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Minimum Flows for Ecosystem Health in the Whakapipi Stream (Pukekohe)

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NIWA Client Report: HAM2007-105
June 2007

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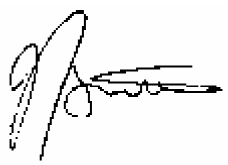

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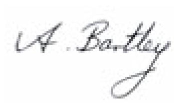


Executive Summary

Managing the water resources in the Waikato Region requires information on instream flow requirements. This report addresses the flow requirements for aquatic ecosystems of the Whakapipi Stream. Abstraction pressure here is high, supplying one of New Zealand's most intensive market gardening areas. Fish habitat and water quality in the lower reaches were the focus of investigations.

The Whakapipi Stream flows into the Waikato River and RHYHABSIM was used to model habitat for fish and other biota in the lowland reach (below State Highway 22). The lowland reach provides pool and sluggish run habitat that supports prolific plant growth. Oxygen was also monitored in this reach to calibrate a model of the effect of flow changes on oxygen concentrations (using WAIORA).

Fish diversity and abundance are higher in the lowland reach, so maintaining adequate flow for habitat is expected to have the greatest benefit there, compared to inland reaches where fewer fish have access. Invertebrate sampling did not reveal communities of greater significance in the upper catchment. So in terms of habitat at least, it is reasonable to base flow requirements on the lower catchment. Flow requirements for fish habitat in the lowland reach were estimated at 0.050 m^3/s (Table 1).

Low oxygen concentrations are stressful to aquatic life and reduced flows have the potential to exacerbate this. With a low stream-gradient and prolific aquatic plant growth, dissolved oxygen concentrations in the lowland reach fluctuated between morning and afternoon (2.7 to 9.7 g/m^3 on average). A flow requirement of 0.083 m^3/s was predicted to achieve a 24-hour oxygen minimum of 4 g/m^3 in the lowland reach, and is expected to be adequate in maintaining the existing aquatic ecosystem. The short duration of diurnal oxygen minima may allow a lower oxygen standard to be adopted without significant impacts on the receiving aquatic ecosystem (flow of 0.071 m^3/s required to maintain 3 g/m^3 of oxygen). Some reaches further upstream were smothered by aquatic plants, and experienced low oxygen conditions as a result (e.g., Barnaby Road). Further investigation may be required to determine flow requirements for these reaches, or other management options explored to provide for aquatic ecosystems.

Table 1: Summary of flow requirements (m^3/s) for various issues in the lowland reach of the Whakapipi Stream. Flow statistics are also presented (MALF is the 7-day mean annual low flow; Q_5 is 1 in 5 year 7-day low flow). All flows are as measured at the State Highway 22 recorder.

Flow requirement for;	Lowland reach
Fish habitat	0.050[A] m^3/s
Invertebrate habitat	0.084[B] m^3/s
3 g/m^3 dissolved oxygen	0.071 m^3/s
4 g/m^3 dissolved oxygen	0.083 m^3/s
MALF	0.12 m^3/s
Q_5	0.085 m^3/s

A. Flow required to maintain 85% of habitat available at MALF for common smelt.

B. Flow required to maintain 85% of riffle habitat available at MALF over the bedrock section.

1. Introduction

1.1 Study brief

Avoiding adverse ecological effects when allocating water requires information on the flow requirements of aquatic ecosystems. The purpose of this report is to assess the minimum flow requirements for aquatic ecosystems inhabiting the Whakapipi Stream.

Issues that need consideration include fish and invertebrate habitat, water temperature, oxygen and contaminants. The relative importance of each of these issues was expected to vary between reaches within a catchment. Determining minimum flows for every reach potentially affected by abstraction is not practical, so the focus turns to reaches containing the highest instream values and that are most likely to limit water allocation. Water quality and the habitat of fish and invertebrates in the lower reaches were investigated as likely critical issues.

1.2 Background on the Whakapipi Stream

The Whakapipi and its tributaries flow from the Bombay Hills (Figure 1.1), before crossing a flat area and discharging to the Waikato River (Figure 1.2). The stepped profile of the stream is a product of bedrock control-points. These control points produce bedrock cascades and falls (Figures 1.3 and 1.4) and flatter slow-flowing sections upstream (Figure 1.5). Sections with an intermediate gradient produce run habitat (Figure 1.6). Riparian vegetation is variable, with open slower-flowing sections supporting a higher biomass of aquatic plants.

The Whakapipi Stream has been the focus of detailed research. NIWA, often in partnership with Environment Waikato, studied the lowland reach focusing on the interaction between aquatic plants and dissolved oxygen (Champion & Tanner 2004, Collier et al. 1999, Collier et al. 1998, Wilcock et al. 1999, Wilcock & Croker 2004, Wilcock & Nagels 2001, Wilcock et al. 1998).

Environment Waikato have a continuous flow recorder on the Whakapipi Stream at State Highway 22 (Table 1.1). Abstraction pressure on the Whakapipi Stream (and associated groundwater resources) is high, because the catchment is one of New Zealand's most intensive market gardening areas.

Auckland Regional Council have studied neighbouring catchments that drain equivalent land-use and geology (Franklin Volcanics), to determine minimum flow requirements for aquatic ecosystems (pers. comm. Jonathon Moores (NIWA), Stephen Crane (ARC), Phil White (ARC)). Most of this research has focussed on dissolved oxygen as a critical issue for water allocation.

Table 1.1: Natural flow estimates (m^3/s) for the Whakapipi Stream at State Highway 22. Environment Waikato operate a continuous flow recorder and weir at this site. Flow statistics were calculated by Environment Waikato, based on the data from 1984 to 2007. Q_5 is the one in five-year 7-day low flow; MALF is the 7-day mean annual low flow.

Stream	Q_5	MALF	Median flow
Whakapipi at SH22	0.085 m^3/s	0.12 m^3/s	0.47 m^3/s

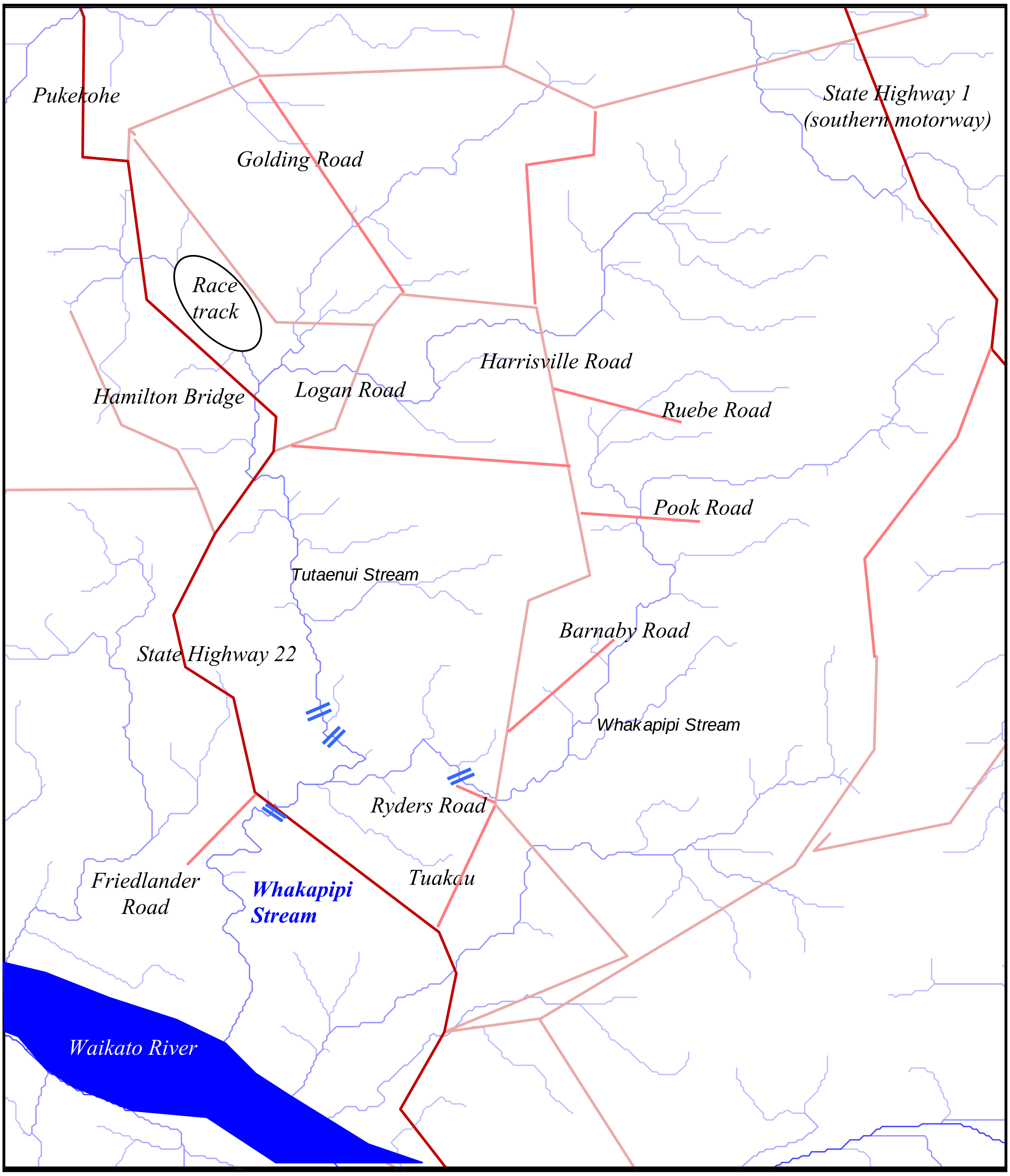


Figure 1.1: Whakapipi catchment, showing the stream and landmarks referred to in the text (line map produced using the Fish Database Assistant). Known waterfalls and cascades are marked as double blue lines, and urban areas are shaded.

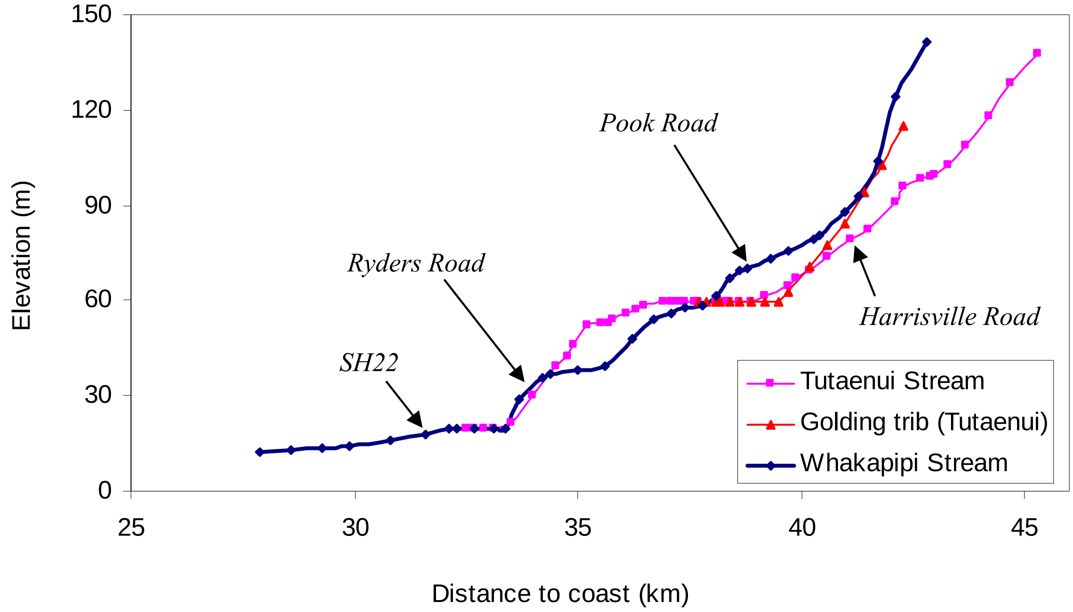


Figure 1.2: Elevation and distance to the coast (from the Fish Database Assistant, using REC data) are plotted to produce a profile for the Whakapipi and two tributaries (Tutaenui Stream and Golding Rd tributary). The point closest to the sea represents the confluence with the Waikato River.

Figure 1.3: Whakapipi Stream beside Ryders Road (Tuakau). This 5 m waterfall is at the base of a short bedrock section (flood flows, 2/07/2007). Grid-reference E2682840 N6436710.

Figure 1.4: Tutaenui Stream drops over these falls (approximately 3.5 m high) 2.4 km upstream of State Highway 22 (grid-refn. E2681523 N6437313). A second waterfall, located 500 m downstream, is 1.5 m in height. (Pictured 2/07/2007 during flood flows).

