at each site on three occasions (Table 3.1). A historical flow record is available for the Whenuakite River at Boat Harbour Road, where a continuous flow recorder was in place up until the mid-1990's (Boat Harbour Road is indicated on Figure 2.1). Environment Waikato provided flow statistics based on this record, scaled to give flows for the Whenuakite River at Hot Water Beach Road (Table 3.2).

The REC (River Environment Classification) includes estimates of mean flow for each section of river and stream in New Zealand (Snelder et al. 2004). These estimates were calculated using a model that incorporated catchment area, rainfall and evaporation (the climate model for rainfall and evaporation was based on parameters such as location and altitude). Scaling the flows for Hot Water Beach Road by the proportion of the REC mean flow provides flow estimates for each site. These estimates were used for the midland reach, lowland reach and Black's Farm (Table 3.2). Flow was measured for the purpose of deriving these flow estimates. However, the results indicated that water was actually being lost from the system between the midland reach and Hot Water Beach Road (e.g., to groundwater or abstraction[2]). It is possible that water is being lost over this reach, but the increase in flow expected between sites is so small (~5%) that the shortfall could be measurement error (the midland and Black's Farm cross-sections allowed accurate gaugings, but the best cross-section available in the lowland reach did not).

The low flow estimates (MALF and Q_5) presented for the upland reach and the Huruhurutakimo Stream are based on averaging the REC-based estimate and the flow measurement based estimate (Table 3.2). The REC based estimate produced MALF estimates quite different to that observed when other sites were flowing at about MALF (17 March gaugings, Huruhurutakimo lower than predicted, upland reach higher than predicted). Neither reach contained uniform cross-sections for accurate flow measurements, so averaging the estimates produced by the two different approaches was considered the safest approach. The median flow derived using REC data (median flow at Hot Water Beach Rd scaled in proportion to REC mean flow estimates) was used for both sites, as flow was not measured at higher than average flows.

[2] All major abstractors were switched off each day that flow measurements were taken.

Table 3.1: Flow measurements (m^3/s) recorded on each of three occasions for the various sites in the Whenuakite catchment (see site map Figure 2.1). Flows in italics are considered unreliable because these deviate from catchment average and/or were outliers on the rating curves produced for that site.

	Upland	Midland	Black's Farm	Lowland	Huruhurutakimo Purangi Rd
1-Mar			0.110		0.015
2-Mar		0.113			
3-Mar	0.026			0.099	
17-Mar	*0.028*	0.101	0.099	0.086	0.010
2-May	0.020	0.089	0.084	*0.086*	0.010

Table 3.2: Natural flow estimates (m^3/s) for each site of interest in the Whenuakite catchment (see site map Figure 2.1). Flows for the tidal reach represent the water quality monitoring site. All are scaled from flow estimates provided by Environment Waikato for Hot Water Beach Road (lowland reach), using various techniques (see text). Q_5 is the one in five-year 7-day low flow; MALF is the 7-day mean annual low flow. The mean flow figure provided by the REC (River Environment Classification) was used in the derivation of flow statistics for some sites.

	Upland	Midland	Black's Farm	Lowland	Tidal	Huruhurutakimo Purangi Rd	Huruhurutakimo Confluence
Q_5	0.017	0.090	0.095	0.100	0.160	0.020	0.024
MALF	0.023	0.115	0.125	0.130	0.210	0.028	0.033
Median flow	0.067	0.465	0.495	0.520	0.840	0.165	0.194
REC mean flow	0.14	0.98	1.045	1.10	1.78	0.35	0.41
Catchment area (ha)	370	2723	2917	3080	5119	1069	1257

3.2 Fish Community

Results are presented for electric fishing from the midland and upland reach, and from fyke netting of the lowland reach (Table 3.3). Other species expected to be resident, are also presented in the table. All potential inhabitants were included in the habitat modelling, but only those species expected to be resident (marked 'E' in Table 3.3), were used in determining the flow requirements for each site.

There are no riffles or gravel/cobble habitat in the lowland reach, so species preferring such habitat are not expected to be resident (torrentfish in particular). Redfin bullies are very abundant in gravel-bed Coromandel streams, but are not expected to reside in habitats such as the lowland reach. Common smelt are likely to be present in reasonable numbers, with giant bully and common bully occasionally observed in similar streams in the area.

Fishing the midland reach revealed most of the species expected to be found in this habitat (well-shaded sandy runs, with woody debris and some bank cover). The relative abundance of smelt was underestimated by electric fishing because this species tends to disperse quickly when disturbed (schools of smelt or inanga were often observed during the habitat survey). Inanga can also be evasive, which is probably the only reason this species was not caught. Most of the eels caught were small, making identification difficult, though it is expected that both eel species are present. A record from the New Zealand Freshwater Fish Database, that was collected from a pastoral tributary of the Whenuakite at about the same altitude as the midland reach (15 m), lists longfin and shortfin eels, inanga, common smelt, redfin bully and koura (card 2208).

No torrentfish were caught in the upland reach (Table 3.3), despite it offering suitable habitat. A record from the New Zealand Freshwater Fish Database a short distance downstream also failed to find torrentfish (card 12571). The site may be beyond the reach of migrating juveniles because of natural or artificial barriers (Figure 3.1). The shallow rocky nature of this site means it is not ideal habitat for common smelt or inanga.

Table 3.3: Fish captured from three sites on the Whenuakite River in March 2005. Electric fishing (EF) or fyke nets were used, depending on method-suitability for each site. In addition to those caught, other fauna observed during the study are marked 'O'. Other species expected to occur, but not caught are indicated ('E'), as well as those species less likely to be resident at each site ('?'). The koaro and kokopu we caught were both juvenile fish, so may have been migrating to adult habitats further upstream (the koaro was too small for confident identification). Invertebrate data for the upland reach are presented in Appendix 3.

	Upland reach EF (100 m^2)	**Midland Reach EF (100 m^2)**	**Lowland reach Fyke net (3)**
Longfin eel	1	1	2
Shortfin eel	E	E	12
Eel	4	21	
Giant bully			E
Common bully	?	?	E
Redfin bully	24	2	?
Torrentfish	?	?	
Common smelt	?	2	E
Inanga	?	E	2
Koaro	(1?)		
Banded kokopu		(1 juv.)	?
Giant kokopu			?
Gambusia		O	E
Koura (crayfish)	O	E	1
Mussels		O	O

Figure 3.1: The concrete apron below State Highway 25 bridge could be a barrier to the upstream migration of torrentfish and inanga, and may explain why none were caught in the upland reach.

3.3 Instream Habitat

Fish habitat was modelled for those species observed or expected to be present, and for reference only, for those species less likely to occur. For the lowland reach, the MALF (mean annual low flow) provides near maximum habitat for inanga, common smelt, longfin and shortfin eel (Figure 3.2). At opposite ends of the spectrum, banded kokopu prefer lower flows and common bully prefer flows in excess of the median flow. Points of inflection were derived for those species displaying a clear breakpoint (as opposed to a gradual reduction in habitat with flow). Only inanga provided a clear point of inflection in the lowland reach. Near-zero flows provide large habitat areas for many species because deep water is maintained by control-points downstream (e.g., shallow bars, weed beds or sea level). Modelling predicted no habitat for redfin bully in the lowland reach, so substrate was set as optimal and habitat re-modelled to produce the flows for this species given in Table 3.4.

In the midland reach, maximum habitat for most species was at flows considerably higher than MALF (Figure 3.3). The habitat modelling predicts that the lowland reach offers better habitat for inanga than the midland reach (Figure 3.2 & 3.3), which is consistent with observed capture rates (Table 3.3). The flow preferences for banded kokopu in the midland reach are unusually high for this species (Table 3.4). Banded kokopu typically inhabit small, slow-flowing streams. Habitat modelling for this reach indicated that suitable slow-flowing habitat is found mainly along the margins of this stream, and that these areas increase in size at high flows, but are lost at low flows. This is plausible, but the prospect of banded kokopu preferring flows in this reach of greater than 2 m^3/s seems erroneous. The presence of resident adult banded kokopu in this reach has not been confirmed (one juvenile was caught and it may have been migrating upstream), hence the minimum flow for the midland reach should not be based on banded kokopu.

The upland reach is wide and shallow with low baseflows (Figure 2.8), hence the habitat of most species declines rapidly below MALF (Figure 3.4). Using the Environment Bay of Plenty method produces a minimum flow requirement for this reach of 0.015 m^3/s, based on redfin bully.

Invertebrate habitat was modelled for species recorded from the upland reach (Appendix 3) for which habitat preference criteria were available (Figure 3.5). As for the fish, invertebrates are expected to prefer flows greater than MALF. The minimum flow produced using the Environment Bay of Plenty method (based on redfin bully), offers habitat protection levels for invertebrates ranging from 67% to 89% (Elmidae and *Aoteapsyche* sp., respectively). The caddisfly *Aoteapsyche* sp. is predicted to have little habitat available at baseflows, yet this taxon was commonly recorded in the upland reach (Appendix 3). This supports concerns expressed by Jowett (2000) regarding the application of invertebrate preferences derived from large rivers to small streams (invertebrates prefer riffle habitat in both large and small streams, despite mean water column velocities in riffles of large rivers being generally higher). Considering the area of riffle habitat provides an alternative representation of invertebrate habitat. Riffle habitat area is expected to increase with flow, and benthic invertebrate populations along with it. A flow of 0.014 m^3/s is expected to maintain 85% of the riffle habitat available at MALF in the upland reach.

Macrophytes (aquatic plants) provide habitat for aquatic ecosystems, but they can also choke waterways, causing stagnation (diurnal oxygen fluctuation), increased flooding and restrict recreational activities. High water velocities scour macrophytes and any associated build-up of organic material and reduced river flows therefore have the potential to allow macrophytes to reach nuisance levels. Habitat preference curves were available for some macrophytes (*Elodea canadensis*, *Myriophyllum triphyllum*, *Potamogeton cheesemanii*). Only one of these three was recorded by Coffey (1997) in the Whenuakite River (*Myriophyllum triphyllum*). One other species was observed during the current study in the lowland reach (*Elodea canadensis*), and the third is from the same genus as a species recorded by Coffey (1997), (*Potamogeton ochreatus*). The effect of flow on these plants was modelled using the lowland reach habitat data. Flows greater than 1 m^3/s are required to exceed the preferences of these aquatic plants (Figure 3.6). So reducing flow to the minimum recommended to maintain adequate fish habitat is not expected to increase the biomass of macrophytes, because velocity is not limiting their growth at baseflows. This indicates the frequency of flood events is more likely to determine macrophyte biomass.

Table 3.4: Results from habitat-flow response curves (Figure 3.2 to 3.4) for the Whenuakite River. The point of inflection is the flow at which habitat begins to decline more sharply, and is presented for species that display such a response. Flows produced using the Environment Bay of Plenty method are given based on the 85% habitat protection level (except banded kokopu & koaro at 95%). Using this method, the recommended minimum flow (in bold) is based on the resident species with the highest flow requirement. Habitat protection levels afforded by existing and historic allocation methods (90% & 70% of Q_5 flow, respectively) are also presented. Species and life stages marked * are not expected to reside in a given reach, and are included for reference only. MALF is the 7-day mean annual low flow; Q_5 is the one in 5-year low flow (see Table 3.2).

	Flow at max. habitat	Point of inflection	EBOP method	Protection level at 70% of Q_5	Protection level at 90% of Q_5
Lowland Reach	(MALF 0.130, Q_5 0.100)				
Longfin eel >300mm	0.225		0.005	101%	101%
Longfin eel <300mm	>2.0		0	98%	99%
Shortfin eel	2.0		0	101%	100%
Common bully	1.2		0	94%	96%
Redfin bully*	0.835		0	93%	95%
Common smelt	0.585		0.030	91%	95%
Inanga feeding	0.135	0.09	**0.075**	78%	92%
Banded kokopu*	0.035		0.005	96%	89%
Midland Reach	(MALF 0.115, Q_5 0.090)				
Longfin eels >300	>2.0	0.98	0.065	81%	90%
Longfin eels <300	1.30		0.045	90%	95%
Shortfin eel	0.270		**0.075**	81%	85%
Common bully *	0.235	0.12	0.105	69%	77%
Redfin bully	0.105	0.05	0.050	91%	97%
Torrentfish*	0.715	0.52	0.085	69%	81%
Common smelt	0.560		0.070	79%	88%
Inanga feeding	0.490		0.020	91%	87%
Koaro*	0.105	0.07	0.105	75%	75%
Banded kokopu	>2.0	0.77	0.095	84%	90%

Upland Reach (MALF 0.023, Q_5 0.017)					
Longfin eel >300mm	>0.5		0.013	80%	88%
Longfin eel <300mm	>0.5		0.013	81%	87%
Shortfin eel	0.186		0.012	84%	90%
Common bully*	0.173		0.015	74%	83%
Redfin bully	0.163	0.06	**0.015**	73%	83%
Torrentfish*	>0.5	0.29	0.017	63%	77%
Common smelt*	>0.5		0.014	76%	85%
Inanga feeding*	>0.5		0.017	64%	79%
Koaro	0.35		0.021	63%	75%

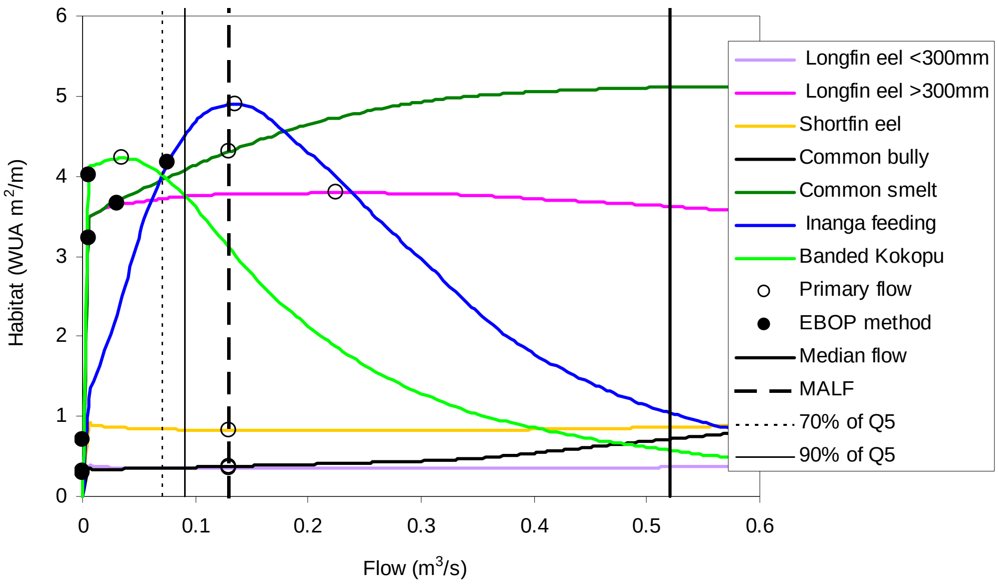

Figure 3.2: The change in habitat with flow for various species and life stages of fish in the **lowland** reach of the Whenuakite River. Primary flow is the available-habitat value to which the habitat protection level is applied to produce the *EBOP method* flow requirement for each species (see Appendix 1). Habitat units are m^2 of suitable habitat per metre length of stream. MALF is the mean annual 7-day low flow. Existing and historic allocation limits are also presented (90% & 70% of the 5 year low flow (Q_5) respectively). Habitat preference curves are given in Appendix 2.

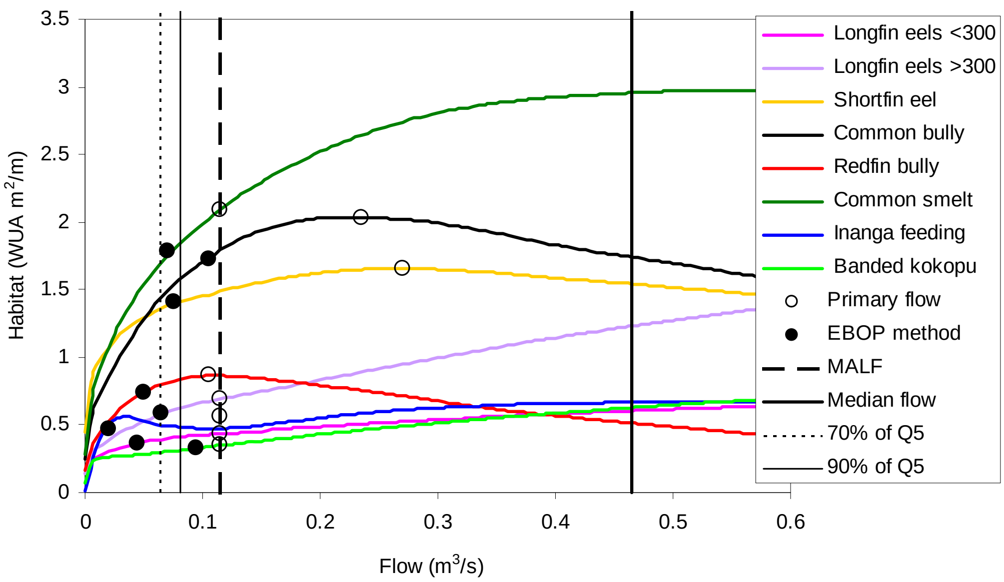

Figure 3.3: The change in habitat with flow for various species and life stages of fish in the **midland** reach of the Whenuakite River. Otherwise as per Figure 3.2.

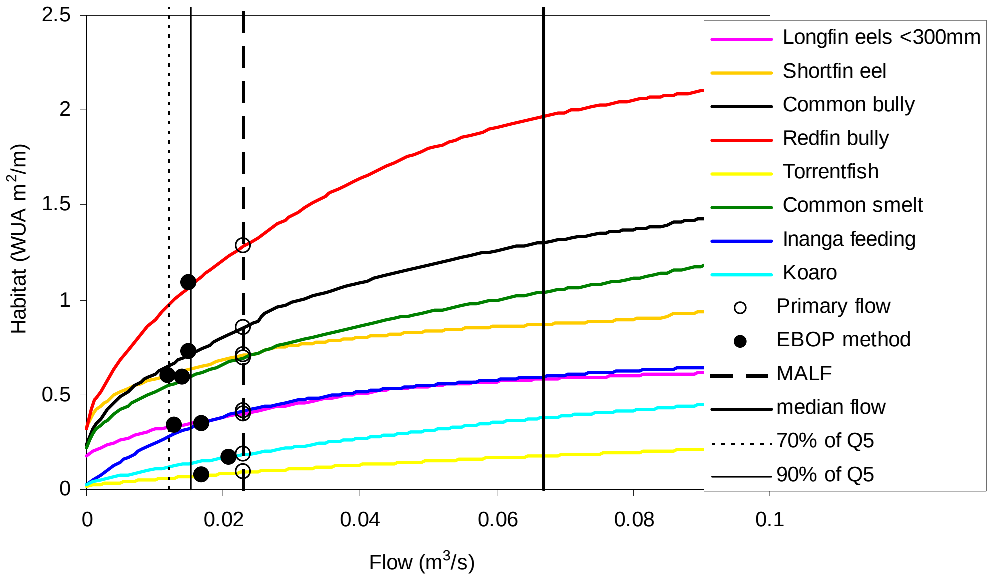

Figure 3.4: The change in habitat with flow for various species of fish in the **upland** reach of the Whenuakite River. Otherwise as per Figure 3.2.

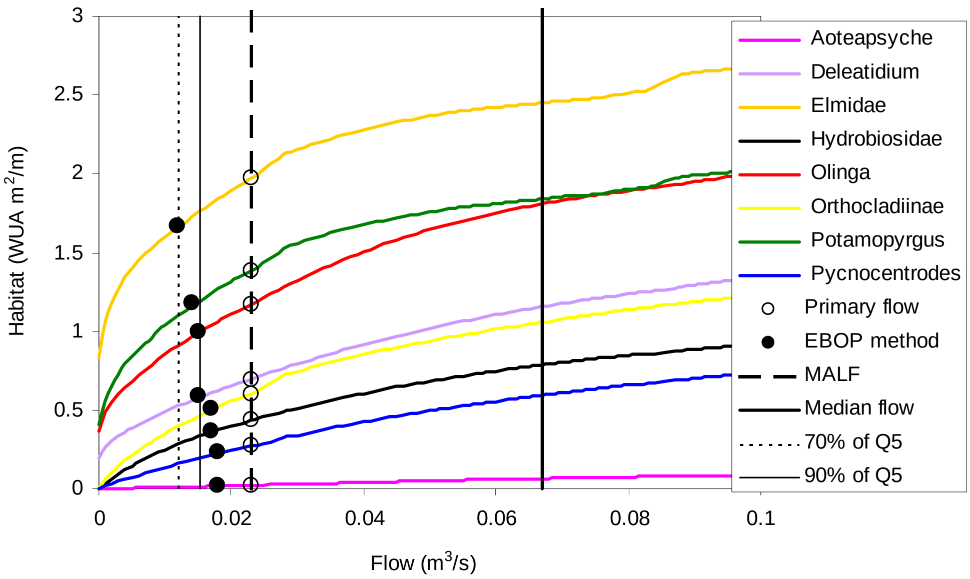

Figure 3.5: The change in habitat with flow for various species of invertebrates in the **upland** reach of the Whenuakite River. Otherwise as per Figure 3.2.

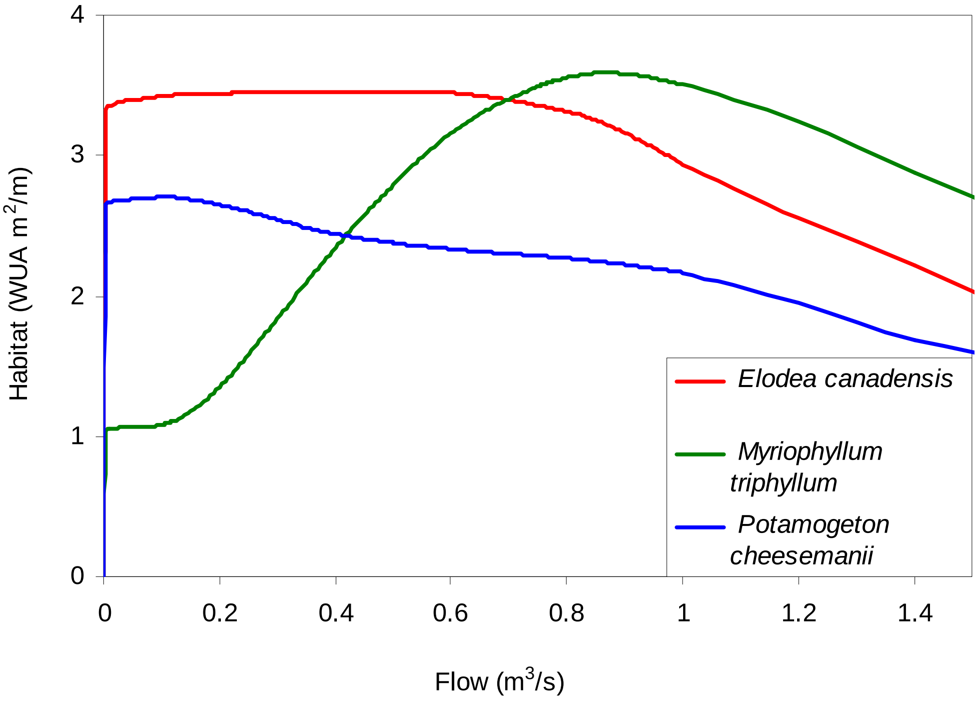

Figure 3.6: The change in habitat with flow for three species of aquatic plant in the **lowland** reach of the Whenuakite River. Water depth was set as optimal within the wetted channel because the preference criteria reflect light conditions in the rivers where the preference curves were developed, and therefore may not be relevant.

3.4 Water Quality

Dissolved oxygen, temperature and nutrients were considered in the water quality assessment. Dissolved oxygen was monitored at three sites – the lowland reach of the Whenuakite River, the Huruhurutakimo Stream and the tidal reach of the Whenuakite River (below the Huruhurutakimo confluence). The lowland reach showed some evidence of diurnal oxygen variation, ranging from 7.5 g/m^3 of dissolved oxygen in the morning to 8.3 g/m^3 at mid-afternoon (Figure 3.7). The minimum oxygen concentrations observed are unlikely to cause significant stress to aquatic communities. In contrast, both the Huruhurutakimo Stream and the Whenuakite tidal reach experienced low dissolved oxygen concentrations during early March 2005 (Figure 3.8 & 3.9). The Huruhurutakimo Stream results, in particular, depict an inhospitable environment, with oxygen levels not reaching the acute limit for aquatic life of 3 g/m^3 recommended by Dean & Richardson (1999). The logger was placed in a typical weedy pool, but there may have been better-oxygenated refuges elsewhere in the reach.

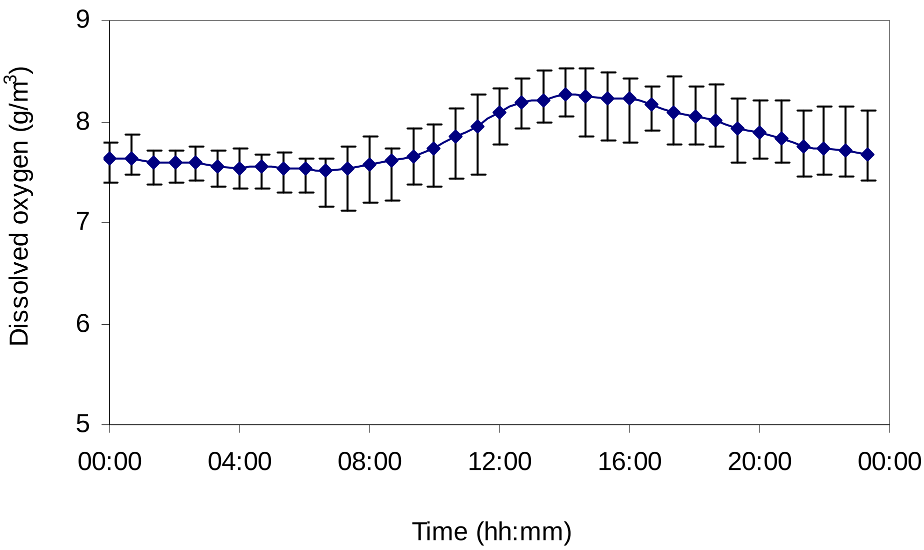

Figure 3.7: Dissolved oxygen concentrations over an averaged 24-hour period in the **lowland** reach of the Whenuakite River. Oxygen concentrations were averaged for each time of day over the 17-day monitoring period (March 2005) to give the average daily cycle of dissolved oxygen. Error bars show the maximum and minimum oxygen concentration over the monitoring period for each time of day. Oxygen saturation ranged from 74% to 88%. Measurement at the time of retrieval, using a portable DO meter (YSI95), indicated calibration had slipped by up to 0.9 g/m^3, though this was not found to significantly affect the calculated averages. Flows at the time were approximately 85% of MALF.