Figure 1.5: Whakapipi Stream beside Ryders Road (Tuakau). This deep and sluggish section is located just above a bedrock control point (Figure 1.3).

Figure 1.6: Whakapipi Stream at Barnaby Road. Sections of the stream with an intermediate gradient form runs with sandy substrate (occasional gravel and cobble). This photo was taken in October and, by March, this section of stream was smothered by emergent plants (water celery).

1.3 Framework for determining minimum 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 (cf. damming or diversion), so only implements the components of the MfE framework that are relevant to this task.

The Proposed Waikato Regional Plan offers guidance for identifying instream values and objectives (August 2005 version of policy was reviewed, and March 2002 classification maps). 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 Whakapipi Stream is classified as Surface Water and no tributaries have a higher classification (presumably reflecting the highly developed state of the catchment).

The Surface Water Class includes policy to avoid, remedy or mitigate any significant adverse effects on existing aquatic ecosystems (Section 3.2.3 Policy 4). The surface water objectives are less protective than other classes, and focus more on avoiding direct effects on the ecosystem rather than maintaining the habitat of ecosystems (as for Fishery Class streams).

Following the MfE flow guidelines (MfE 1998), the next step is to identify potentially critical issues for each study stream. The issues that are most likely to be critical are expected to vary with stream type. The Whakapipi has no major in-stream impoundments, so the magnitude of flood flows are not assessed in this report. Issues relating to flow regime requirements (flushing flows etc.) are therefore not considered here. The mouth of the Waikato River is not closed-off from the sea by sand or gravel accumulation, so access for fish (e.g., whitebait) from the sea is not expected to be a critical issue for setting minimum flows. Providing adequate habitat conditions for native fish is expected to require greater flows compared to fish passage and migration. Inanga (whitebait) spawning may occur in the lower reaches of the Whakapipi, but spawning is not expected to be affected by low flows, as fish spawn on areas inundated by spring tides (i.e., area determined by tide height rather than stream flows). Flow requirements for native fish habitat and water quality are likely to be significant. With generally low ammonia concentrations (median for 2002-06 was 0.02 g/m^3 NH_4-N, (Beard 2007)), oxygen is the water quality parameter of greatest concern. Flow requirements for the habitat of stream invertebrates is also a potentially issue in determining flow requirements. The sites selected and methods used to assess likely critical issues for the Whakapipi Stream are described in Section 2.

1.4 Introduction to Instream Habitat Modelling

1.4.1 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 flow assessment using habitat methods is to provide or retain a suitable physical environment for aquatic organisms. The consequences of loss of habitat are well known; 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; Biggs 1996; Jowett 1997; MfE 1998).

1.4.2 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°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, 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, species of native fish are found in similar habitats over a wide range of rivers. In New Zealand, a quantitative approach was taken to develop general habitat suitability criteria for a species using data collected from multiple rivers. To date, general habitat suitability curves have been developed for many native fish species (e.g., Figure 1.7), some of it published (e.g., Jowett & Richardson 1995; McCullough 1998) and some of it unpublished.

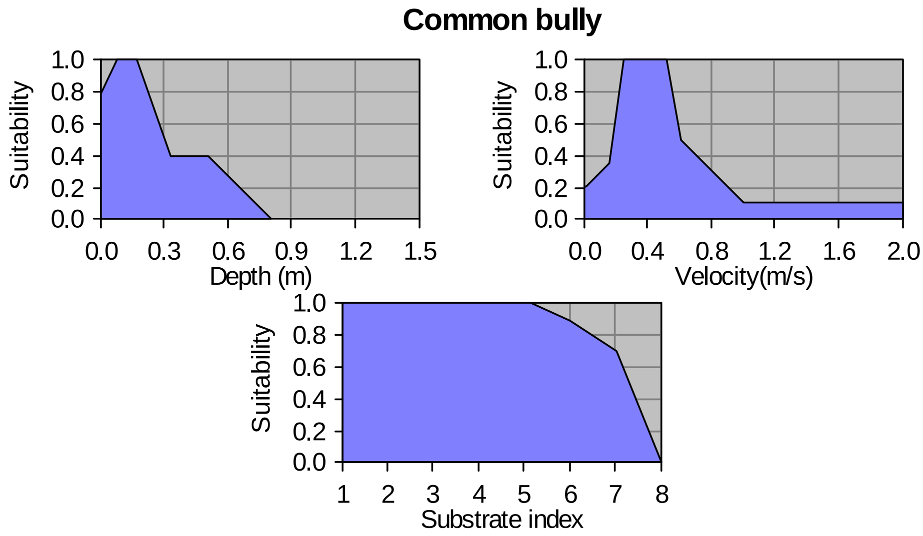


Figure 1.7: Habitat suitability curves for common bully, where suitability ranges from 0 (unsuitable) to 1 (optimal). Substrate index: 1=vegetation, 2=silt, 3=sand, 4=fine gravel, 5=gravel, 6=cobble, 7=boulder, 8=bedrock (Jowett & Richardson 1995).

1.4.3 Procedure for Calculating Instream Habitat

The procedure for an instream habitat analysis is to select appropriate habitat suitability curves or criteria (e.g., Figure 1.7). 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 1.8. 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. HSI (average habitat suitability index) is the percentage of suitable habitat within the wetted area. Both WUA (m^2/m) and HSI 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 over a range of flows 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.

1.4.4 Assessing Minimum Flow Requirements

There are two decisions to be made when assessing minimum flow requirements based on habitat modelling results; firstly, which species to assess, 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 the 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). Setting a minimum flow requirement at the point that provides maximum habitat for fish 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. However, a clear inflection point is not always present.

Environment Bay of Plenty developed a more prescriptive approach, leaving less to observer interpretation. This approach prescribed a percentage of habitat (termed the habitat protection level) that was 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 are 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). A given disturbance regime (frequency and severity of floods and drought) will also favour specific fish and riparian communities, and a greater impact of invasive species on native fish can sometimes be attributed to altered flow regimes (Moyle & Light 1996; Olden et al. 2006). These flow regime issues 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).

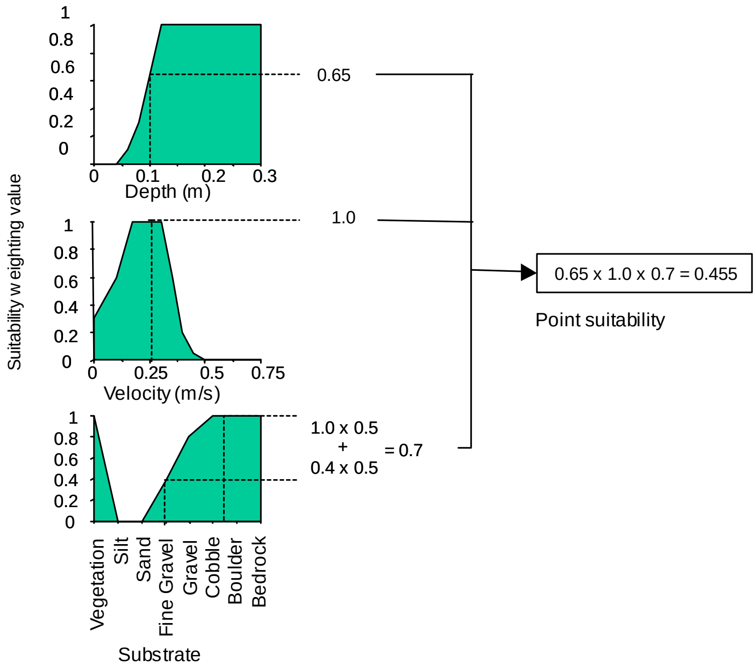


Figure 1.8: Calculation of habitat suitability for a fish species at a point with a depth of 0.1 m, velocity of 0.25 m/s, and substrate comprising 50% fine gravel and 50% cobble. The individual suitability weighting values for depth (0.65), velocity (1.0), and substrate (0.7) are multiplied together to give a combined point suitability of 0.455.

2. Methods

2.1 Selection of sites and methods

Several options were considered to assess minimum flow requirements for aquatic ecosystems of the Whakapipi Stream. The selected approach focuses on the lowland area of the Whakapipi Stream as the critical reach. This reach extends upstream of the Waikato River confluence (Figure 1.1 and 2.1). Fish diversity and abundance was expected to be higher in the lowland reach, compared to further upstream, because of potential barriers for migrant fish (cascade and weir at State Highway 22 (Figure 2.2) and falls further upstream (Figures 1.3 and 1.6)). NZFFD records (New Zealand Freshwater Fish Database) indicate that eels and some common bully were caught at sites upstream of State Highway 22. By comparison, very high numbers of inanga were caught below State Highway 22 (Ian Jowett, pers. comm.), and common smelt and torrentfish were only recorded below State Highway 22 (NZFFD). A habitat survey was therefore carried out in the lowland reach of the Whakapipi Stream.

The lowland reach of the Whakapipi Stream provides sluggish run and pool habitat, and supports prolific plant growth during summer and autumn (Figure 2.3). Part of the lowland reach is tidally influenced (Figure 2.4), with some channel realignment and stop-banking over this section (Figure 2.1). The lowland reach refers to the section of stream between the Waikato River confluence and the bedrock section below State Highway 22 bridge. The bedrock section extends a few hundred metres downstream of the bridge, forming cascades, riffles and runs (Figure 2.5). Habitat was also surveyed over the bedrock section.

Dissolved oxygen was expected to be critical in the low-gradient reaches that have prolific growth of aquatic-plants. The lowland reach has the greatest length of flat-gradient stream (Figure 1.2) with little shade, compared to reaches upstream of State Highway 22. Modelling of dissolved oxygen was therefore carried out for the lowland reach to determine flow requirements.

Dissolved oxygen was also monitored in low-gradient reaches further upstream, to confirm that dissolved oxygen concentrations are higher than in the lowland reach. These extra sites were monitored concurrently with the lowland reach to enable direct comparison (using loggers and/or spot-measurements).

The technical assessment methods chosen to investigate the effects of reduced flows on aquatic ecosystems were WAIORA for oxygen modelling and RHYHABSIM for habitat modelling. The methods used are further described below and in Section 2.

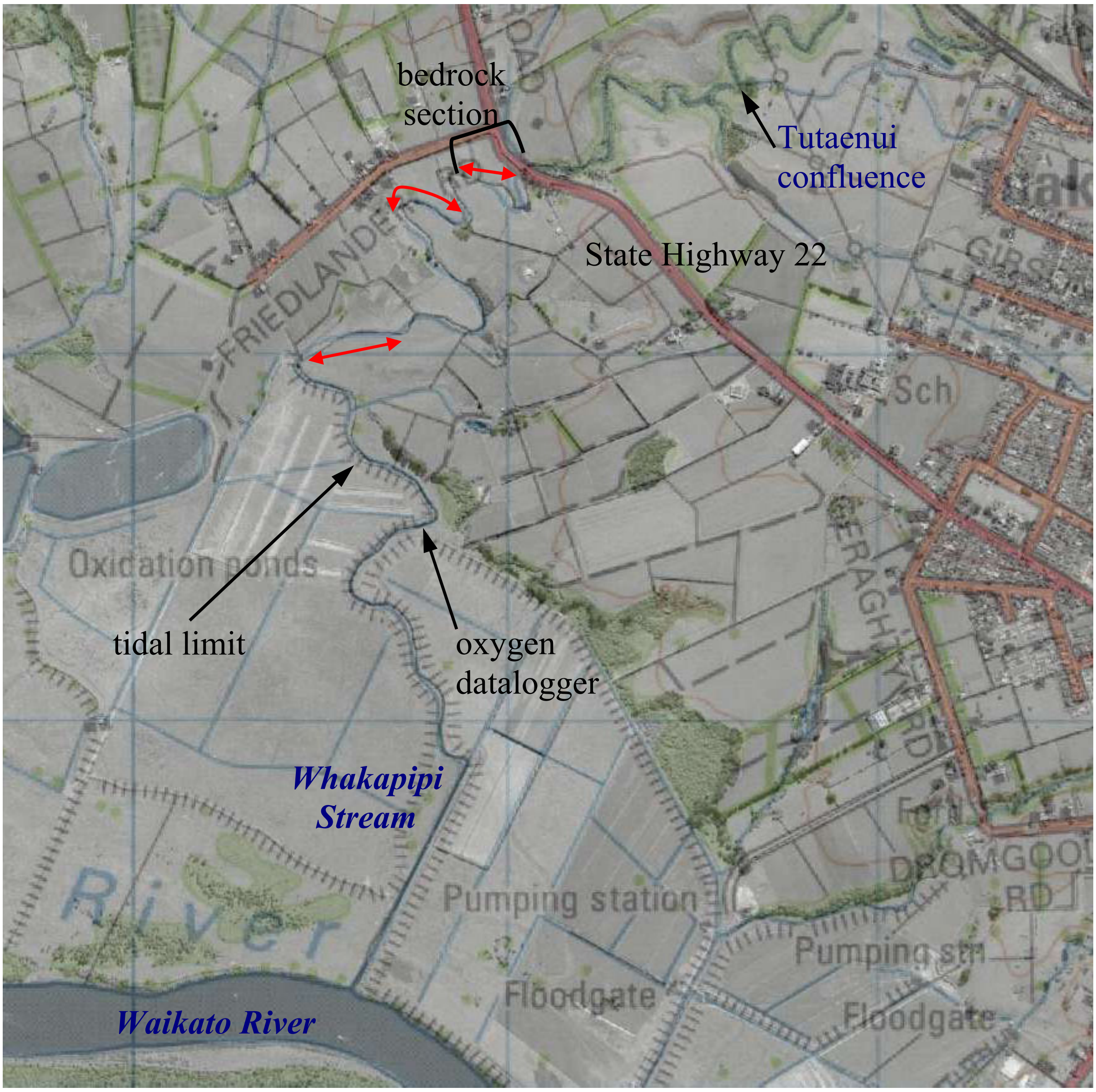


Figure 2.1: The lower Whakapipi Stream, between the Tutaenui confluence and the Waikato River. Habitat was surveyed at 15 cross-sections, with three groups of 5 cross-sections indicated by red arrows on the map. Oxygen was monitored at the site indicated and the tidal limit was also assessed. Flood control stop-banks are indicated by hatching. Note that the oxidation ponds do not discharge to the Whakapipi Stream. The aerial photo and topomap overlay were sourced from Maptoaster software.

Figure 2.2: A weir was installed to improve the accuracy of the flow recorder at State Highway 22. The entire flow passes over the V-notch metal weir at lower flows (upper picture view upstream 17/1/2007, flow 0.27 m^3/s), with higher flows spilling over the full width of the concrete-lip (middle picture looking downstream 26/10/2006, flow 1.02 m^3/s, lower picture 2/07/2007 flow 5.4 m^3/s).

Figure 2.3: The lowland reach of the Whakapipi Stream. This photo was taken 17 January 2007.

Figure 2.4: The tidal section of the lowland reach (Whakapipi) was similar to the non-tidal section, though generally wider. This photo was taken in October 2006 - aquatic plants reached a higher biomass subsequently, during summer.

Figure 2.5: A bedrock section of riffle, cascade and run extends about 280 m downstream of the bridge at State Highway 22. Moss and periphyton formed a mat over the rock (photos taken 17 January 2007).

2.2 Fish and invertebrates

In addition to fishing the lowland reach of the Whakapipi Stream, other sites were fished to test the assumption that inland reaches are less diverse (Table 2.1). Fish inhabiting shallow areas (< 0.5 m deep) were caught by electric fishing for six reaches, with fyke-nets used at three sites (where deeper habitat was present). An EFM 300 machine (Kainga battery powered backpack set) was used to fish an area of at least 40 m^2. Fine-mesh fyke-nets (8 mm mesh, with leaders) were baited and set overnight. The New Zealand Freshwater Fish Database was searched for other records from the Whakapipi catchment.

Benthic macroinvertebrates were sampled at eight sites using a dip-net (Table 2.1), and followed standard Environment Waikato protocols (Collier and Kelly 2005). The net had a 0.3 m triangular frame and 0.5 mm mesh (tail 0.5 m long). Ten dip-net samples were composited from the range of stable substrates present at each site. Samples were preserved in isopropyl alcohol and forwarded to Stephen Moore at Landcare Research for sorting and identification (along with samples collected by Environment Waikato from regional monitoring sites). As per Environment Waikato protocol, a fixed count of 200 animals was undertaken, plus a scan for rare taxa. Environment Waikato's habitat assessment form was completed for each site.

Table 2.1: Location description for fish and invertebrate sampling sites. The Tutaenui Stream is a major tributary of the Whakapipi Stream (see map, Figure 1.1).

Stream	Site	GPS grid reference (NZMS260)	Electric fishing (area fished)	Fyke nets (number set)	Invertebrate sampling
Whakapipi	Friedlander Road	E2680432 N6435929		5	Yes
Whakapipi	SH22	E2681048 N6436448	50 m^2		
Whakapipi	Ryders Road	E2683019 N6436613		5	Yes
Whakapipi	Barnaby Road	E2684157 N6437859	45 m^2		Yes
Whakapipi	Pook Road	E2684355 N6439239		3	
Whakapipi tributary	Ruebe Road	E2684277 N6440188	50 m^2		Yes
Tutaenui	SH22	E2681181 N6439510	50 m^2		Yes
Tutaenui	Logan Road	E2681666 N6440578	40 m^2		Yes
Tutaenui	Harrisville Road	E2683583 N6440932			Yes
Tutaenui tributary	Golding Road	E2681827 N6441889	50 m^2		Yes

2.3 Instream Habitat

RHYHABSIM was used to model habitat for fish and other biota in the non-tidal section of the Whakapipi Stream, below State Highway 22 (Figure 2.1). The lowland reach was represented by 10 cross-sections (surveyed 14/2/2007). Two groups of five cross-sections were located at each end of the non-tidal lowland reach (Figure 2.1), with 50 m spacing between cross-sections. The bedrock section extends below State Highway 22, forming cascades, riffles and runs. An additional five cross-sections were located in the bedrock section (Figure 2.1), and were placed to represent the range of width, depth, and velocity characteristics present. Habitat was mapped over the bedrock section to determine the proportion of pool, riffle and run. The weighting given to each cross-section reflected the proportion of habitat it represented between State Highway Bridge and the limit of tidal influence.

For each cross-section, water velocities, depths, and substrate composition were recorded. 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 (Table 2.2) 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. The predicted velocity and depth for each point at each simulated flow was evaluated using 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 minimum flow requirements.

The rating curves generated at Step 2 were generally good, with few changes necessary. Aquatic plant growth was assumed to have affected two water-level measurements, and were deleted as outliers (deleted 0.192 m^3/s gauging for cross-section 3 rating, deleted 0.084 m^3/s gauging for cross-section 12 rating). The measured flows produced better ratings than flows calculated from the water level recorder.

Different approaches can be used to determine minimum flow requirements from the plots of habitat (WUA) against flow, as discussed in Section 1.4.4. Several approaches are presented for this study. The flow that provided maximum habitat and the flow at which habitat began to reduce sharply (inflection point) were 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 mean annual low flow (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. Habitat protection levels are scaled according to population/ecosystem significance (Appendix 1). (Environment Bay of Plenty's Criteria 5 (85%) is relevant to the species observed in the Whakapipi).

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

Table 2.2: Flow measurements from the Whakapipi Stream for the habitat survey. Flows were measured above the weir at State Highway 22 (* habitat survey). Weed and debris were cleared from the weir prior to gauging.

Date & time (NZST)	Flow	Stage (water level at recorder tower)
17 Jan 2007 12:15pm	0.192 m^3/s	8.020 m
14 Feb 2007 14:25*	0.103 m^3/s	8.005 m
12 Mar 2007 07:35	0.084 m^3/s	7.994 m

2.4 Dissolved Oxygen

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 deployed in two reaches to monitor oxygen and temperature. In addition, oxygen measurements were recorded in the morning to determine if other sites in the catchment experienced low oxygen conditions.

A Hydrolab minisonde was deployed in the tidal reach below State Highway 22 for the period 2 March to 12 March 2007. This measured dissolved oxygen (using a Clark Cell membrane with stirrer), temperature, conductivity and pH every 30 minutes A second logger was deployed at Hamilton Bridge on the Tutaenui Stream for the same period, measuring dissolved oxygen and temperature every 10 minutes (RBR TDO-2050, which uses an Oxyguard membrane-covered galvanic cell). The RBR logger measured percent dissolved oxygen, and the Benson-Krause formula (Benson and Krause 1984) was used to convert these measurements to the concentration of dissolved oxygen, based on temperature.

Calibration was checked in the lab (oxygen and pH) prior to deployment for all loggers, with membranes and solute replaced as needed. Dissolved oxygen was measured at the time of recovery to determine any calibration drift. Loggers were deployed in January, as this is typically when stream temperatures are high and oxygen low. The continuous flow recorder at State Highway 22 provided flow information for the monitoring period. Loggers were attached to a waratah placed in a flowing part of the stream.

The effect of flow on 24-hour minimum dissolved oxygen was modelled using WAIORA (Version 2.0, Hill & Jowett 2004). Parameters were derived from the monitoring data to calibrate the model, including 24-hour average dissolved oxygen concentration, 24-hour range of oxygen, oxygen lag (time between solar noon and oxygen maximum) and average temperature.

2.5 Tide and Aquatic Plant Survey

It was important to know the extent of tidal influence for the study sites. Habitat surveys of tidal reaches were avoided because the habitat model (RHYHABSIM) is based on the relationship between flow and depth, which is broken by tidal fluctuations. Tidal extent was also important for the dissolved oxygen monitoring. The tidal section was targeted for oxygen monitoring because of the higher risk of oxygen suppression here (see Wilding 2007).

For the tide survey, a total of ten wooden stakes were pushed into the stream bed prior to high tide. These were spaced every 200 m or so, over the reach bordered by the stop bank (see Appendix 3 for locations). A floating PVC tube was dropped over the stake and fine bark shavings deposited into the tube (Figure 2.6). These shavings left a water mark on the stake at the high tide water level. By returning at the next low tide, the distance from the water level to the water mark could be measured as the tidal range. The tidal limit was narrowed down to a section of stream between monitoring points, which is indicated on Figure 2.1. Tide height varies with time-scale (e.g., spring tides, storm surges), and the survey was intended to give a typical tidal range, rather than a maximum.

Aquatic plants were surveyed as they can be responsible for dissolved oxygen suppression at night-time. Percent-cover of plants was recorded at each habitat survey cross-section, and species composition noted for each reach.

Figure 2.6: The change in water level between high and low tide was measured using bark shavings to leave a water mark on the stake at high tide. The PVC tube (with floats) stopped the shavings from washing away.

3. Results

3.1 Fish and invertebrates

As expected, native fish communities were more diverse and generally more abundant below State Highway 22 (Tables 3.1 and 3.2). The lowland reach supported inanga, common smelt, giant bully, longfin and shortfin eel. Schools of inanga and smelt were commonly observed. The bedrock section, closer to the State Highway 22 bridge, also supported common bully and there is one record of torrentfish.

The bedrock cascade and weir at State Highway 22 may present a barrier to less capable migrant fish. A 5 m high waterfall at Ryders Road (Figures 1.1 and 1.3) would be a barrier to all but the most capable climbers (e.g., eels, kokopu). The Tutaenui Stream also has falls (2.5 km upstream of weir) posing a likely barrier for some species (Figure 1.4). Densities of shortfin eel were relatively high at sites upstream of State Highway 22 (Table 3.1 and 3.2), but other species were less commonly encountered. Three species of bully were observed upstream of the State Highway in low numbers. Of these, redfin bully are diadromous (require sea access), while common and Cran's bully are able to maintain landlocked populations. Including previous records from the New Zealand Freshwater Fish Database, only common bully were encountered at more than one site. Koura (freshwater crayfish) were caught at several inland sites and one was collected in the lowland reach with invertebrate samples (Appendix 4).

Introduced species of fish are widespread in the catchment, including goldfish (*Carassius auratus*) and *Gambusia* (mosquito fish). The biomass of koi (*Cyprinus carpio*) was conspicuous in the lowland reach, with 54 large koi observed (from the bank) over a 1500 m length of stream. There is one record of an unidentified trout from Logan Road, and landowners commented on seeing trout in the tidal reach. It is assumed the Whakapipi Stream does not support a recreational trout fishery.

Stream invertebrates were sampled from various stable substrates at eight sites (Appendix 4). Invertebrate communities at most sites were dominated by pollution tolerant taxa, as indicated by low SB-MCI scores (range from 66 to 83) and %EPT less than 10% (Appendix 4). The snail *Potamopyrgus* was the dominant taxon at most sites, but a surprising exception was the lowland reach where snail numbers were very low. Instead, the lowland reach had a higher proportion of amphipods, Chironomidae and purse caddis (*Oxyethira*). The mayfly *Zephlebia* was encountered at the three sites with higher MCI scores. Normally common in lowland streams, the shrimp *Paratya* was conspicuous by its absence from all sites. Koi carp feed on benthic invertebrates, and may have something to do with the lack of snails and shrimps. Very few caddisflies (Order Trichoptera) were observed, except for piercing/sucking taxa that are normally associated with aquatic plants (*Oxyethira* and *Paroxyethira*).