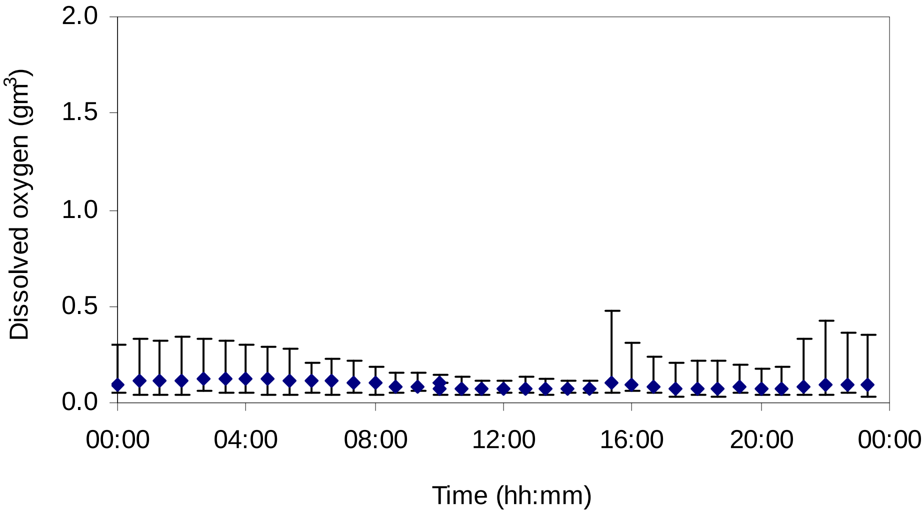

Figure 3.8: Dissolved oxygen concentrations over an averaged 24-hour period in the **Huruhurutakimo** Stream at Purangi Road. Oxygen concentrations were averaged for each time of day over the 17-day monitoring period (March 2005) to give the average daily cycle of dissolved oxygen. Error bars show the maximum and minimum oxygen concentration. Oxygen saturation ranged from 0.3% to 5.1%. Measurements at the time of retrieval, using a portable DO meter (YSI95), confirmed the anoxic result (logger 0.06 g/m^3, meter 0.48 g/m^3). Flows at the time were approximately 85% of MALF.

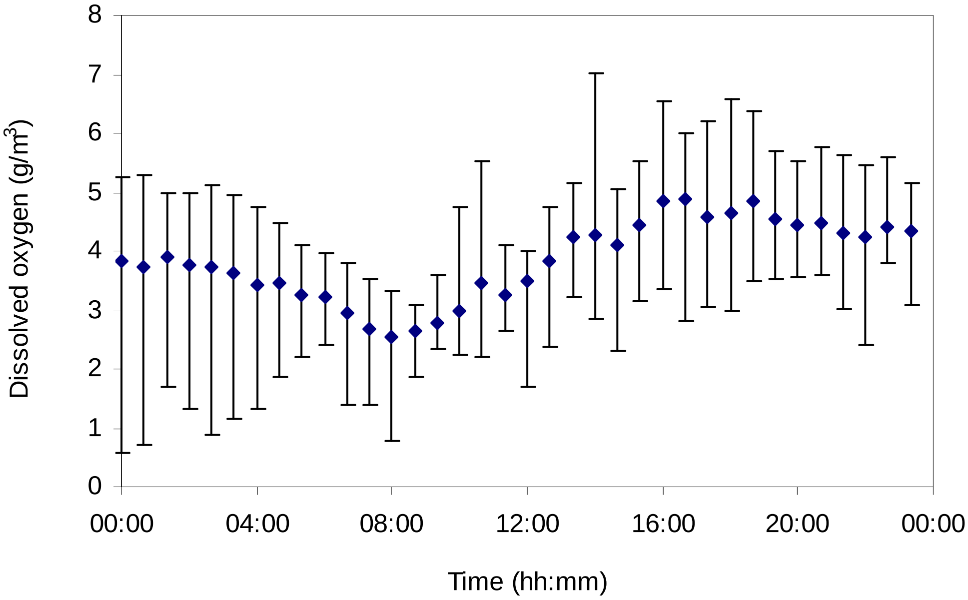

Figure 3.9: Dissolved oxygen concentrations in the tidal reach of the Whenuakite River (below the Huruhurutakimo confluence). Oxygen concentrations were averaged for each time of day over the 17-day monitoring period (March 2005) to give the average daily cycle of dissolved oxygen. Error bars show the maximum and minimum oxygen concentration. Oxygen saturation ranged from 5.9% to 74.2%. Tidal fluctuations at this site left the probe dry at times, producing an incomplete dataset (erroneous data were omitted). Measurements upon retrieval confirmed the logger was still reading accurate oxygen concentrations (the logger was reading 2.13 g/m^3 and the YSI95 meter recorded 2.97 g/m^3). Flows at the time were approximately 85% of MALF.

WAIORA was used to model the effects of reduced flow on dissolved oxygen concentrations for two sites. The Huruhurutakimo Stream was not modelled because the results indicated there is an oxygen problem here regardless of water abstraction. For the lowland reach of the Whenukite River, modelling indicated oxygen levels would decline at flows less than MALF (Figure 3.10). The flow requirement for fish habitat produced using the Environment Bay of Plenty method (0.075 m^3/s) is expected to produce a dissolved oxygen concentration of 6.1 g/m^3 (daily minimum). This oxygen concentration is considered adequate for a river supporting inanga, eels and other lowland species (Dean & Richardson 1999). A minimum flow of 0.062 m^3/s is required to meet the slight impairment standard (5 g/m^3 for non-salmonid waters) presented by Dean & Richardson (1999).

The oxygen model for the tidal reach indicated that a flow of 0.205 m^3/s is required to maintain oxygen concentrations above the moderate impairment limit for adult native fish (4 g/m^3), and 0.24 m^3/s is required for the slight impairment standard (5 g/m^3) presented by Dean & Richardson (1999). Maintaining a slight impairment standard for early life stages (5.5 g/m^3), such as whitebait, requires a flow of 0.26 m^3/s. A data-logger was deployed in the same section of river in December 2004, and provides a second dataset to re-model oxygen concentrations for this reach (this dataset is shorter, as the datasonde only recorded for 4 days before the batteries failed). Flows in December were estimated by scaling data from the Tairua River flow recorder (based on the logarithmic relationship observed using later flow measurements). Using this second dataset, it was estimated that 0.26 m^3/s is required to maintain oxygen concentrations greater than 5 g/m^3. The two datasonde records did not produce identical flow requirements (0.24 m^3/s & 0.26 m^3/s), but both demonstrate that this reach has dissolved oxygen issues which are expected to be exacerbated by abstraction at times of low flow. Flow requirements from the March oxygen record were used in preference, as the data were collected under summer low flow conditions. The reach to which these results apply is expected to extend as far downstream as the confluence with the Parakau Stream (Figure 2.2). The Parakau drains a forested catchment that is slightly smaller than the Whenuakite catchment, and its flow is likely to increase oxygen concentrations downstream of the confluence.

Both oxygen datasets from the tidal reach show a diurnal pattern of evening maxima and morning minima. Both also show a weak tidal cycle overlaid upon the diurnal cycle, creating a depression of oxygen levels at some high tides (Figure 3.12). A rising tide would increase depths and reduce water velocity, which in turn reduces re-aeration rates. WAIORA does not use such factors in the oxygen model, so any effect of tide is only incorporated insomuch as the observed oxygen concentration (daily average) would be slightly lower because of the high tide affect.

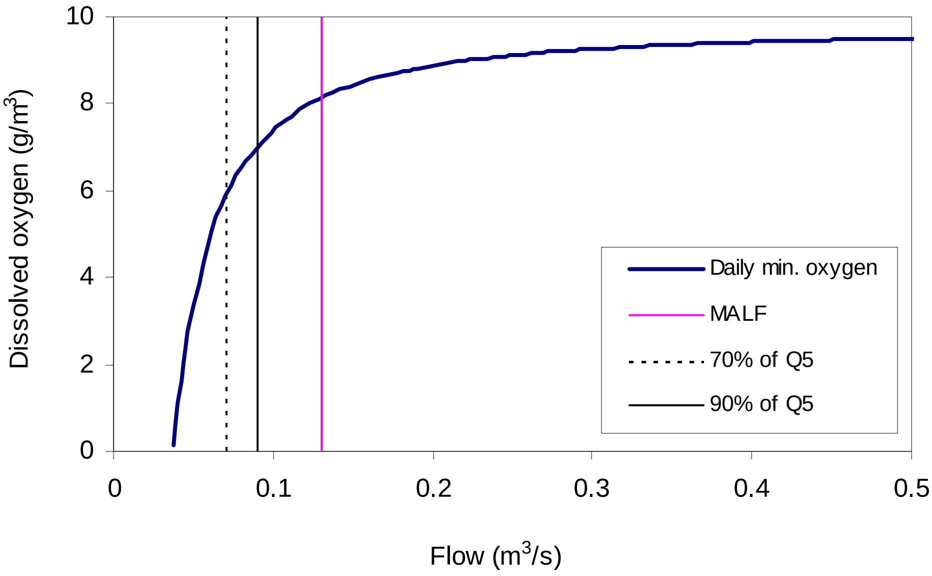

Figure 3.10: Predicted effect of reduced flows on dissolved oxygen concentrations (daily minima) for the Whenuakite **lowland** reach. MALF is the mean annual low flow (0.13 m^3/s). Existing and historic allocation limits are also presented (90% & 70% of the 5-year low flow).

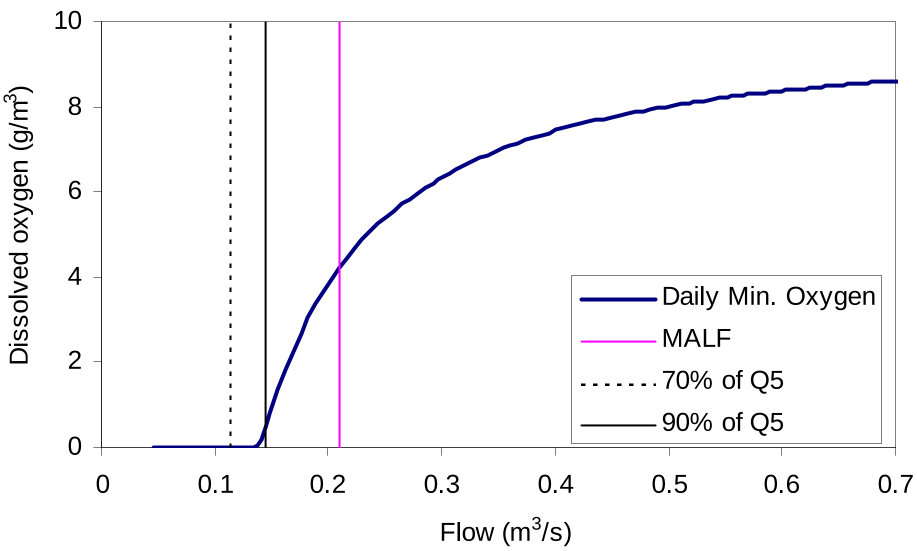

Figure 3.11: Predicted effect of reduced flows on dissolved oxygen concentrations (daily minima) for the **tidal** reach of the Whenuakite River (below the Huruhurutakimo Stream confluence). MALF is the mean annual low flow (0.215 m^3/s). Existing and historic allocation limits are also presented (90% & 70% of the 5-year low flow).

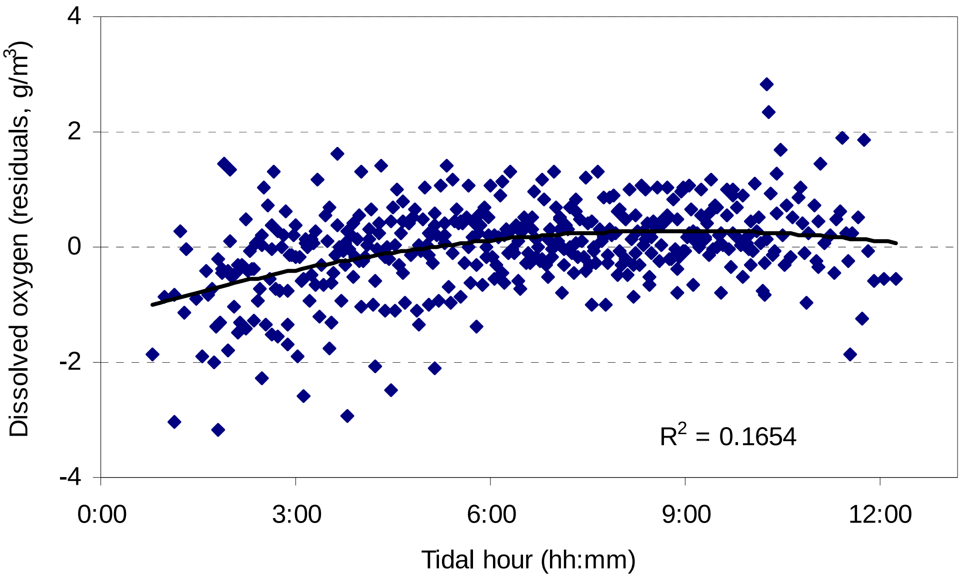

Figure 3.12: To investigate whether high-tides reduce oxygen concentrations in the Whenuakite River, the diurnal pattern was first removed from the March dataset (by subtracting the oxygen concentration predicted for the time of each measurement). The residual data are plotted against 'tidal hour'. Tidal hour indicates what stage of the tidal-cycle each measurement was taken (tide at Whitianga Harbour entrance). High tide is 00:00 and low tide 06:13, based on a tidal cycle of 12 hours 25 minutes.

The oxygen data-loggers also monitored water temperature at the three water-quality monitoring sites (deployed 1 to 17 March 2005). All three sites remained below 20°C (Figures 3.13, 3.14 & 3.15), indicating a moderate degree of shading. Water temperatures were warmer than average during early March (continuous temperature data collected by Environment Waikato from the adjacent river (Waiwawa) for this period was 1.0°C warmer than the long term average for early March, and was within 1°C of the long term average for January-February). The tolerances of aquatic biota can be expressed as a preferred temperature - that is, temperatures they like, or alternatively, as a lethal temperature - the temperature at which they die. Native fish tested by Richardson (et al. 1994) have temperature preferences in the range of 16.1°C to 26.9°C. The temperatures recorded at the three sites are therefore considered tolerable for most native fish (even if we add 1°C to temperatures to reproduce February conditions). Lethal temperatures for stream invertebrates are greater than 20°C (Cox & Rutherford 2000), suggesting temperatures in the lower Whenuakite River are tolerable.