Table 3.1: Fish caught on 3/04/2007 at sites fished on the Whakapipi Stream (for Tutaenui results see Table 3.2). Electric fishing (EF) was used at shallow sites and fyke-nets at deep sites (see Table 2.1 for fishing effort). In addition to those caught, other fauna observed during the study are marked 'obs.' and species recorded in the New Zealand Freshwater Fish Database at that site are marked 'NZFFD'. Other species expected to occur, but not caught are indicated ('E'), as well as those species that are less likely to be resident at each site ('?').

Site:	**Lowland reach**	**SH22 bedrock**	**Ryders Road**	**Barnaby Road**	**Pook Road**	**Ruebe Road**
Method:	Fyke	EF	Fyke	EF	Fyke	EF
Altitude:	0 m	10 m	35 m	55 m	70 m	85 m
Longfin eel	18	14	9			
Shortfin eel	17	1	1	10	4	7
Unident. eel		66				
Giant bully	3					
Common bully		9	NZFFD			
Cran's bully			1			
Torrentfish		NZFFD				
Common smelt	4	49				
Inanga	15	2				
Gambusia (intro.)	E	NZFFD	NZFFD		15	
Goldfish (intro.)	1		1			
Koi carp (intro.)	Obs.					
Trout (intro.)	?					3
Koura (crayfish)						3

Table 3.2: Fish caught on 3/04/2007 at sites fished on the Tutaenui Stream (for Whakapipi results see Table 3.1). Electric fishing (EF) was used at shallow sites and fyke-nets at deep sites (see Table 2.1 for fishing effort). In addition to those caught, other fauna observed during the study are marked 'obs.' and species recorded in the New Zealand Freshwater Fish Database at that site are marked 'NZFFD'. Other species expected to occur, but not caught are indicated ('E'), as well as those species that are less likely to be resident at each site ('?').

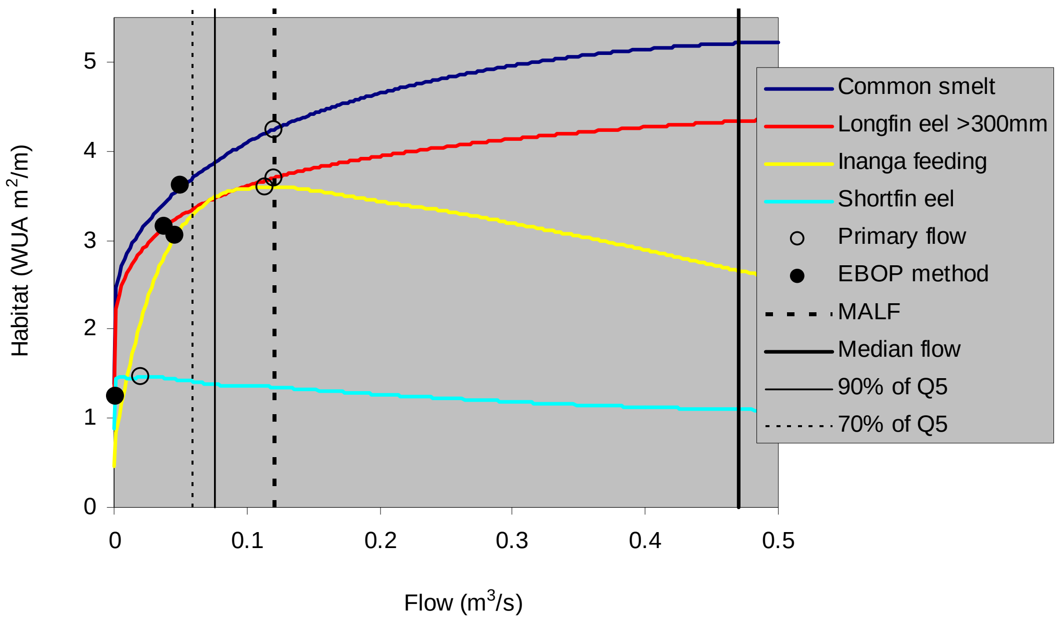
Site:	**SH22**	**Logan Road**	**Golding Road**	**Harrisville Road**
Method:	EF	EF	EF	EF
Altitude:	55 m	60 m	60 m	80 m
Longfin eel	1			
Shortfin eel	10	7	80	NZFFD
Unident. eel	2			
Common bully		NZFFD		NZFFD
Redfin bully		1		
Gambusia (intro.)				NZFFD
Trout (intro.)		NZFFD		
Koura (crayfish)	NZFFD	common		

3.2 Instream Habitat

Fish habitat was modelled for those species observed or expected to be present in the lowland reach and bedrock section. Those species less likely to occur are also presented for reference only. Base flows (MALF) provide maximum or near-maximum habitat for most species except rainbow trout and torrentfish (Figure 3.1). The short length of stream providing habitat for torrentfish does limit the potential benefit of this flow to a small number of fish. Given the short length of riffle and run habitat (excluding pools, the bedrock section is 190 m long) and the small proportion of weighted usable area over this section (0.037 m^2/m), the estimated total area of suitable habitat for torrentfish is only 7 m^2. This would explain why only one of the three electric fishing surveys of this bedrock section caught torrentfish (from two previous records on the New Zealand Freshwater Fish Database, in addition to fishing for this study). It is therefore more defensible to base the minimum flow on common smelt – one of the most common species in the lowland reach, which requires a flow of 0.050 m^3/s to maintain 85% of habitat at MALF. If including torrentfish as a resident population, the Environment Bay of Plenty method produces a minimum flow for the lowland reach of 0.086 m^3/s (Table 3.3). Points of inflection were derived for those species displaying a clear breakpoint, as opposed to a gradual reduction in habitat with flow (Table 3.3).

A minimum flow based on torrentfish or common smelt is expected to provide adequate flow for fish passage over the shallow bedrock section. At 0.050 m^3/s the average depth of the shallowest cross-section surveyed would be 0.07 m and average velocity 0.17 m/s, which whitebait and elvers could navigate (stream width predicted to be both <0.3 m/s and >0.05 m deep at a flow of 0.05 m^3/s is 1.2 m). Fish passage to the upper catchment is likely to be restricted by barriers, and reduced flows are not expected to be a constraining factor.

In providing for macroinvertebrates, the bedrock section requires a flow of 0.084 m^3/s to maintain 85% of the riffle habitat available at MALF (Table 3.3, Appendix 5). The RHYHABSIM model predicts negligible riffle or run habitat downstream of the bedrock section (< 0.1% at MALF), so a flow requirement was not calculated (invertebrates here are expected to be slow- or still-water species). In addition, invertebrate species habitat criteria were not considered applicable to streams of this type and size (criteria developed from large gravel-bed rivers).



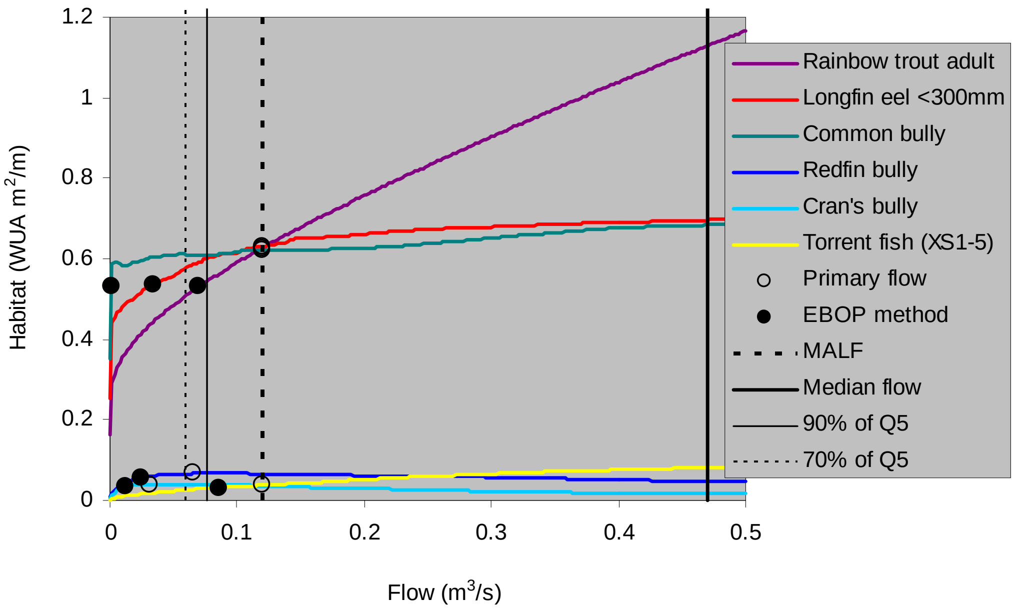


Figure 3.1: The change in habitat with flow for various species and life stages of fish in the lowland reach of the Whakapipi Stream (two graphs are used to allow presentation of each species on an appropriate scale). Using the Environment bay of Plenty method, the primary flow is the available-habitat value to which the habitat protection level is applied to produce the 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 suitability curves are given in Appendix 2.

Table 3.3: Results derived from the habitat-flow response data for the **Whakapipi Stream** (as plotted in Figure 3.1). 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. Habitat protection levels afforded by existing and historic allocation methods are also presented (90% & 70% of Q_5 flow, respectively). Species and life stages marked * are not expected to reside in this 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 1.1).

	Flow at max. habitat (m^3/s)	EBOP method (m^3/s)	Point of inflection (m^3/s)	Protection level at 70% of Q_5	Protection level at 90% of Q_5
(MALF 0.12 m^3/s, Q_5 0.085 m^3/s)					
Common smelt	0.57	0.050		87%	91%
Inanga	0.114	0.046	0.05	91%	97%
Longfin eel >300mm	0.85	0.038		90%	94%
Longfin eel <300mm	1.5	0.034	0.13	91%	95%
Shortfin eel	0.02	0.002		96%	94%
Common bully	0.6	0.002		98%	98%
Redfin bully	0.066	0.024	0.03	99%	100%
Torrent fish (bedrock section)	1.5	0.086		68%	78%
Cran's bully*	0.032	0.012	0.02	98%	98%
Rainbow trout adult*	>2	0.070		80%	87%
Invertebrate riffle habitat (bedrock section)	>2	0.084		73%	84%

3.3 Aquatic Plant Survey

Aquatic plants were surveyed as they can be responsible for dissolved oxygen suppression at night-time (respiration continues after photosynthesis stops). The bedrock section below State Highway 22 had a predictably low cover of plants, with an average cover of 16%. There was a relatively even mix of emergent and submerged vegetation, with some grass along the edges. Moss and periphyton formed a mat up to 20 mm thick in places, though overall coverage was less than 10%.

The lowland reach was dominated by aquatic plants, covering 83% of the channel on average. Submerged aquatic plants covered 47% of the channel, with emergent plants over 36% of the channel (normally along the edges, see Figure 2.3). In terms of species composition, *Egeria densa* was the primary submerged species, with a very minor component of *Potamogeton crispus* (<1%). Water celery (*Apium nodiflorum*) was the dominant emergent plant, with a small component (<5%) of watercress, *Polygonum persicaria* and sweet grass. Cows had access to the stream edge and the cover of water celery seemed to fluctuate from grazing pressure (stems were chewed off at water level).

Plant composition, for the other sites where oxygen was monitored, is summarised in Table 3.4 (species composition at each site is summarised in Appendix 6). This is based on a visual assessment of percent cover (24 April 2007) for all sites except the lowland reach and bedrock section, where cross-sections were surveyed (14 February 2007). Golding Road and Barnaby Road sites were blanketed in aquatic plants.

Table 3.4: Aquatic plant cover at sites in the Whakapipi catchment.