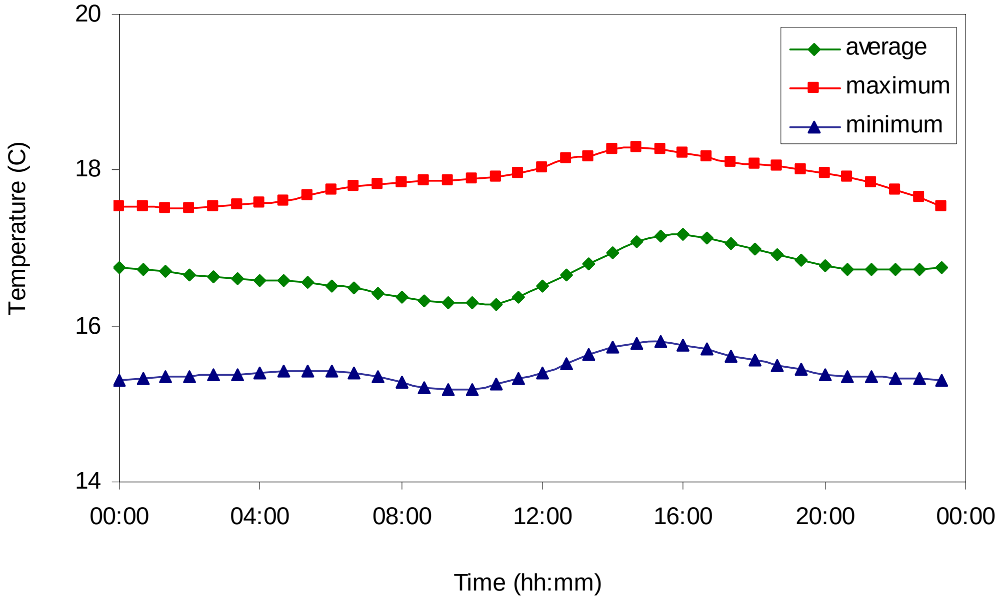

Figure 3.13: Water temperature over an averaged 24-hour period in the lowland reach of the Whenuakite River. Temperatures were averaged for each time of day over the 17-day monitoring period (March 2005) to give the average daily fluctuation in temperature. The maximum and minimum for each time of day is also presented.

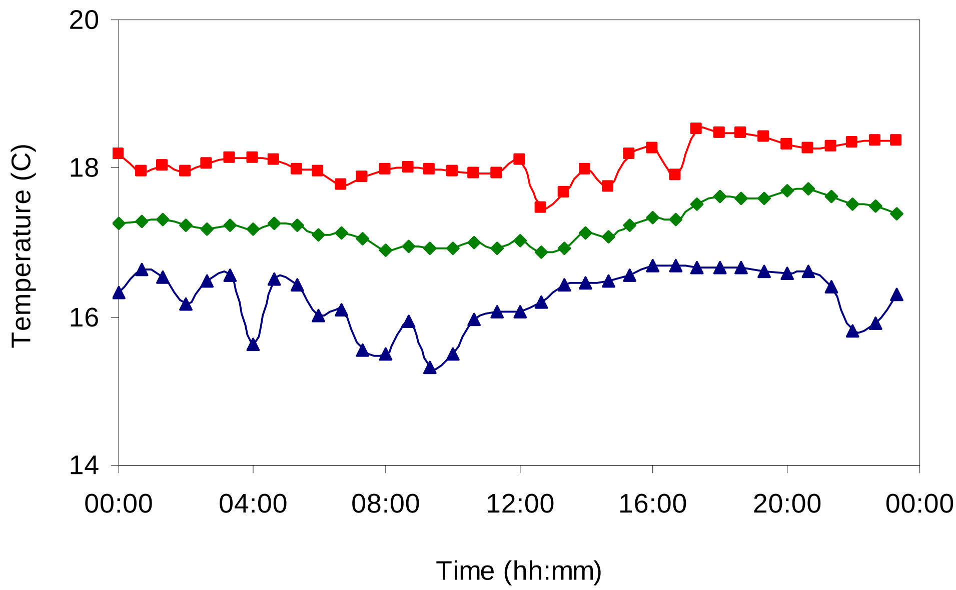

Figure 3.14: Water temperature over an averaged 24-hour period in the tidal reach of the Whenuakite River (below the Huruhurutakimo confluence). Temperatures were averaged for each time of day over the 17-day monitoring period (March 2005) to give the average daily fluctuation in temperature. The maximum and minimum for each time of day is also presented. Tidal fluctuations at this site left the probe dry at times, producing an incomplete dataset (erroneous data were omitted).

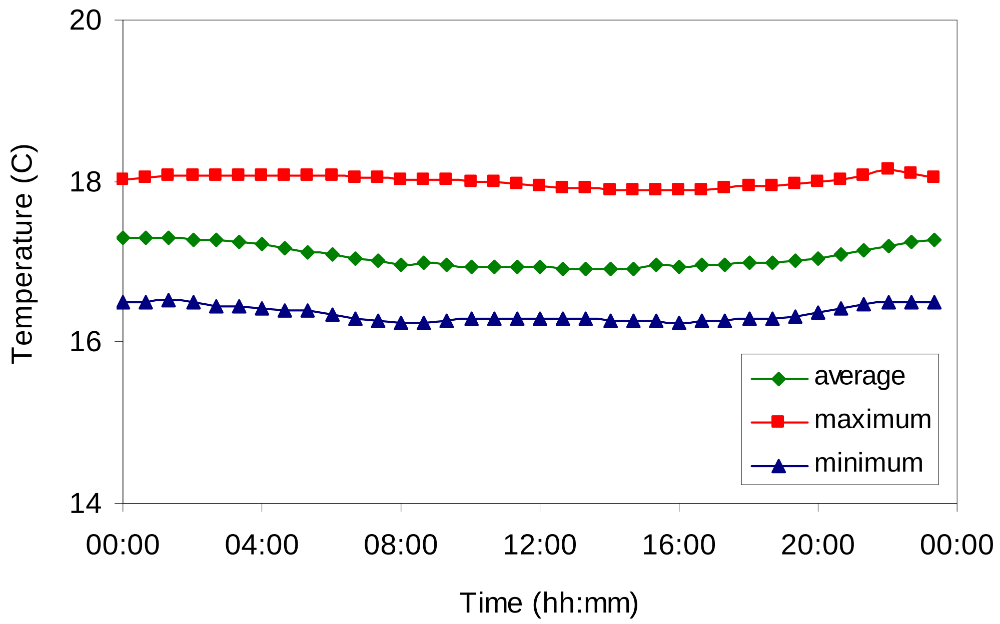

Figure 3.15: Water temperature over an averaged 24-hour period in the Huruhurutakimo Stream at Purangi Road. Temperatures were averaged for each time of day over the 17-day monitoring period (March 2005) to give the average daily fluctuation in temperature. The maximum and minimum for each time of day is also presented.

Water temperature was modelled using RHYHABSIM for the lowland reach. The model was calibrated to reproduce the observed temperatures (+ 1°C to reproduce February conditions) including the increase in temperature observed between the lowland and tidal reaches (default settings that were changed for the calibration included setting a canopy angle of 90° upstream, 72° downstream with 19% of solar radiation making it through the canopy upstream and 32% downstream). Reducing the flow in the lowland reach from MALF to the minimum flow for fish habitat produced using the Environment Bay of Plenty method (0.13 m^3/s to 0.075 m^3/s) was predicted to increase mean daily water temperatures up to 0.3°C (this was the largest increase predicted, and occurred 2 to 3 km downstream).

Water temperature in the upland reach was also modelled. Temperature spot measurements were taken by Environment Waikato a short distance downstream of the upland reach (at the State Highway 25 bridge), and these measurements correlated well with temperatures recorded from the forested Mahakirau River (this river also flows into the Whitianga Harbour). The temperature model was therefore calibrated to reproduce February averages observed for the Mahakirau River (18°C daily mean and 20.1°C daily maxima). The canopy angle was set to 90° with 10% fraction of radiation through the canopy, and bed temperature set at 17.5°C. This provided the modelled temperatures at the top of the reach (at the bushline). Below the bush line, the stream is relatively unshaded for about 1 km before entering the more-shaded midland reach (Figure 2.8, 3.1 & 2.1). Because of its shallow and wide channel, temperatures for the upland reach were expected to reach equilibrium temperature over a short distance (Figure 3.16).

Without calibration data (at the bushline and above the shaded midland reach), the temperature model cannot be confidently calibrated to predict the increase in temperature downstream of the bushline. Two scenarios are therefore presented (Figure 3.16); the lower temperature scenario reproduces high summer temperatures as observed in nearby rivers (Environment Waikato data for the Tairua and Waiwawa Rivers), and the higher temperature scenario represents the highest temperatures recorded in 14 years monitoring of the Tairua River. To achieve this change in temperature, the model was re-calibrated by reducing downstream shade from 80° to 75° and the fraction of radiation through the canopy increased from 30% to 45%. Given the small changes to shade required to achieve a considerable increase in temperature, riparian shading may be an important issue for this stream. The first scenario represents stressful temperatures for many fish and invertebrates, while the high temperature scenario approaches lethal temperatures for sensitive species, such as mayflies (Richardson et al. 1994, Cox & Rutherford 2000). Spot data measurements by Environment Waikato from midway though this reach (SH25 bridge, 400 m from the bushline) suggest the low temperature scenario is more realistic (maximum observed 20.1°C)

The lower-temperature scenario predicts an increase in daily maximum temperature of 0.23°C if flows are reduced from MALF to the minimum flow for fish habitat produced using the Environment Bay of Plenty method (at equilibrium >2 km downstream of the bush line). The high-temperature scenario predicts an increase of 0.68°C. Given the small predicted changes in temperature with flow and moderate observed temperatures (maximum 20.1°C at SH25), temperature does not appear to be a critical issue for this reach.

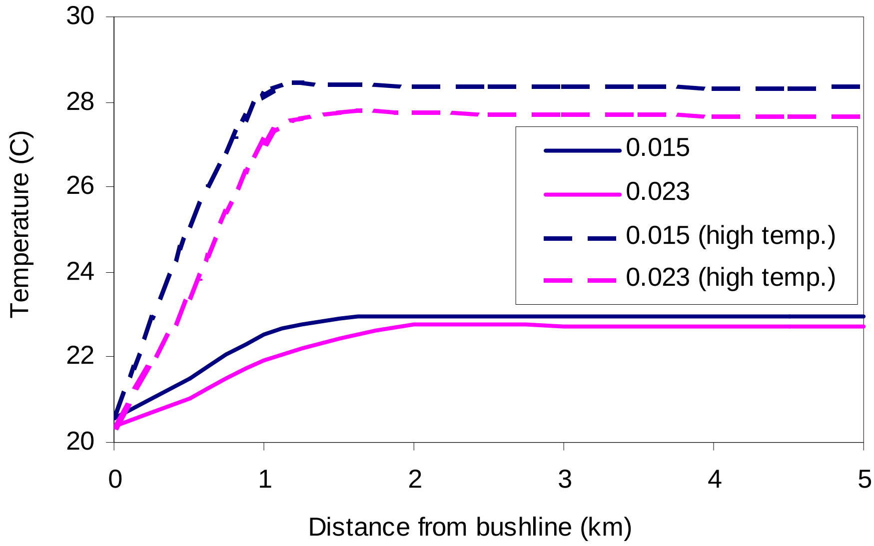

Figure 3.16: Maximum daily water temperature in the upland reach was modelled at different flows using RHYHABSIM. The change in temperature as the streams flows downstream from the bush line (top of the upland reach) is presented at MALF (0.023 m^3/s) and at the minimum flow produced using the Environment Bay of Plenty method (0.015 m^3/s). Two scenarios are presented; the first was modelled to reproduce the equivalent of high summer temperatures (95%ile for Tairua & Waiwawa Rivers), and the second scenario (*high temp.*) based on the highest temperatures observed in Coromandel streams (~ one in 5-year daily-maximum for the Tairua River).

Nutrient samples were collected at the three water quality monitoring sites (Table 3.5) to investigate the significance of inflows from the Huruhurutakimo Stream and the potential effect of flow reductions. Macrophyte growth is an issue because high biomasses reduce oxygen concentrations in the tidal reach. Increased nutrient concentrations have the potential to exacerbate this problem (MfE 1998). Mass flows from the Huruhurutakimo Stream were equivalent to the mass flows from the larger Whenuakite catchment (Table 3.6). The two values should add to give the mass flow below the confluence, however this was not the case. This could be a result of sample variability, but, given the stable flow conditions during the study, more likely reflects uptake of nutrients by macrophytes. For the purpose of these calculations, the mass flows observed below the confluence have been ignored and have simply worked with what is entering the tidal reach.

Abstraction does not increase the mass flows of nutrients directly (nutrients are removed from the system along with the water being used), but abstraction can increase the concentration of nutrients by reducing the dilution of downstream inputs. The flows required below the Huruhurutakimo confluence to achieve the ANZECC trigger values (Table 3.3.10 in ANZECC 2000) are 0.071 m^3/s for DRP, 0.080 m^3/s for NH_4-N and 0.013 m^3/s for NO_3-N.