Stream	Site	Emergent plants	Submerged plants	Total
Whakapipi	lowland reach	36%	47%	83%
Whakapipi	SH22 (bedrock)	7%	7%	14%
Whakapipi	Ryders Rd	0%	35%	35%
Whakapipi	Barnaby Rd	100%	0%	100%
Whakapipi	Ruebe Rd	0%	0%	0%
Tutaenui	SH22	0%	60%	60%
Tutaenui	Hamilton Bridge	10%	25%	35%
Tutaenui	Logan Rd	20%	60%	80%
Tutaenui trib.	Golding Rd	65%	35%	100%
Tutaenui	Harrisville Rd	65%	10%	75%

3.4 Dissolved Oxygen

Dissolved oxygen was monitored in the lowland reach of the Whakapipi Stream, near the limit of tidal influence (Figure 2.1). Stream flows were very low at the time (2 to 12 March 2007), averaging 86% of Q_5. Dissolved oxygen concentrations displayed a strong diurnal fluctuation and a weak tidal effect during the biggest tides (Figure 3.2). Temperature also fluctuated between day and night (Figure 3.3). Excluding the period of higher flows and cooler temperature did not measurably affect the model output, so all data were retained. The average diurnal pattern is presented in Figure 3.4 and derived parameters in Table 3.5. The tidal effect averages out as a small dip before 16:00 (Figure 3.4), and does not affect modelling parameters.

Based on these parameters, the response of dissolved oxygen to flow was modelled using WAIORA. In calibrating to the observed conditions, the model produced a respiration rate similar to that produced by Wilcock et al. (1998) and Wilcock and Nagels (2001) for the Whakapipi Stream. The reaeration coefficient was at the lower end of the range from previous studies (2.77 d^{-1} for this study, cf. 2 to 7 d^{-1} from previous studies), reflecting the low flows during monitoring. The modelling results predict a steep decline in oxygen concentrations at flows less than MALF (Figure 3.5). The flow requirement for fish habitat (0.05 m^3/s) would fail to maintain oxygen concentrations greater than 2 g/m^3, with 83% of Q_5 (0.071 m^3/s) necessary to exceed oxygen concentrations of 3 g/m^3 (Table 3.6).

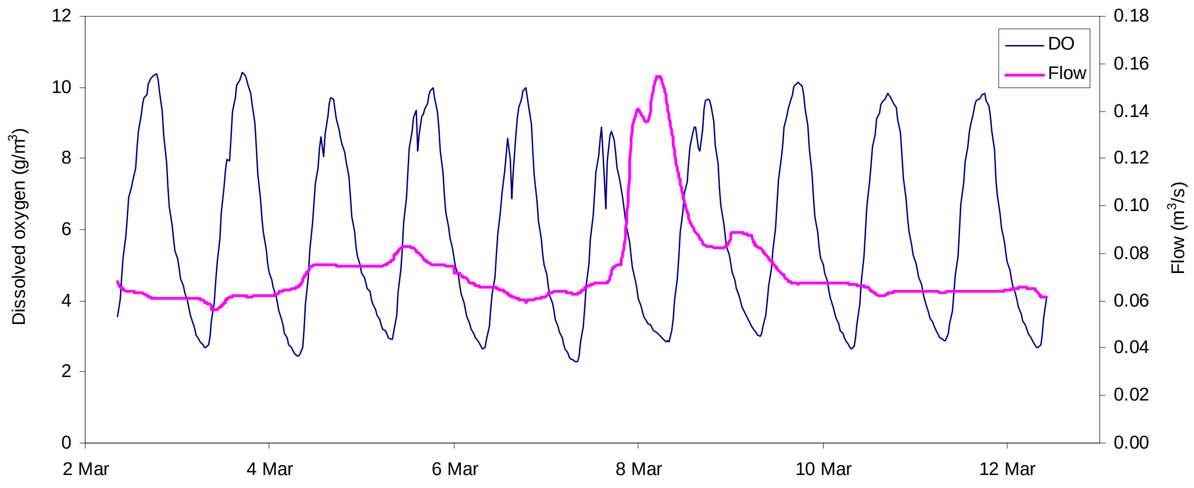


Figure 3.2: Dissolved oxygen and flow results for the Whakapipi Stream (March 2007). Dissolved oxygen was monitored in the tidal lowland reach and flow monitored by Environment Waikato at State Highway 22 (2 km upstream).

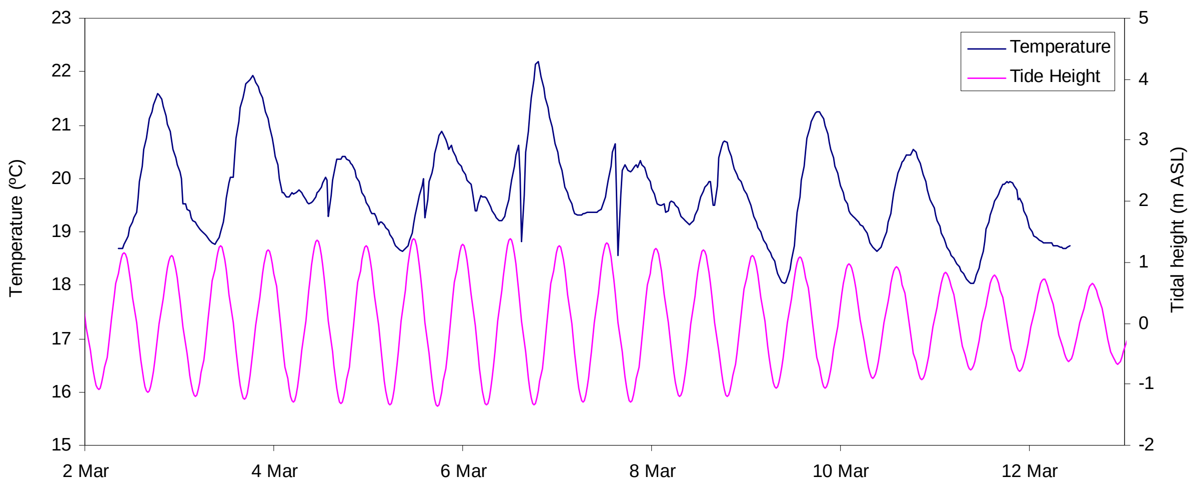


Figure 3.3: Temperature results for the tidal lowland reach of the Whakapipi Stream are plotted along with tide height at Port Waikato (tide height above mean sea level, from the NIWA tide forecaster).

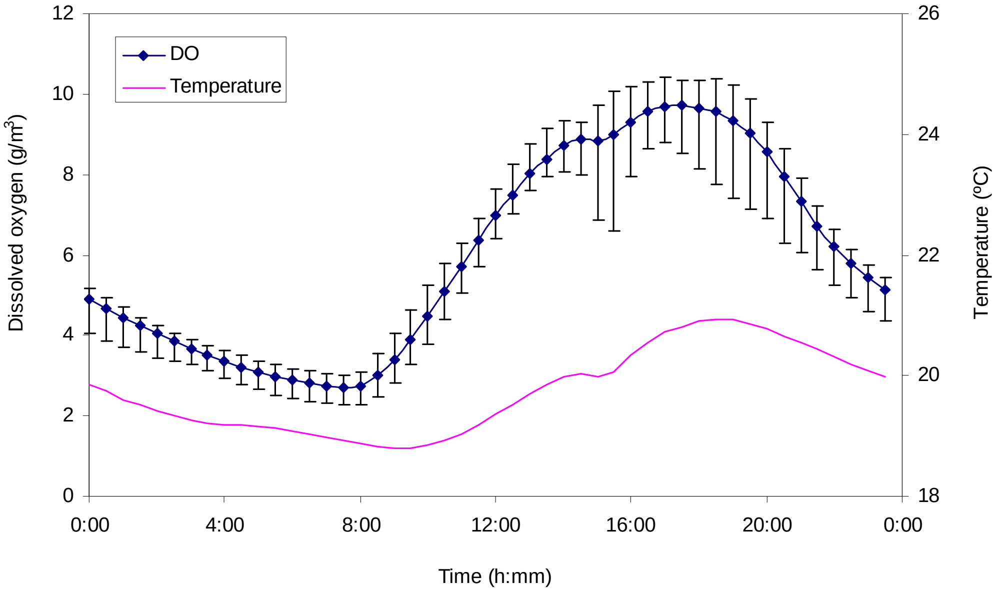


Figure 3.4: Dissolved oxygen concentrations in the upper-tidal area of the lowland reach (Whakapipi Stream). Oxygen concentrations were averaged for each time of day over the monitoring period (2 to 12 March 2007) to give the average 24-hour cycle of dissolved oxygen. Bars show the maximum and minimum for each time of day. The average temperature for each time of day is also presented (lower line). Derived parameters are presented in Table 3.5, including average flow (0.073 m^3/s).

Table 3.5: Parameters derived from the monitoring results for use in the WAIORA oxygen model. Output coefficients produced by the WAIORA model are also presented.

Parameter	Lowland	Hamilton Bridge
Average DO	6.0 g/m^3	4.2 g/m^3
Max DO	9.7 g/m^3	5.2 g/m^3
Min DO	2.7 g/m^3	3.4 g/m^3
Range DO	7.0 g/m^3	1.8 g/m^3
Time of max (h:mm)	17:20	17:20
Solar-noon lag (h:mm)	3:50	3:50
Absolute max DO	10.4 g/m^3	5.6
Absolute min DO	2.3 g/m^3	2.2
Average temperature	19.74 ºC	18.95
Monitoring period	2/3 to 12/3/2007	2/3 to 12/3/2007
Excluded data	None	None
Average flow	0.073 m^3/s	
24-hour community respiration (R_{20})	24.2 g[O_2]/m^3/day	
24-hour production/respiration ratio	0.635	
Reaeration coefficient ($K_{2(20)}$)	2.77 d^{-1}	

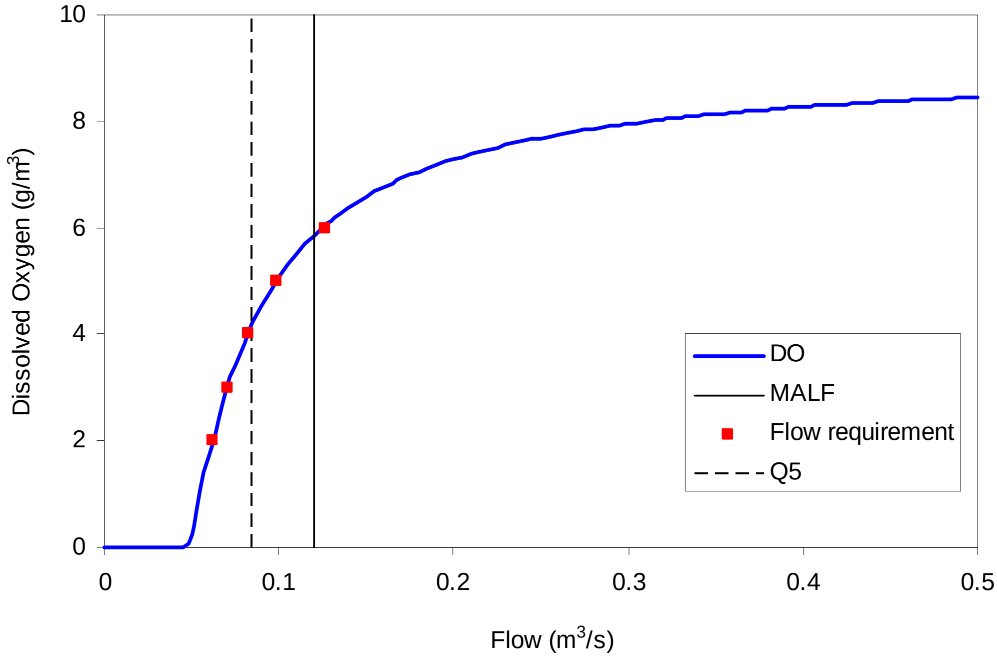


Figure 3.5: Predicted effect of reduced flow on dissolved oxygen concentrations (24-hour-minimum) for the lowland reach. The MALF (mean annual low flow) is plotted, in addition to the flow requirements for nominal oxygen thresholds (as presented in Table 3.6).

Table 3.6: Predicted flow requirements to achieve various dissolved oxygen thresholds (24-hour minimum) modelled using WAIORA. Q_5 0.085 m^3/s, MALF 0.12 m^3/s.

Dissolved oxygen threshold	Flow requirement
2 g/m^3	0.063 m^3/s
3 g/m^3	0.071 m^3/s
4 g/m^3	0.083 m^3/s
5 g/m^3	0.099 m^3/s
6 g/m^3	0.126 m^3/s

Dissolved oxygen was monitored at several other sites throughout the catchment to test the assumption that oxygen suppression would be greatest in the lowland reach. The Tutaenui Stream was monitored continuously at Hamilton Bridge (Figure 1.1) during the same period when oxygen was monitored in the lowland reach. Oxygen concentrations followed a diurnal pattern, dropping to 3.4 g/m^3 in the morning, on average (Table 3.5). This is higher than oxygen concentrations in the lowland reach for the same period (minimum 2.7 g/m^3) and the Hamilton Bridge site is therefore not a critical reach for dissolved oxygen (i.e., flow requirements are expected to be proportionately less).