Reducing the flow in the Whenuakite River at the lowland reach by 0.055 m^3/s (from MALF) would increase the concentration of inorganic phosphorous (DRP) by 24% (below the Huruhurutakimo confluence). The concentration of inorganic nitrogen (NH_4-N + NO_3-N) would be increased by 20% (calculations assumed the mass flow of nutrients above the confluence is reduced proportionately by abstraction). If nutrients are limiting macrophyte growth, then increased nutrient concentrations could increase macrophyte biomass. Macrophytes grow to nuisance levels even in low nutrient (oligotrophic) lakes such as Okataina and Tarawera (*total* phosphorous less than 0.009 g/m^3; cf. *dissolved reactive* phosphorous measured here), because nutrients are taken up from root-zone sediments as well as from the water column. Macrophytes can be limited by flow regimes, substrate, light and dissolved carbon (Barendregt & Bio 2003; Carr et al. 1997). The high density of macrophytes observed in the tidal reach suggests competition for light and space are the primary limiting factors in the Whenuakite River. The effect of reduced flows on nutrient concentrations is therefore not expected to measurably affect macrophyte growth.

Table 3.5: Nutrient concentrations from monitoring of three sites in March 2005. Flows were also measured on each occasion to enable calculation of mass flows (Flows at Whenuakite tidal were estimated by summing the other two measured flows). DRP is dissolved reactive phosphorous; NH_4-N is ammoniacal nitrogen; NO_3-N is nitrate nitrogen. Monitoring sites are shown in Figure 2.1.

Site	Date	Flow m^3/s	DRP g/m^3	NH_4-N g/m^3	NO_3-N g/m^3
Whenuakite lowland	3/03/05	0.111	0.007	0.024	0.069
Huruhurutakimo	1/03/05	0.015	0.080	0.947	0.249
Whenuakite tidal	1/03/05	0.126	0.006	0.022	0.031
Whenuakite lowland	17/03/05	0.100	0.007	0.027	0.057
Huruhurutakimo	17/03/05	0.010	0.122	0.704	0.052
Whenuakite tidal	17/03/05	0.110	0.008	0.008	0.025
Whenuakite lowland	2/05/05	0.087	0.007	0.032	0.077
Huruhurutakimo	2/05/05	0.010	0.035	0.015	0.119
Whenuakite tidal	2/05/05	0.097	0.005	0.014	0.110

Table 3.6: Mass flows of nutrients calculated as an average for each site. DRP is dissolved reactive phosphorous; DIN is dissolved inorganic nitrogen, calculated by summing ammoniacal nitrogen and nitrate nitrogen.

Site	DRP (g/s)	DIN (g/s)
Whenuakite lowland	0.00069	0.00939
Huruhurutakimo	0.00093	0.00899
Whenuakite tidal	0.00071	0.00743

3.5 Tidal Survey

Whitebait spawn along the water's edge during spring high tide at a site that often coincides with the limit of salt water penetration (Mitchell & Eldon 1991). Coffey (1997) identified the limit of saltwater penetration to be within a kilometre upstream of the Te Kauanga Road bridge (Figure 2.2). The vertical tidal range over this reach was measured at close to 1.5 m (Figure 3.14). There is a riffle just below the Parakau Stream confluence, which is about 3.3 km upstream of the river mouth, which reduces the tidal range upstream of this point (Figure 3.17). The tide pushes upstream, beyond the tidal survey reach, to where the data logger was installed near Whenuakite Hall (Figure 2.2). No tidal effect was detected above Hot Water Beach Road. The tidal limit is therefore somewhere within 1.3 km downstream of the bridge at Hot Water Beach Road (probably in the vicinity of the Huruhurutakimo Stream confluence).

Cross-section profiles were taken at two points; one at Te Kauanga Road bridge, and the other just below the Parakau Stream confluence. The Te Kauanga cross-section is closest to where inanga are likely to spawn. Reducing the flow from MALF to the minimum flow requirement for fish habitat at the lowland reach (Hot Water Beach Road), reduces the water depth by 0.009 m. If we assume abstracting this volume of water has the same effect on water level in the spawning reach, this would reduce the wetted perimeter of the channel by 0.08 m (0.2% of total width). Using the habitat data from the midland reach instead, where water levels dropped more with flow (0.027 m), gives a change in wetted perimeter at the spawning reach of 0.23 m (0.5% of total width). This approach assumes water levels at high tide are affected by stream flows. At baseflows, it could be argued that water levels over the spawning reach are determined solely by tide height, in which case abstraction would not change the area of spawning habitat at all (presumably flood flows would be required to affect high tide level).

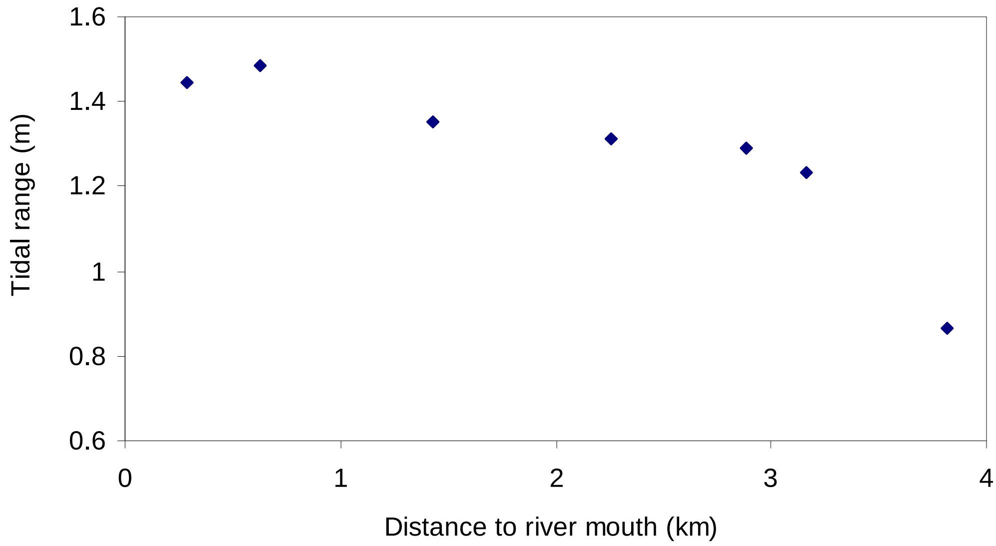

Figure 3.17: Tidal range recorded at seven sites on the lower Whenuakite River. Water level measurements were taken at high tide on 1 March and at low tide on 2 March 2005. The river mouth was nominated as the coastal outline on NIWA's GIS layer, which coincides with the point where the river opens out to mudflats, 300 m downstream of the Te Kauanga Road Bridge.

4. Discussion

A range of issues were investigated to quantify possible critical flow issues for maintaining aquatic ecosystems in the Whenuakite River. Recommended minimum flows are based on necessary levels or standards required for the critical issue.

Natural low flow conditions were found to maintain adequate habitat and water quality in the lowland and upland reach. However, the tidal reach requires flows greater than Q_5 to maintain oxygen levels above the moderate impairment standard and flows greater than MALF to achieve standards for slightly impaired systems (standards recommended by Dean & Richardson 1999). Oxygen concentrations will fall to low levels in the absence of abstraction, although abstracting water during low flows is expected to exacerbate oxygen depletion and extend the time that the river experiences low oxygen concentrations. This suggests the critical issue for setting limits on abstraction from the Whenuakite is oxygen depletion in the tidal reach.

A minimum flow of 0.205 m^3/s is expected to prevent dissolved oxygen (daily minimum) from declining below 4 g/m^3 (standard for moderate impairment of adult native fish) as a consequence of abstraction. Using the slight impairment standards for adult native fish (5 g/m^3), a minimum flow of 0.24 m^3/s is required. Standards from the Proposed Waikato Regional Plan do not allow changes in dissolved oxygen that have any significant adverse effects on existing aquatic ecosystems (Section 3.2.4.1 a. i. January 2004 version). The tidal reach is currently classified as Indigenous Fishery under the Proposed Waikato Regional Plan, meaning that it is believed to support “significant diversity or populations of indigenous fish” (Plan Section 3.2.4 Explanation). Given the low oxygen conditions experienced in this reach (in the absence of abstraction), only the most tolerant of native fish are expected to reside here. The tidal reach should therefore be classed as a Degraded Water Body (Section 3.2.3 Policy 8; defined as “water bodies that do not currently meet the standards that apply to their identified uses and values”). The Degraded Water Body policy requires that further degradation of water quality be taken into account when allocating water (Section 3.2.3 Policy 8). A minimum flow based on the moderate impairment standard for oxygen is considered adequate for maintaining the resident fish communities (0.205 m^3/s). However, in achieving regional plan objectives for a net improvement in water quality (Section 3.1.2 b), allocations should be subject to mitigation requirements where practical (discussed below). In addition to the resident fish community, the tidal reach is also a migratory pathway for all diadromous native fish living in the greater Whenuakite catchment. Therefore, the slight impairment oxygen standard for early life stages (5.5 g/m^3 of oxygen) is recommended during whitebait migration periods, producing a recommended minimum flow of 0.26 m^3/s for the period 1 August to 30 November (Wilding 2000a).

Deoxygenation of the tidal reach is driven by the large biomass of macrophytes respiring and consuming oxygen. The low gradient and deep waters offer limited re-aeration and, to makes matters worse, the reach becomes deeper and slower flowing at high tide. Reducing the biomass of macrophytes would be an option for increasing oxygen concentrations in the tidal reach and mitigating the effects of water abstraction (riparian planting in the tidal reach would be less straight forward for those taking water further upstream, requiring off-site mitigation). Macrophytes represent stable habitat for aquatic ecosystems and act as a buffer to nutrient and sediment discharge from the catchment. However, biomass could be reduced significantly and still maintain these values. Increasing riparian vegetation can be effective because it shades out the macrophytes (Bunn et al. 2002). The wider the stream the taller the trees needed to shade the channel. Whether the Whenuakite is too wide to achieve adequate shading would need further investigation. Herbicide control or mechanical methods such as excavation may be less practical than other methods of macrophyte biomass control given the ongoing costs and the potential to further reduce oxygen concentrations. Avoiding abstraction during times of daily oxygen minima (midnight to 10am) is a simple way of minimising the effects of abstraction on aquatic ecosystems.

The freshwater tidal reach is not often assessed in minimum flow studies or other stream ecology work. This transition zone between the estuary and river is normally expected to be short because most Coromandel streams maintain a moderate gradient as they approach the coast. Other low gradient rivers in the Coromandel and the greater Waikato may have extensive tidal zones, and if oxygen is found to be a widespread issue in these areas, then research may be warranted into the influence of tidal fluctuation on oxygen levels.

No abstractions are currently proposed for the upland reach. This site was included to build on the number of habitat surveys in the Coromandel so that regional flow methods can be developed. Modelling indicated the potential for high temperatures in this reach if shade is inadequate. The minimum flow based on fish habitat requirements was not predicted to increase temperatures significantly, but the small increase would exacerbate potentially high temperatures. It is recommended that minimum flow investigations in poorly shaded Coromandel streams include temperature modelling (preferably based on temperature logger data from the upstream and downstream end of the reach). Mitigation requirements to allow abstraction, in the form of riparian planting, can then be assessed.

5. Acknowledgements

I thank Wayne McGrath of NIWA for carrying out the fieldwork, with assistance from Ian Jowett and Audrey Meriaux. John Nagels organised data-loggers and assisted with data manipulation. Thanks to property owners for allowing access onto their farms and for switching off pumps. Doug Stewart from Environment Waikato provided flow information for the Whenuakite River, while Paul Taylor provided temperature data for nearby rivers. Ed Brown and Kevin Collier from Environment Waikato provided consent information and useful advice during set-up and on the draft report.

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7. Appendix 1: Environment Bay of Plenty Instream Management Objectives

1. Background

The environmental flows (or habitat) project was set up by Environment Bay of Plenty to provide a more defensible approach for water allocation. The project looks at the effects of abstraction on aquatic life both directly (reduced habitat) and indirectly (water quality, temperature). This appendix, reproduced from Environment Bay of Plenty reports (Wilding 2003), only deals with one aspect of minimum flow determination – interpreting habitat-flow response curves. Irrigation abstractions are the main focus, while issues associated with water impoundment are not addressed (flushing flows, etc.).

Modelling techniques are used to address the habitat issue. The RHYHABSIM programme models change in depth, velocity and substrate with flow and relates this to habitat preferences of native fish and trout. But it does not produce a minimum flow. As a result, deriving a minimum flow figure is subjective to the point where two people working with the same data can produce two different figures. The aim therefore is to establish an objective approach for deriving minimum flows from RHYHABSIM habitat modelling. Not only will this enable a consistent environmental outcome in setting minimum flows throughout the project but also provide external consultants with guidance for interpreting such data to the satisfaction of Environment B·O·P.

2. Objectives and Options

The first step was to review legal planning objectives. Relevant objectives in the Proposed Regional Water and Land Plan are:

33. Water flows in streams and rivers are maintained to:

    a) Provide adequate protection for existing aquatic life in the waterbody.

    b) Maintain identified significant values of rivers and streams.

    c) Maintain water quality relative to the assimilative capacity of the water body.

    d) Avoid or mitigate adverse effects on downstream environments.

Part a) is directly relevant here (background to this policy can be found in Appendix II of Wilding 2000b). The MfE flow guidelines (1998) provide guidance on developing instream management objectives, pointing out the need to identify the values to be protected as well as the level of protection. From the above policy, values addressed by this project are existing aquatic life and in terms of level of protection we need to define what is adequate. This will vary depending on the significance of the aquatic ecosystem.

Features of a good instream management objective include:

- Retain adequate flow for ecosystem protection based on ecosystem significance.

- Provide an objective approach so 2 people can get the same answer.