Spot measurements of dissolved oxygen were taken at various sites in the Whakapipi catchment from early- to mid-morning. Most sites had similar or greater oxygen concentrations, compared to the lowland reach, and so are not expected to have greater flow requirements (Table 3.7). Dissolved oxygen concentrations at Barnaby Road were less than half that measured in the lowland reach (oxygen measured at 1.3 and 1.6 g/m^3). Emergent plants (water celery) smothered most of the channel at the time of monitoring (see Section 3.3).

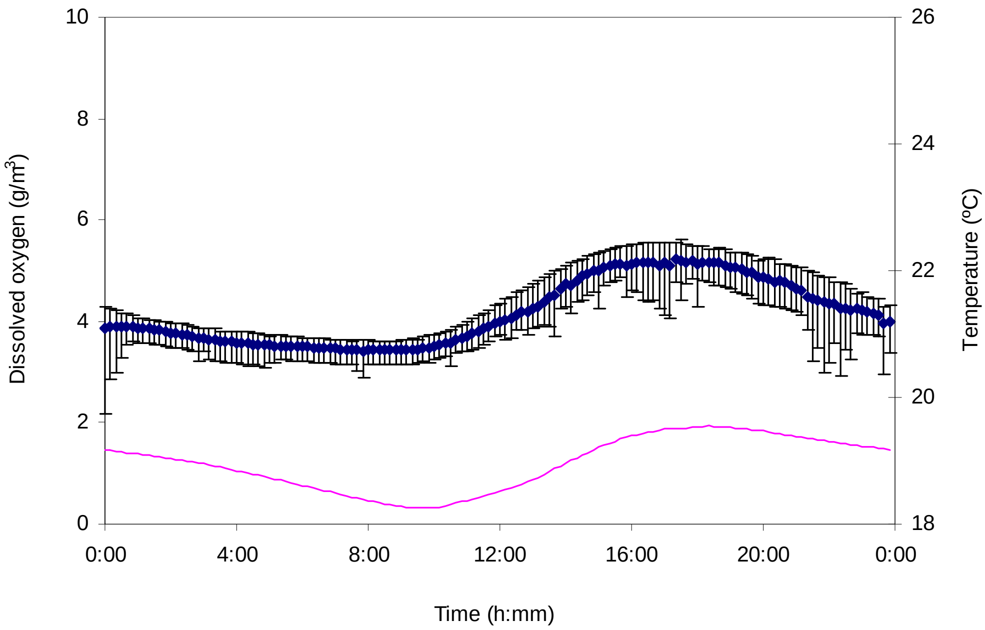


Figure 3.6: Dissolved oxygen concentrations in the Tutaenui Stream at Hamilton Bridge. Oxygen concentrations were averaged for each time of day over the monitoring period (2 to 12 March 2007) to give the average 24-hour cycle of dissolved oxygen. Bars show the maximum and minimum for each time of day. The average temperature for each time of day is also presented (lower line).

Table 3.7: Spot measurements of dissolved oxygen were recorded on two mornings at various sites in the Whakapipi catchment. Oxygen results are expressed as a percentage of oxygen concentrations in the tidal lowland reach at the same time (as measured by the data logger). The average of the two measurements is also presented. Sites with less oxygen than the lowland reach are highlighted (<100%). See Figure 1.1 for a site map.

Stream	Site	Easting	Northing	% of oxygen at lowland tidal site		
				2 March	12 March	average
Whakapipi	lowland tidal	2681025	6440511	98%	102%	100%
Whakapipi	above tide	2680455	6435967	120%	120%	120%
Whakapipi	below bedrock	2680886	6436458	196%	212%	204%
Whakapipi	above weir	2681048	6436479	138%	167%	152%
Tutaenui	SH22	2681181	6439487	121%	-	121%
Tutaenui	Hamilton Bridge	2681773	6440511	99%	155%	127%
Tutaenui	Logan Road	2680768	6440620	107%	134%	120%
Tutaenui trib.	**Golding road**	2681824	6435532	83%	84%	**84%**
Tutaenui	Harrisville Road	2683584	6440912	142%	189%	165%
Whakapipi	**Pook Road**	2684461	6439244	75%	84%	**79%**
Whakapipi	**Barnaby Road**	2684162	6437850	30%	49%	**39%**
Whakapipi	Harrisville Road	2683059	6436595	96%	158%	127%
Whakapipi	Ryders Road	2682831	6436691	165%	324%	245%

4. Discussion

The purpose of this report is to assess the minimum flow requirements for aquatic ecosystems inhabiting the Whakapipi Stream. The approach selected focuses on the lowland area of the Whakapipi Stream as the critical reach. Fish diversity and abundance is higher in the lowland reach, where fish have better access. Maintaining adequate flow for habitat is expected to have the greatest benefit here, compared to inland reaches where fewer fish have access. Invertebrate sampling did not reveal invertebrate communities of greater significance in the upper catchment. So in terms of habitat at least, it is reasonable to base flow requirements on the lower catchment.

Flow requirements for fish habitat in the lowland reach were estimated at 0.050 m^3/s, based on common smelt (Table 4.1). This species, together with inanga, shortfin and longfin eels, are expected to dominate the biomass of native fish in the lowland reach. A higher flow would be required to maintain 85% of habitat for the few torrentfish inhabiting the short bedrock section below State Highway 22 (0.086 m^3/s), or for the larger number of invertebrates inhabiting the same section (0.084 m^3/s).

Low oxygen concentrations are stressful to aquatic life (Dean & Richardson 1999) and reduced flows have the potential to exacerbate this by reducing the reaeration rate. Oxygen suppression in the lowland reach of the Whakapipi Stream is well documented from previous research (Wilcock and Nagels 2001, Wilcock et al. 1998). With a low stream-gradient and prolific aquatic plants, dissolved oxygen concentrations fluctuate widely (2.7 to 9.7 g/m^3 on average). The fluctuation is a consequence of the change from net photosynthetic oxygen production during the day to net consumption at night (from respiration). Flow requirements were calculated to achieve a range of oxygen levels in the lowland reach (Table 3.6). Setting a high standard for oxygen may represent an unreasonable expectation, given the reaches low gradient and high plant biomass. A 24-hour oxygen minimum of 3 or 4 g/m^3 is expected to maintain the existing aquatic ecosystem, and is consistent with the "Surface Water" classification of the Whakapipi in the Waikato Regional Plan (March 2002 maps). To achieve these oxygen levels requires a flow of 0.071 m^3/s to 0.083 m^3/s respectively (cf. Q_5 0.085 m^3/s).

These flow requirements are considered robust, given that oxygen monitoring was carried out at similar flows (average 0.073 m^3/s) and the modelling results are comparable to previous oxygen studies at this site (see Section 3.4). Auckland Regional Council have studied neighbouring catchments that drain equivalent land-use and geology (Franklin Volcanics), to determine minimum flow requirements for aquatic ecosystems (pers. comm. Jonathon Moores (NIWA), Stephen Crane (ARC), Phil White (ARC)). Their estimates are based on observational data, rather than predicted from modelling. Flow requirements to maintain dissolved oxygen standards above 4 g/m^3 are 75% of MALF for the lowland weedy sections (or 50% of MALF for streams with a greater spring-component). The flow requirement to maintain 4 g/m^3 in the lowland reach of the Whakapipi is comparable (69% of MALF).

Dissolved oxygen concentrations at Barnaby Road (see Figure 1.1) were a third of that measured in the lowland reach, suggesting flow requirements would be greater at this site (proportional to the natural flow). This reach was smothered by emergent vegetation (water celery), a situation that could be remedied with shade from riparian vegetation. Alternatively, additional work could be undertaken to determine the flow requirement for oxygen at Barnaby Road and other sections smothered by aquatic plants (e.g., Golding Road).

Table 4.1: Summary of flow requirements (m^3/s) for various issues in the lowland reach of the Whakapipi Stream. Flow statistics are also presented (MALF is the 7-day mean annual low flow; Q_5 is 1 in 5 year 7-day low flow). All flows are as measured at the State Highway 22 recorder.

Flow requirement for;	Lowland reach
Fish habitat	0.050^A m^3/s
Invertebrate habitat	0.084^B m^3/s
3 g/m^3 dissolved oxygen	0.071 m^3/s
4 g/m^3 dissolved oxygen	0.083 m^3/s
MALF	0.12 m^3/s
Q_5	0.085 m^3/s

A. Flow required to maintain 85% of habitat available at MALF for common smelt.

B. Flow required to maintain 85% of riffle habitat available at MALF over the bedrock section.

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

Reproduced from Wilding 2003.

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 2000). 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 5 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 5) 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.

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 Cran's 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 Cran's 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 Cran's 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, amended to reflect recent plan changes (2006).

Significance Criteria		Protection level (percentage of primary habitat)
1.	Short-jawed kokopu; giant kokopu	100%
2.	Banded kokopu; koaro; black mudfish; dwarf galaxias[1]	95%
3.	Significant trout fisheries and spawning habitat as identified in Schedule 1D [of BOP regional plan].	95%
4.	Diverse indigenous fish communities. Fish community featuring a significantly high number of native species. Constituent species that don't meet criteria in (a) or (b) are individually given this protection level.	90%
5.	Other indigenous aquatic species, migratory pathways of trout to Schedule 1D areas, and other legally established trout populations.	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, (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).

[1] 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.

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 weighted 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

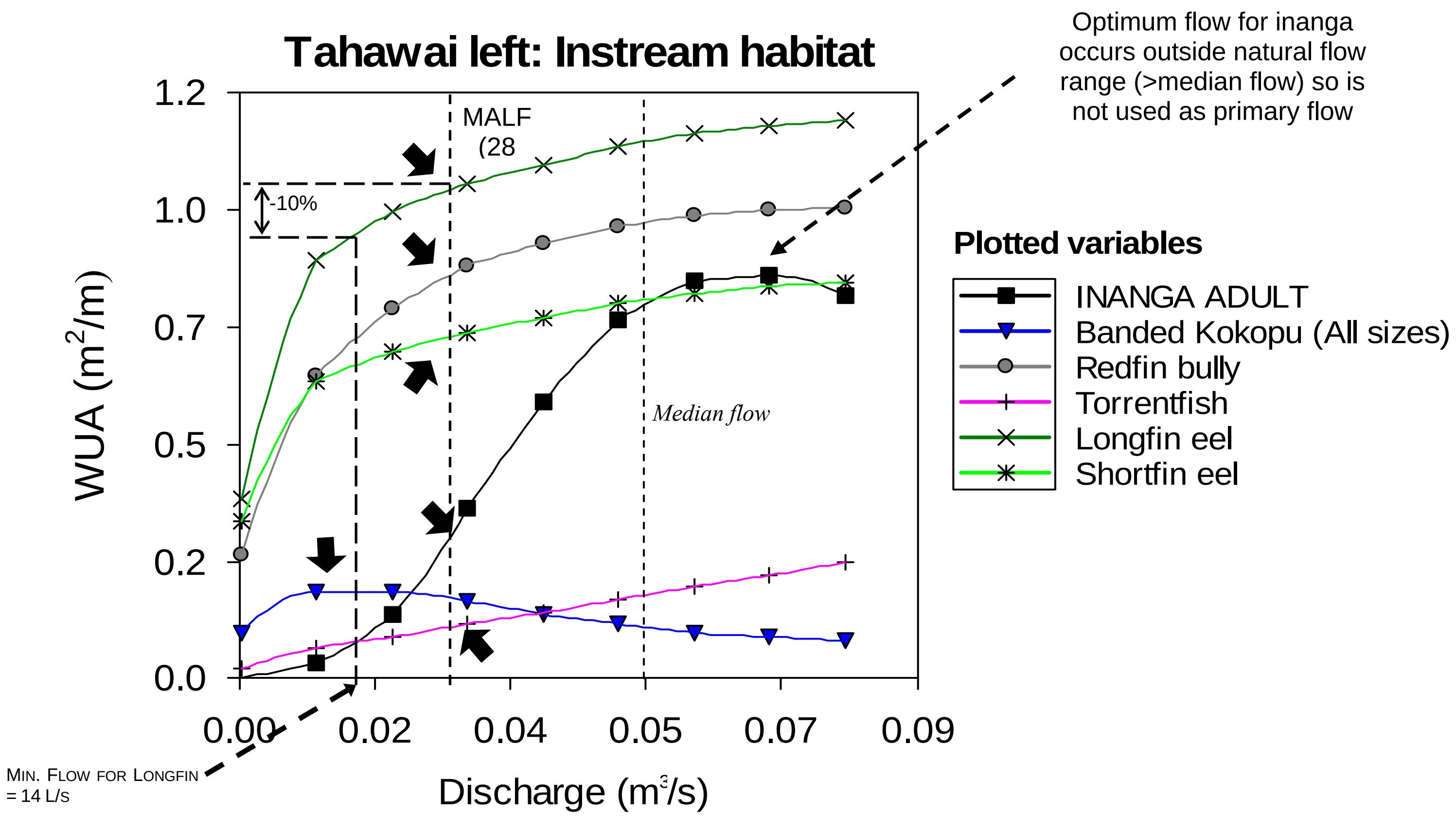
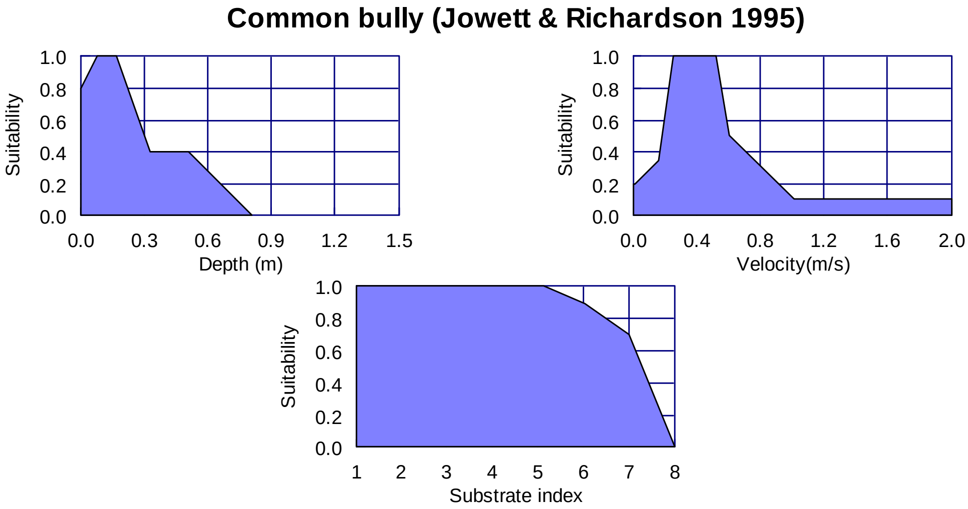
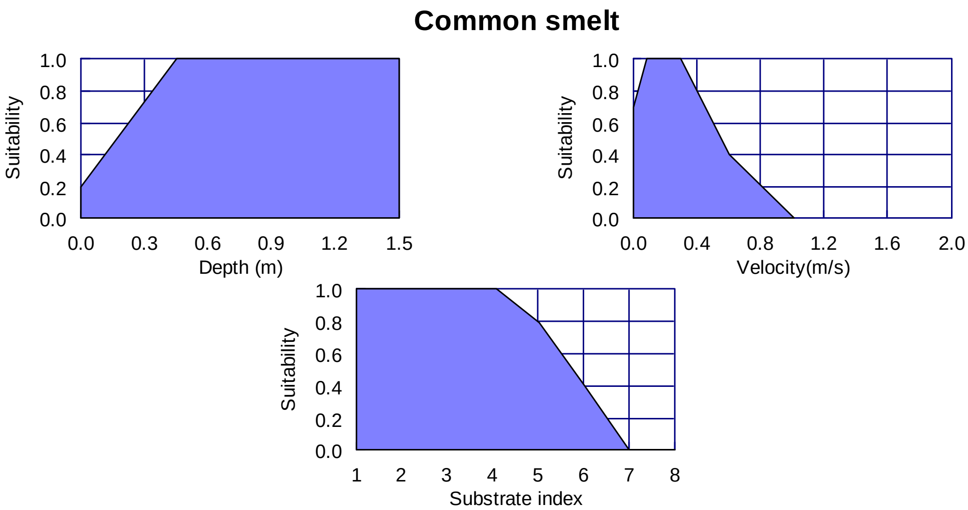


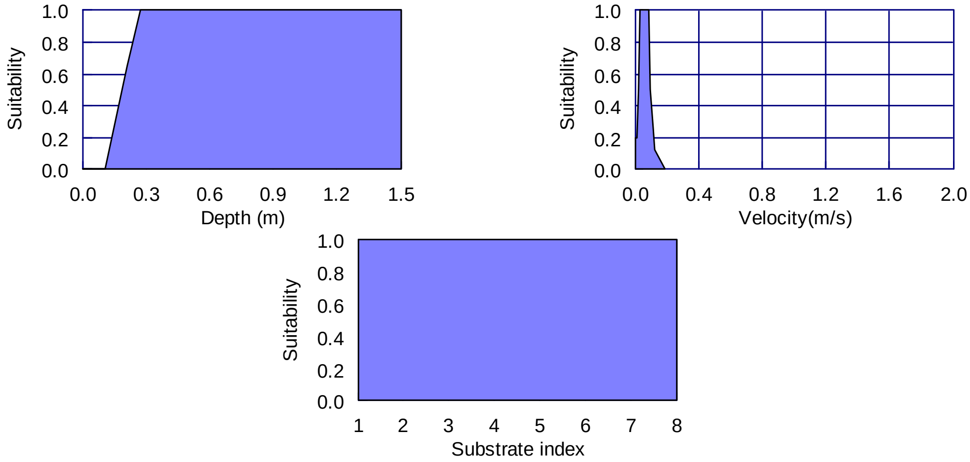
Figure 1: Modelled habitat for the Tahawai Stream (western BOP) expressed as habitat (WUA m^2/m) versus flow. Primary flows determined using established criteria are arrowed for each species. Minimum flow calculation for longfin eel illustrated. Note, this is presented as an example only, as taxa and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

8. Appendix 2 Habitat Suitability Curves

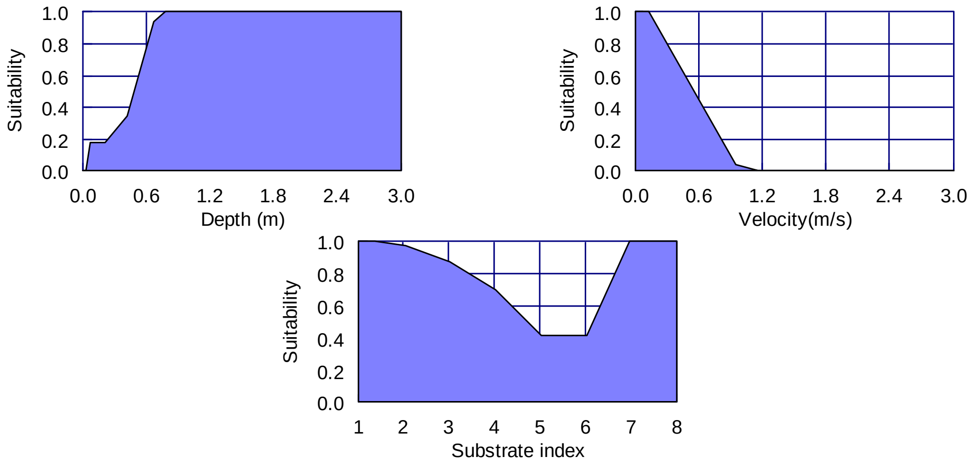




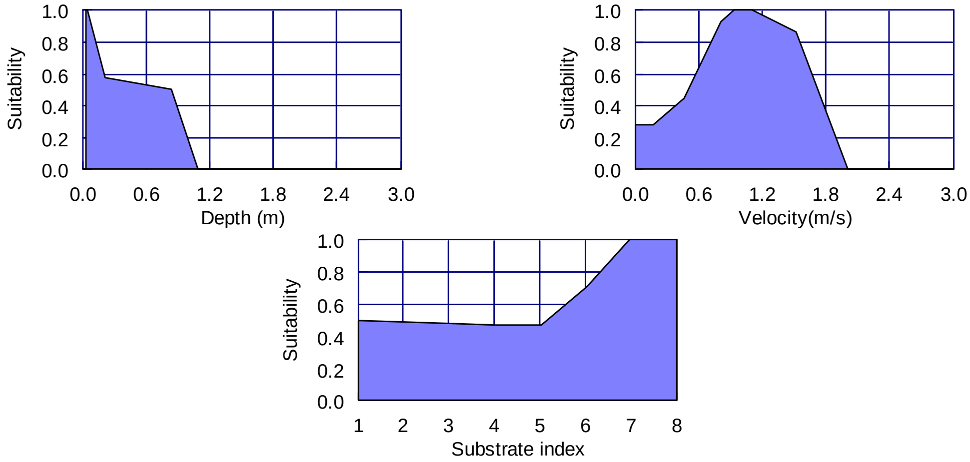
Inanga feeding (Jowett 2002)



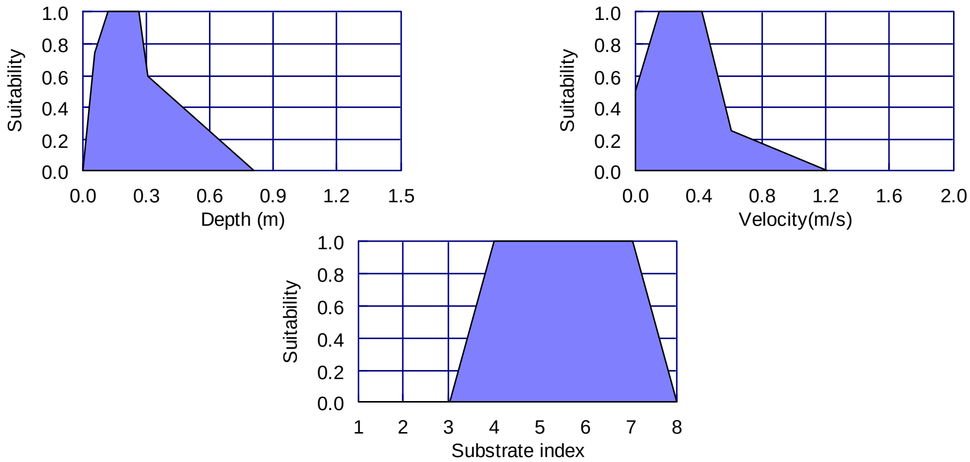
Longfin eels >300 mm (Jellyman et al. 2003)



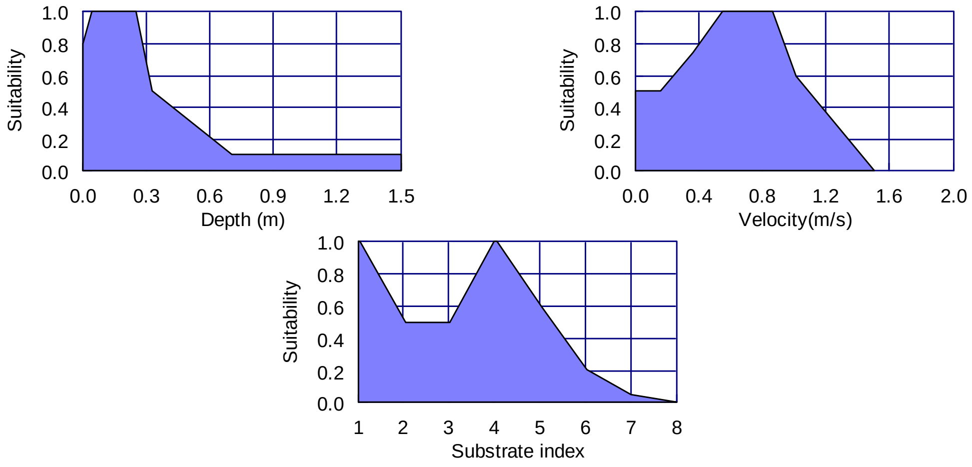
Longfin eels <300 mm (Jellyman et al. 2003)



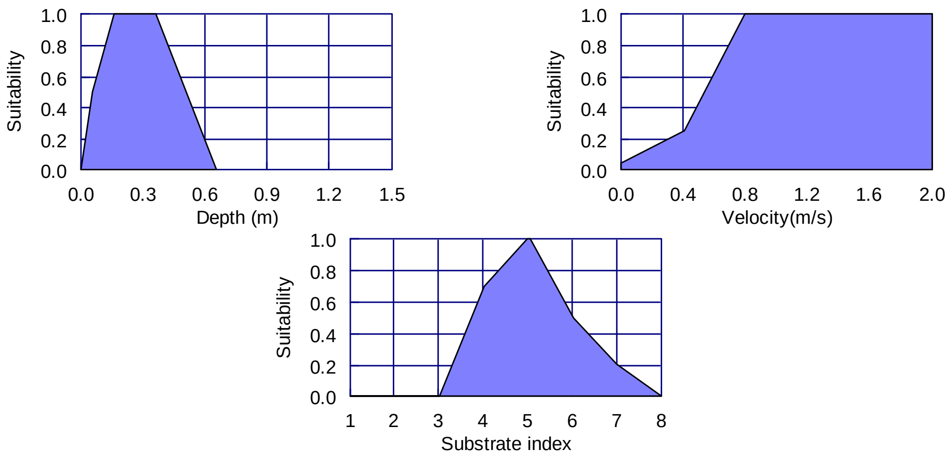
Redfin bully (Jowett & Richardson 1995)