Options for instream management objectives include:

1. Habitat remains unchanged.

2. Allow a percent reduction in habitat.

3. Allow change based on individual reach assessment, i.e., leaving it open to interpretation.

4. Allow change down to a region wide standard. For example, a NIWA study for Wellington and Taranaki Regional Councils suggested setting a minimum flow based on the 85%ile of percent brown trout habitat from the national "100 Rivers" study, (Jowett 1993a, 1993b).

Option 1 will often prevent water being made available and fails to recognise the potential for improved habitat at lower flows. Allowing an across-the-board reduction in habitat provides a consistent environmental outcome (Option 2), but it is somewhat clumsy because again it ignores the potential to optimise habitat at different flows. Option 3 doesn't provide the necessary objectivity, and achieving consistency in case by case negotiations may be difficult. Option 4 relies on a sentinel species that is likely to have the highest flow requirements. Brown trout are not present in all Bay of Plenty catchments and few native species with high flow requirements are sufficiently widespread. Also, standards based on the "100 rivers" study may set an unrealistic expectation for the small pressure catchments, (many pressure streams have flows <1 m^3/s, cf. only 2 of the "100 rivers" had flow < 2 m^3/s). It seems these more straightforward approaches won't produce the desired result in many instances so a more complex approach is recommended.

3. Recommended Approach

1. Using the habitat flow response curve, identify a primary flow for each species. This is the flow where habitat is optimal (greatest), unless the optimum exceeds the median flow (and is therefore unreasonable). In the latter case the MALF is used as the primary flow.

2. Multiply habitat at the primary flow by the protection level. Plot this point on the flow response curve and read the minimum flow for each species off the X-axis. The level of protection is scaled according to ecosystem significance. Significance criteria are given in the last section of this appendix. For example, habitat for Criteria 6 species can be reduced to 85% of that offered by the primary flow, while habitat for the most significant species cannot be reduced at all. (Note this percentage is a change in habitat, which may or may not equate to a similar drop in flow.)

3. Having produced a minimum flow for each species present, the highest of these is chosen as the minimum flow for the stream reach. This is to ensure adequate protection for the existing stream community (i.e., all taxa).

Although relatively complex it is not a difficult process, and objectivity is achieved.

The minimum flow is based on the species with the highest flow requirements. An alternative approach offered by Jowett & Richardson (1995) for native fish communities, is to set minimum flows at that preferred by fish with intermediate flow requirements (redfin bully or common bully), rather than fast water species (torrentfish, bluegill bullies). While offering a compromise, Jowett & Richardson’s approach will in some cases allow large reductions in habitat for fast water species, and this does not ensure adequate protection for the existing aquatic community. The tendency for fast water species to prefer the equivalent of flood flows is circumvented here by not allowing the primary flow to exceed the median flow.

The point of inflexion is sometimes advocated for setting minimum flows. The point of inflexion is the point above which there is little increase in habitat with flow – the graph levels off, (the longfin and shortfin eel curves in Figure 1 are good examples). A point of inflexion does not always exist and, where it does, can be influenced by the scale used for the axes. Where a point of inflexion exists, the recommended approach effectively recognises it because the flatter the curve the greater the flow reduction for a percentage reduction of habitat.

The basic principle of the recommended approach is to identify the optimum (or best available) flow and allow a reduction below this which recognises the significance of the stream community. It recognises that natural stream flows are not always ideal, and the risk associated with small reductions in habitat is acceptable for more common species. If one accepts this approach, the only room for debate is in the protection levels specified. One way to test the levels chosen is with follow up monitoring, the results of this feeding into consent reviews. Unfortunately conclusions can only really be certain if stream flows are drawn down to the minimum flow for an extended period. Baseline data would need to be collected before abstractions begin. This approach will tell us if too much water was allocated. However, determining if minimum flows are too conservative would rely on natural low flows falling below the set minimum for an extended period. Even then it is possible any effect would be a consequence of lack of floods rather than reduced flows *per se*.

4. Other Considerations

When estimating stream flows, this should be corrected for existing takes (municipal, industrial, irrigation). This necessitates measuring flows when water is not being abstracted or measuring the abstracted flow and correcting accordingly. There is some argument for not correcting for permitted domestic takes (< 15 m^3/day).

5. Significance criteria and allowable habitat reductions

Significance criteria were established to scale the level of protection (Table 1). The 100% protection level (Criteria 1) is only afforded to the most threatened species. Any reduction in habitat is unacceptable because the risk of irreversible population decline (i.e., extinction) is too high. The 85% level (Criteria 6) is intended to provide adequate protection for relatively widespread species. Intermediate criteria are protected accordingly.

Significant recreational trout fisheries are afforded a relatively high level because their value lies in the abundance of fish, a factor directly affected by habitat. While less fished trout populations are afforded the 85% protection level, populations that support negligible fishing are given the least protection (15%). This is because trout were introduced to New Zealand principally to provide a recreational fishery. The 15% level is specified to reduce the chance of fish kills.

The 90% level afforded to diverse communities reflects the non-threatened status of the taxa it applies to, (any threatened taxa are covered by the more protective criteria), and the desire to maintain an assemblage of species. The more species present the more likely one will have relatively high flow requirements. Although not presented in the table, appropriate food producing habitat for these species should be given the same level of protection.

No rules are set for deciding if the community represents a diverse assemblage (Criteria 4). Streams closer to the sea generally have higher diversity and so an inland stream with only a few taxa may still represent a relatively diverse community given the streams potential.

In some cases Crans bully should be given a Criteria 2 protection level. As a non-diadromous species, recruitment success is more dependent on a suitable instream environment. By contrast, local extinction of inanga from a stream would be more reversible with whitebait migrations from the sea. Likewise if a population of Crans bully was lost from a tributary, the species could eventually re-establish itself from the main river or lake. However, if abstraction affected the majority of the reproducing population in a catchment then Criteria 2 protection should be given. This is not stated as separate criteria because only one non-diadromous native species is present in the Bay of Plenty (that is not already given a higher protection level), and Crans bully is mostly confined to the East Cape streams where abstraction pressure is low.

Some may argue depauperate streams should be given a lower protection level. If a stream is proven to be depauperate it seems unlikely that in-depth RHYHABSIM assessments would be justified. Factors other than fish habitat may become the critical factor determining flow requirements (see MfE 1998).

Table 1: Significance criteria and protection levels.

	Significance Criteria	Protection level (percentage of primary habitat)
1.	DoC priority A & B species[3]. Short-jawed kokopu; giant kokopu	100%
2.	DoC priority C species & regionally threatened species. Banded kokopu; koaro; black mudfish; dwarf galaxias[4]	95%
3.	Regionally significant trout fisheries plus habitat on which these fisheries depend for spawning and rearing. Brown trout; rainbow trout; etc.	95%
4.	Diverse native fish communities. Fish community featuring a significantly high number of native species. Constituent species are individually given this protection level, unless afforded higher protection by Crit. 1-3.	90%
5.	Unfished trout populations.	15%
6.	Other.	85%

6. Worked Example

A change in available habitat, be it up or down, is largely unavoidable if we want to make any water available for abstraction (see Figure 1). So where possible we want to optimise habitat available in the stream. For the Tahawai Stream, optimum habitat occurs at approximately 13 L/sec for banded kokopu (Figure 1). In some cases it is unreasonable to expect optimum conditions. For example, optimal habitat for longfin eel occurs at more than twice the median flow. In this case we set the primary flow at the MALF.

This provides a starting point for each species (Table 2). We then need to set a protection level that recognises ecosystem significance. Because the Tahawai Stream supports a high number of species we set the level of protection at 90% for all native species except banded kokopu, which fall into Criteria 2 (95%). A minimum flow is produced for each species and we adopt the highest figure to ensure the ecosystem is sustained. In this case inanga have the highest flow requirement, so the recommended minimum flow for Tahawai would be set at 26 L/s. This is termed the IMFR,

[3] Molloy & Davis, 1994.
[4] Dwarf galaxias is classed as regionally threatened. The only records of this species in the Bay of Plenty are from a few streams on the Galatea Plains (an area of high abstraction pressure). These records, until recently represented the northern limit of the species.

(instream minimum flow requirement). Allocable flow is based on Q_5 minus the IMFR, so with a Q_5 of 23 L/s no water is available for abstraction (23-26=-3 L/s). Note that reducing the minimum flow for shortfin eel from 14 L/s, down to the point of inflexion at 11 L/s, would make no difference to the IMFR, which is based on inanga for this stream.

Table 2: Tahawai Stream minimum flow evaluation. The primary wetted usable area (Primary WUA, m^2/m) is derived from Figure 1 using the recommended approach. This value is multiplied by the protection level (see last section) and a minimum flow is derived.

	Primary WUA	WUA x prot. level	Corresponding minimum flow (L/s)
Inanga	0.29	0.26	**26**
Torrentfish	0.11	0.095	24
Redfin bully	0.86	0.77	19
Longfin eel	1.04	0.93	14
Shortfin eel	0.73	0.66	13
Banded kokopu	0.18	0.17	8

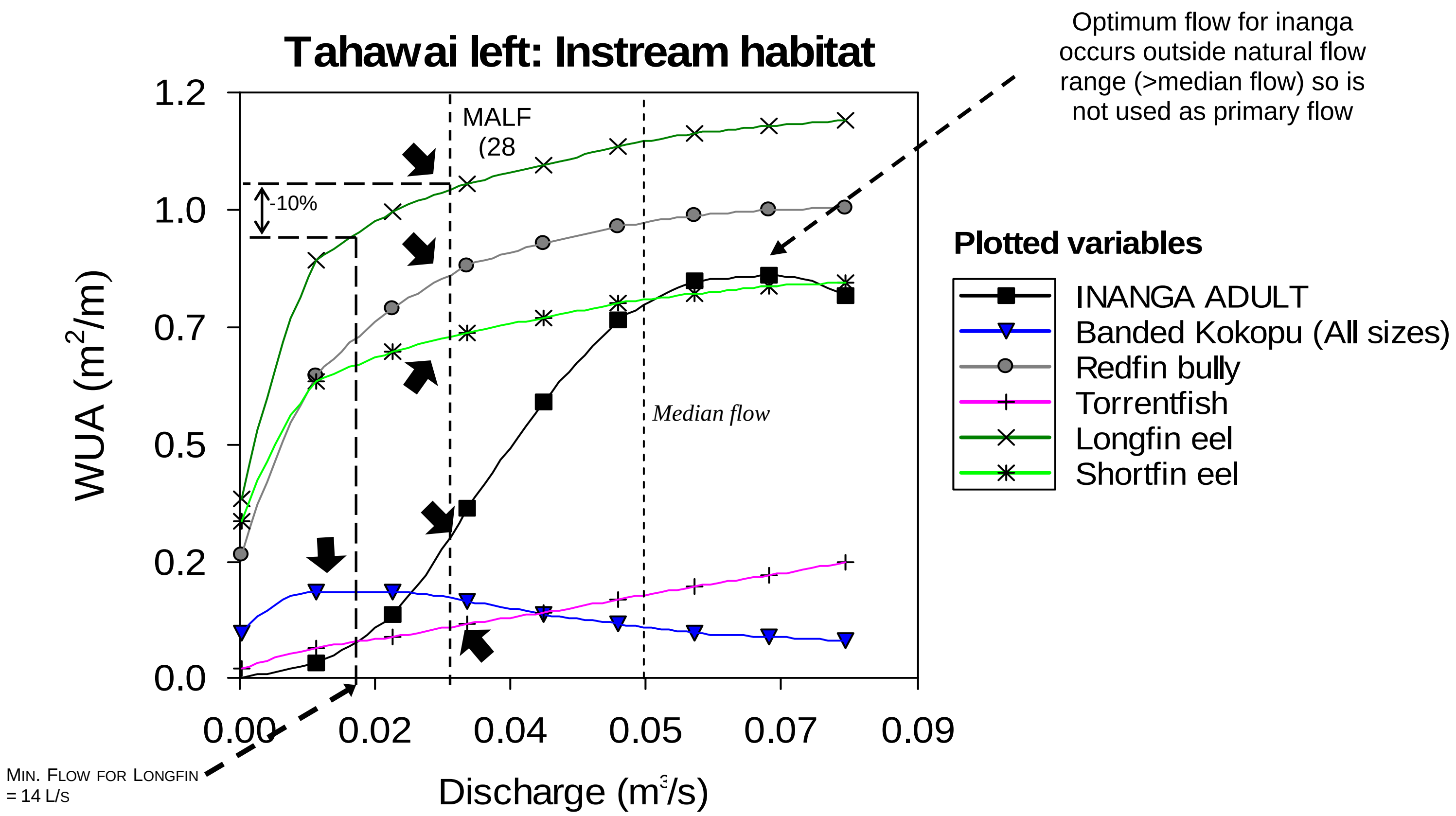
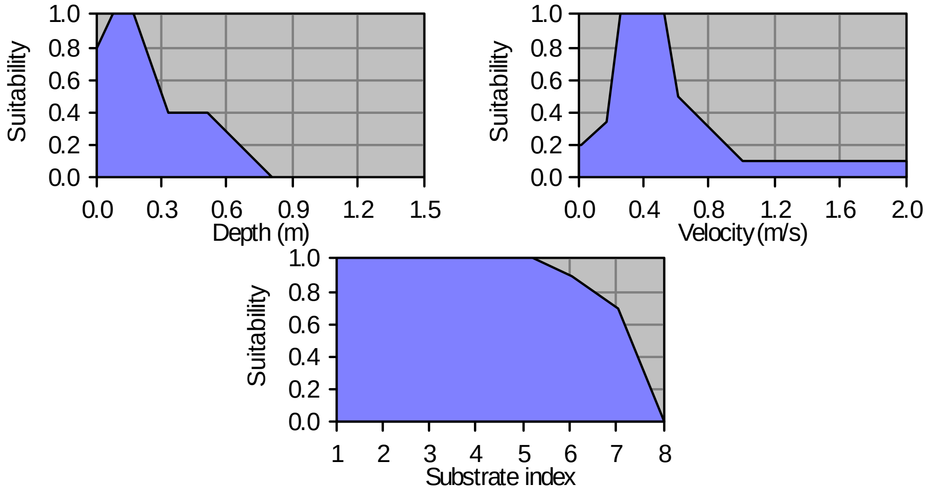


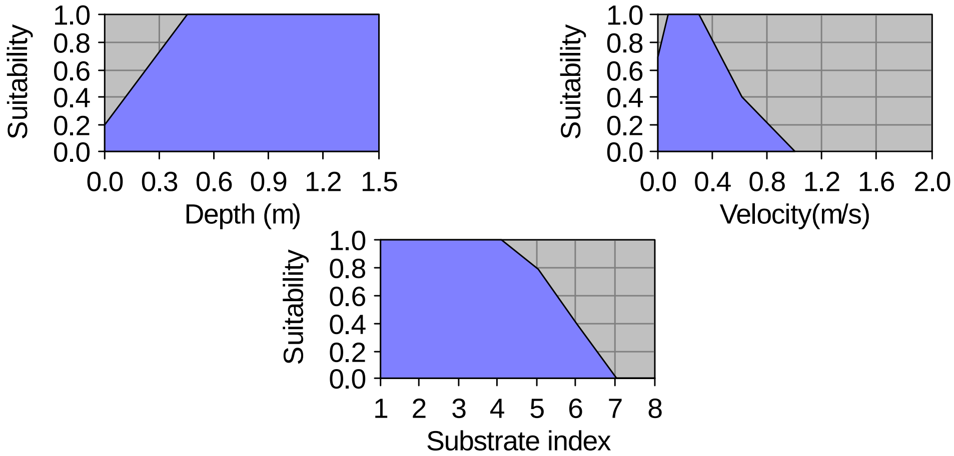
Figure 1: Modelled habitat for the Tahawai Stream (western BOP) expressed as habitat (WUA m^2/m) versus flow. Primary flows determined using established criteria are arrowed for each species. Minimum flow calculation for longfin eel illustrated. Note, this is presented as an example only, as taxa and baseflow estimates were altered to illustrate the method.

8. Appendix 2: Habitat suitability curves

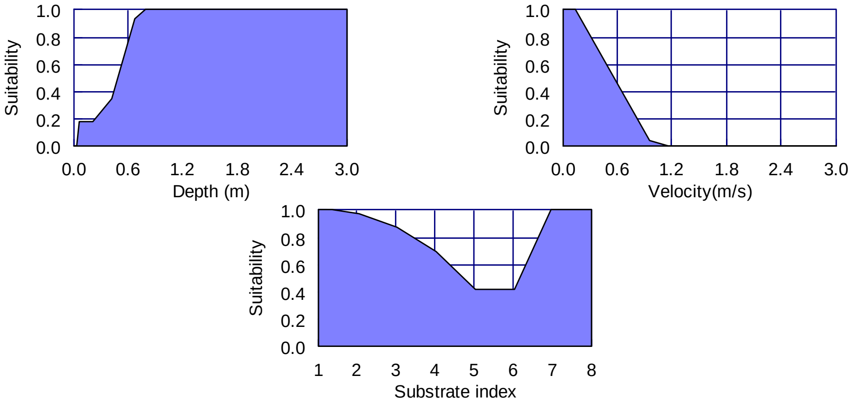
Common bully



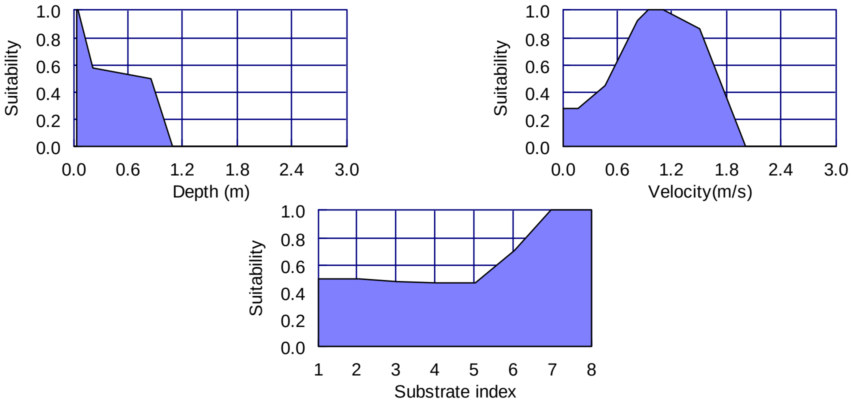
Common smelt



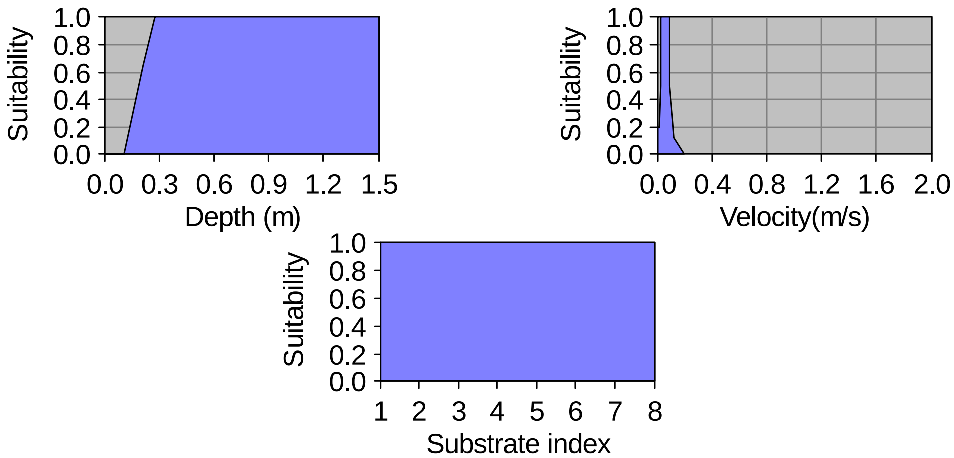
Longfin eels >300 mm

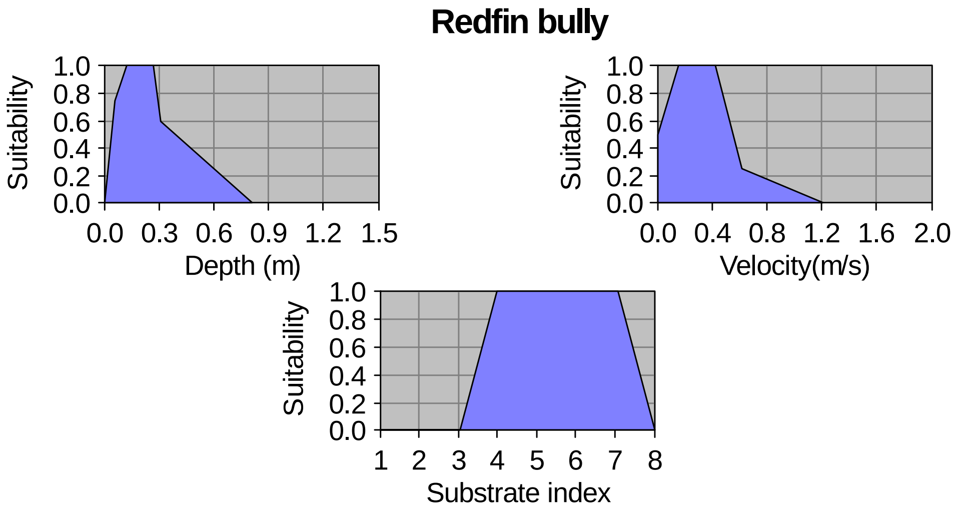


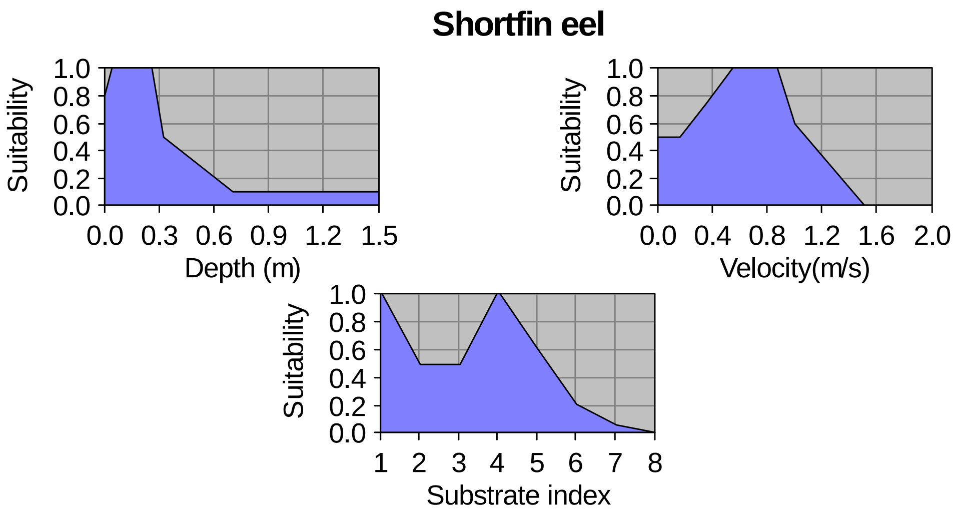
Longfin eels <300 mm

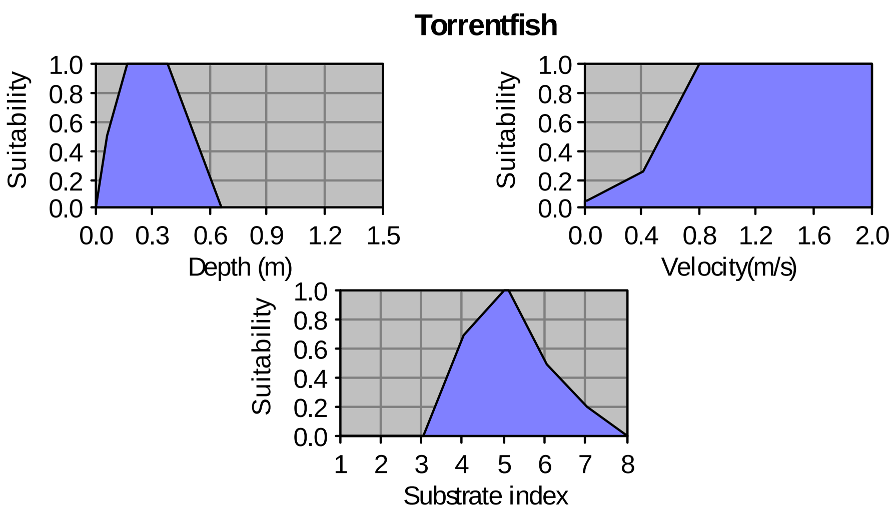


Inanga feeding

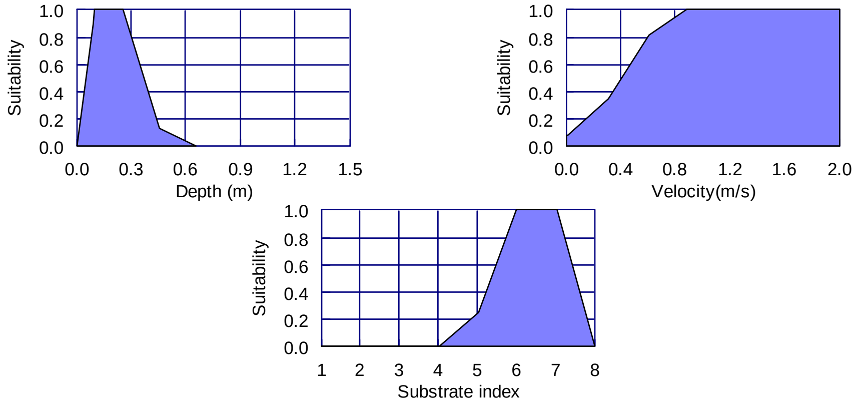



Redfin bully
Suitability
Depth (m)
Velocity(m/s)
Substrate index

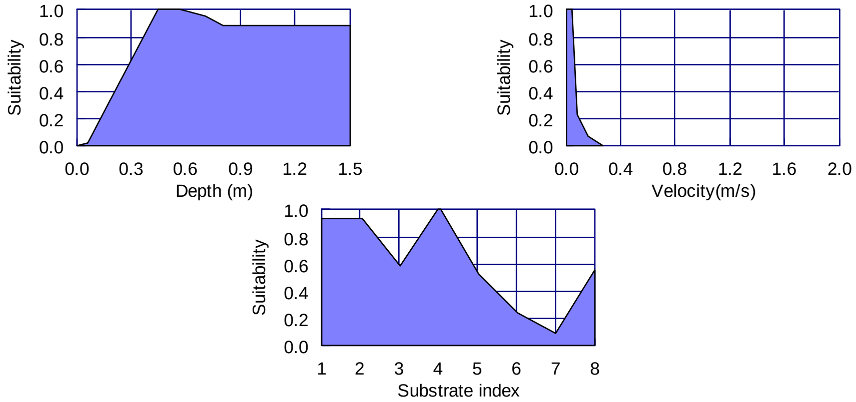

Shortfin eel
Suitability
Depth (m)
Velocity(m/s)
Substrate index


Torrentfish
Suitability
Depth (m)
Velocity(m/s)
Substrate index

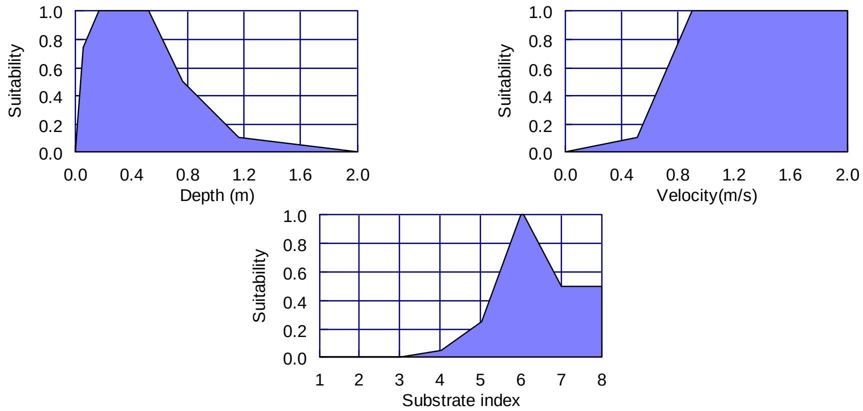
Koaro



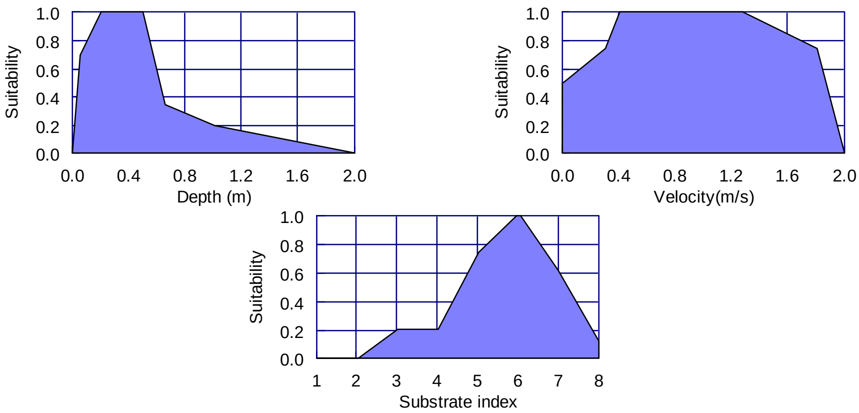
Banded Kokopu (1+)



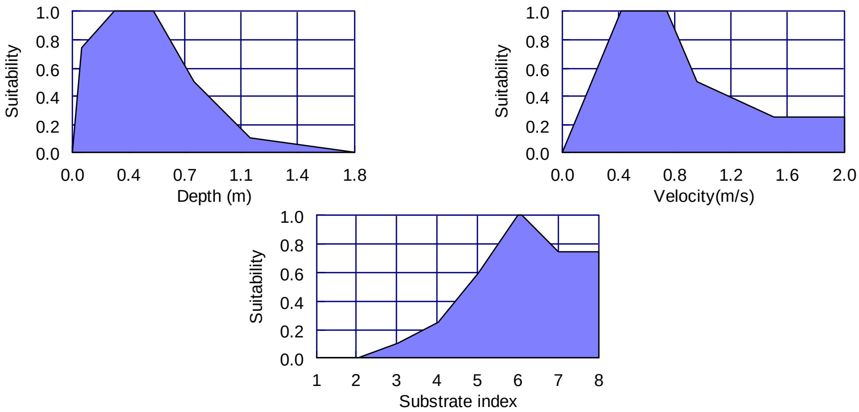
Aoteapsyche (net-spinning caddis)



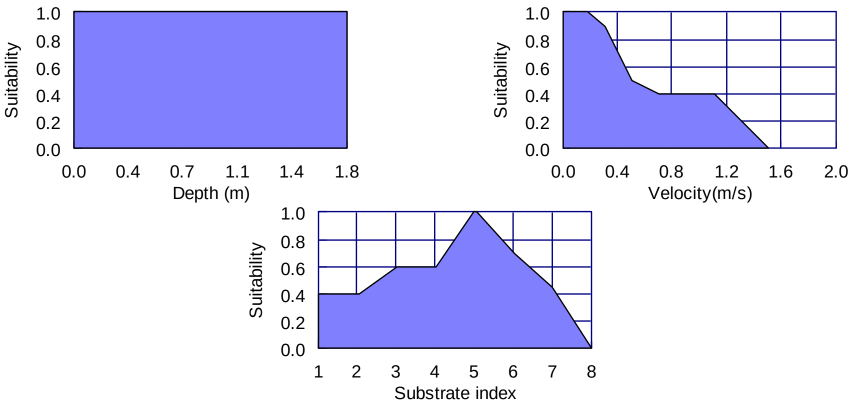
Deleatidium (mayfly)



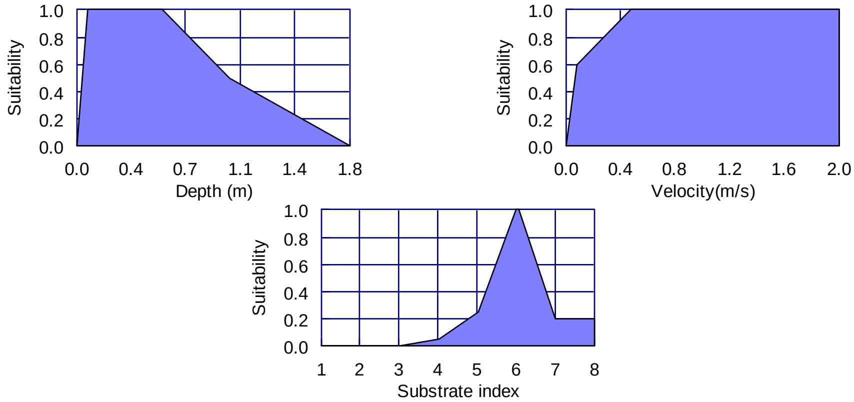
Pycnocentrodes (stony-cased caddis)



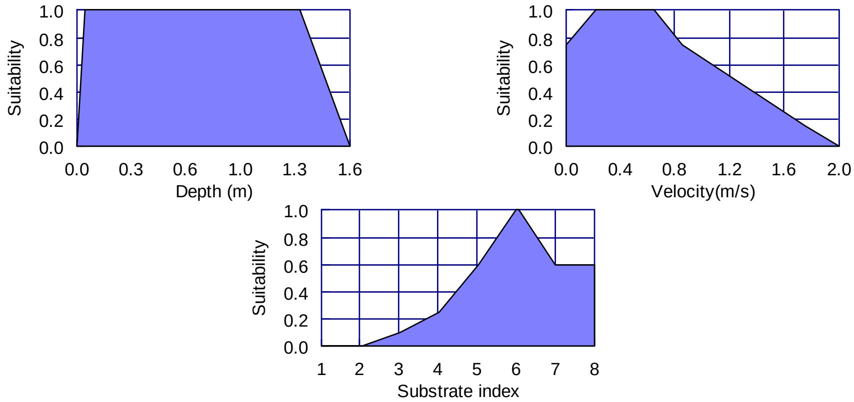
Elmidae (Waitaki)



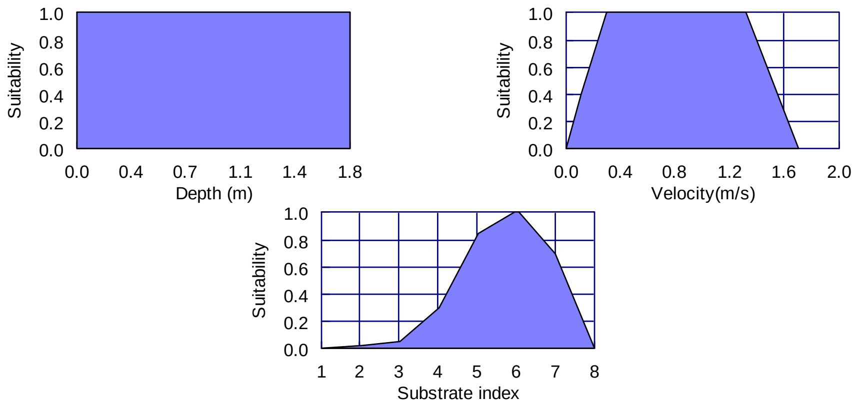
Hydrobiosidae (free-living caddis)



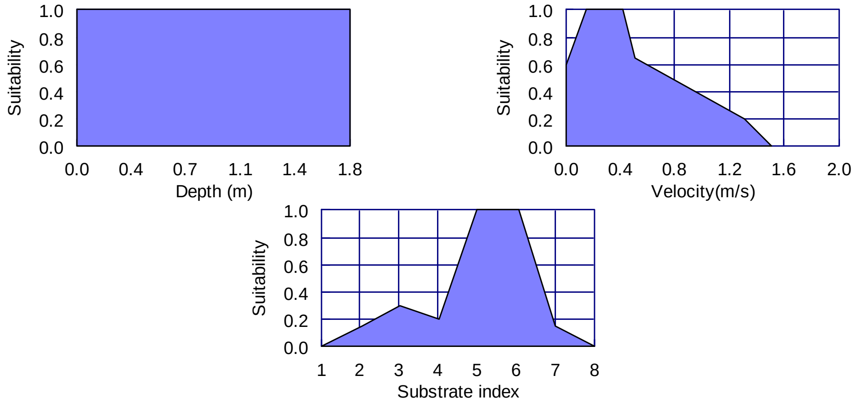
O. feredayi (horny-cased caddis)



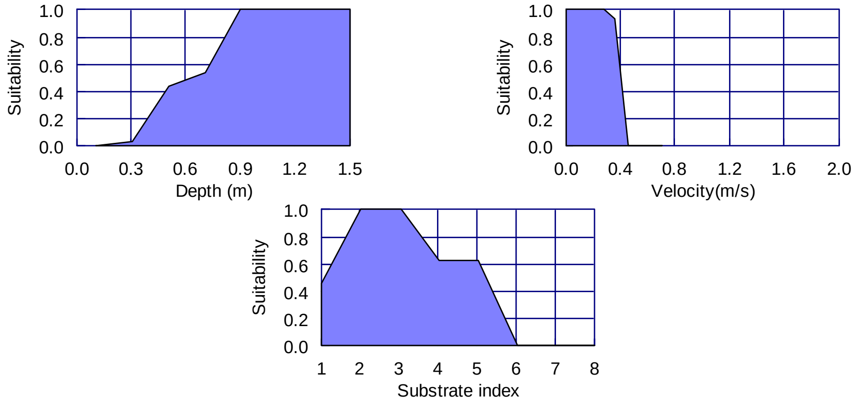
Orthocladinae (Waitaki)



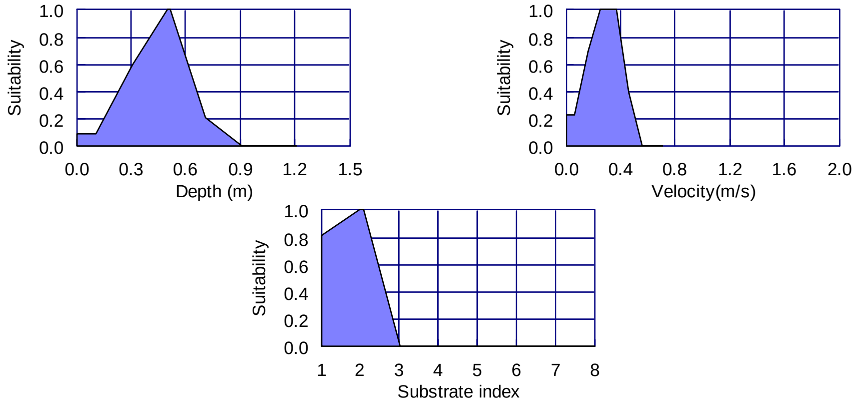
Potamopyrgus (Waitaki)



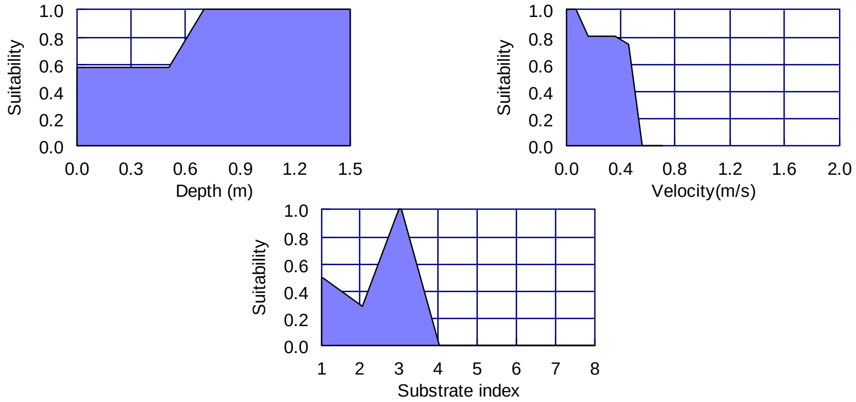
Elodea canadensis



Myriophyllum triphyllum



Potamogeton cheesemanii



9. Appendix 3: Invertebrate data

Samples from the Whenuakite River at State Highway 25 Bridge, collected by Environment Waikato.

LOC KEY	1321-13	1321-6
Date	**3/03/05**	**29/01/98**
Sample#	**81400**	**57915**
Elmidae	61	21
Hudsonema	39	1
Pycnocentrodes	30	0
Tanytarsini	15	0
Olinga	12	1
Oligochaeta	9	0
Potamopyrgus	6	0
Orthocladiinae indet.	5	0
Aoteapsyche	4	12
Tanypodinae	4	0
Archichauliodes	3	5
Austroclima	3	2
Psilochorema	2	5
Deleatidium	2	1
Polypedilum	2	0
Hydrobiosis	2	0
Paratya	1	7
Pycnocentria	1	0
Oeconesidae	1	0
Neurochorema	1	0
Austrosimulium	1	0
Triplectides	0	27
Chironomidae indet	0	8
Tabanidae	0	5
Zephlebia	0	3
Hexatomini - other	0	3
Eriopterini other	0	3
Nesamaletus	0	2
Oxyethira	0	1
Oniscigaster	0	1
Antipodochlora	0	1