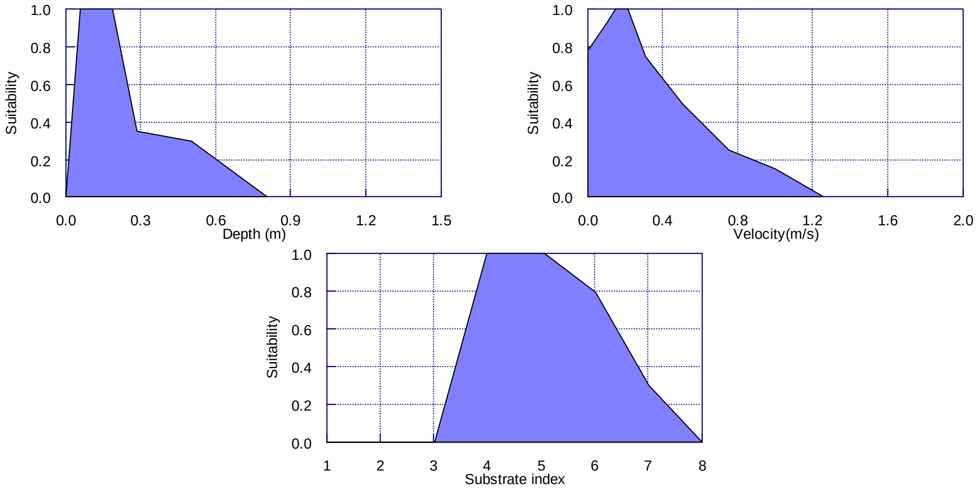
Shortfin eel <300mm (Jowett & Richardson 1995)



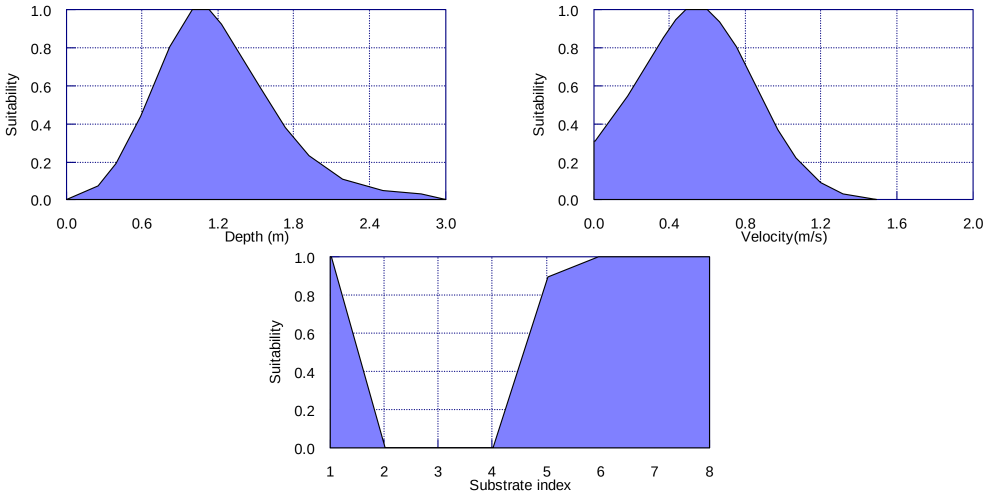
Torrentfish (Jowett & Richardson 1995)



Cran's bully (Jowett & Richardson 1995)



Rainbow trout adult feeding (Thomas & Bovee 1993)



9. Appendix 3: GPS locations for survey sites

Metric grid-references recorded from Garmin e-trex GPS units. These are given for habitat survey cross-sections, tide survey stakes and dissolved oxygen logger locations.

Stream	Easting	Northing	Notes
Habitat cross-section 1	2681039	6436472	
Habitat cross-section 5	2680902	6436482	
Habitat cross-section 6	2680843	6436369	
Habitat cross-section 9	2680704	6436410	
Habitat cross-section 10	2680689	6436059	
Habitat cross-section 15	2680453	6435986	
tide peg 10	2680426	6435962	
tide peg 9	2680587	6435733	<tide limit
tide peg 8	2680761	6435639	
tide peg 7	2680665	6435485	
tide peg 6	2680588	6435341	
tide peg 5	2680754	6435216	
tide peg 4	2680759	6435123	
tide peg 3	2680827	6434928	
tide peg 2	2680803	6434702	
Oxygen logger Tutaenui	2681025	6440511	
Oxygen logger Whakapipi lowland	2680768	6435532	

10. Appendix 4: Invertebrate Raw Data

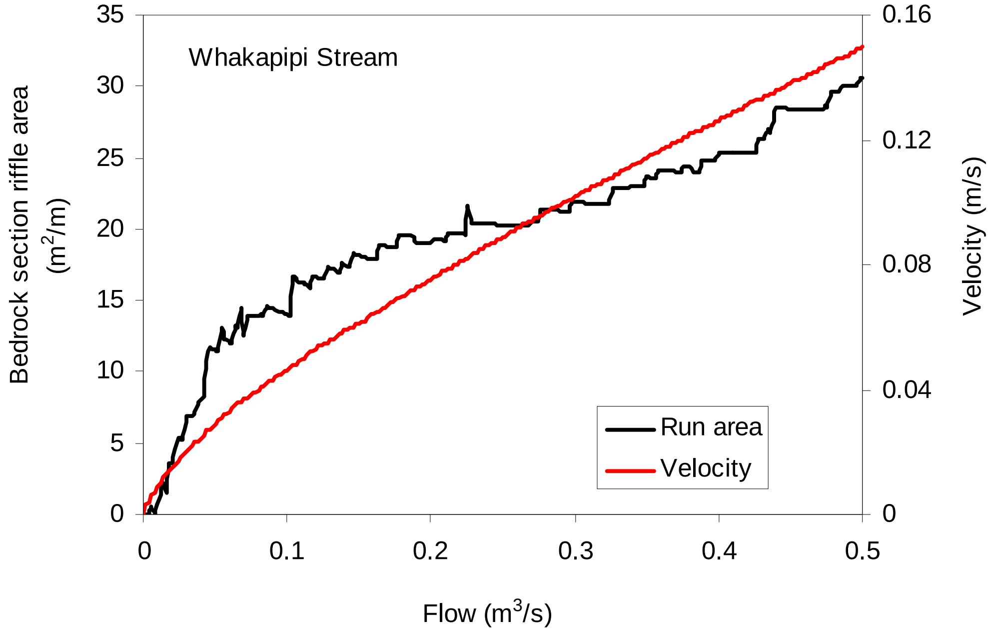
P = rare taxa observed after 200 animal fixed-count.

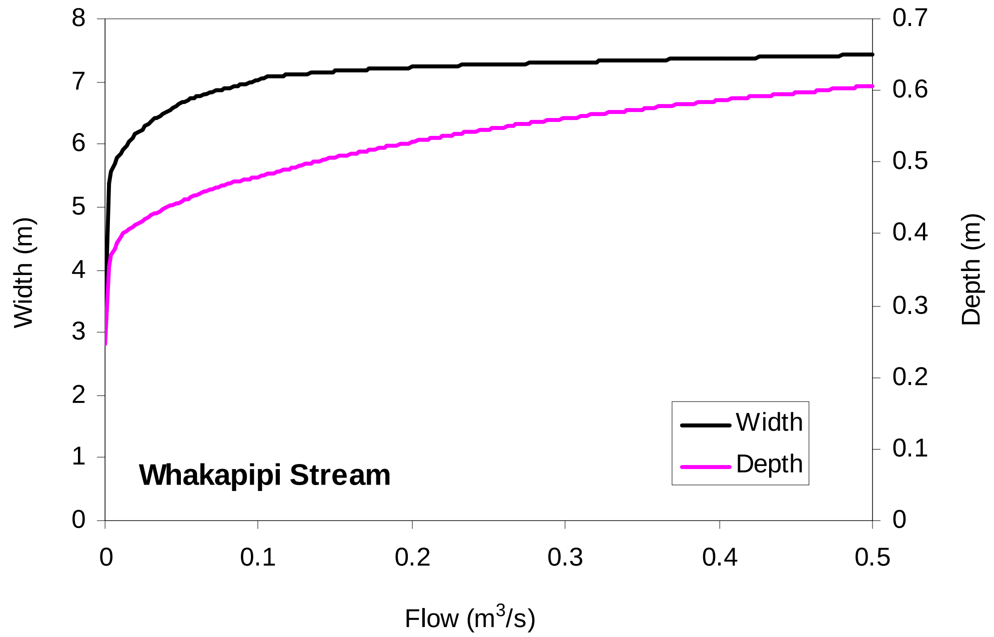
Stream	Tutaenui	Tutaenui	Tutaenui	Whakapipi	Whakapipi	Whakapipi	Tutaenui	Whakapipi	
Site	SH22	Logan Rd	Golding Road	Lowland reach	Ryders Road	Ruebe Road	Harrisville Road	Barnaby Road	average
EPHEMEROPTERA									0
Austroclima					p				0
Zephlebia		19			p		9		4
TRICHOPTERA									0
Aoteapsyche	4								1
Hydrobiosis		1					p		0
Oxyethira	49	1	6	41	p	2	16	4	15
Paroxyethira		3		p					0
Polyplectropus						4			1
Psilochorema							p		0
Triplectides		p					1		0
HEMIPTERA									0
Anisops						p			0
Microvelia			p			7			1
COLEOPTERA									0
Elmidae					1		1		0
Hydrophilidae			p				p		0
DIPTERA									0
Austrosimulium		3	3	1	1	1	11	2	3
Ceratopogonidae			p						0
Culex						p			0
Ephydridae							p		0
Muscidae			p	p			p	p	0
Paradixa					2				0
Zelandotipula						p			0
Chironomidae Orthoclads	16	3	6	45	3	2	9	3	11
Chironomidae Tanytarsini				3		4	1		1
Chironomidae Tanypodinae		p		1		6			1
Chironomidae Polypedilum		2		2	10	1	1	3	2
Paralimnophila							p		0
ODONATA									0
Antipodochlora						p			0
Austrolestes			p						0
Hemicordulia		1	3						1
Xanthocnemis	1	5	3	p	1	24	4	p	5
MOLLUSCA									0
Ferrisia						3			0
Gyraulus								1	0
Lymnaea								1	0
Physa	1	2	6	4	p	9	1	7	4
Potamopyrgus	123	141	176	3	116	15	3	179	95
Sphaerium						2		p	0
Glyptophysa						p		p	0

Stream	Tutaenui	Tutaenui	Tutaenui	Whakapipi	Whakapipi	Whakapipi	Tutaenui	Whakapipi	
Site	SH22	Logan Rd	Golding Road	Lowland reach	Ryders Road	Ruebe Road	Harrisville Road	Barnaby Road	average
LEPIDOPTERA									0
Hygraula	p	p		p					0
OLIGOCHAETA	4	2	2	14	3	24	15	4	9
PLATYHELMINTHES	10	17	6		3	3	8	9	7
HIRUDINEA	3	3	1	p	1				1
CRUSTACEA									0
Amphipoda		3		89	73	90	96	2	44
Ostracoda		8	4	p			37		6
Paranephrops				1					0
Cladocera						1			0
Copepoda						2			0
Isopoda						p			0
ACARINA		p	1				p	1	0
NEMERTEA	3			p			3		1
COLLEMBOLA	p	1		1		p			0
no. of taxa	12	21	17	19	15	25	23	16	18.5
no. of taxa (excl. rare)	10	17	12	12	11	18	16	12	13.5
MCI-SB	67	77	72	68	80	83	82	66	74
%EPT (excl. Oxyethira)	2%	9%	0%	0%	0%	2%	5%	0%	2%
Habitats Sampled									
Stones	30%	0%	0%	0%	10%	0%	20%	10%	9%
Wood	10%	10%	0%	10%	30%	50%	0%	10%	15%
Aquatic plants	40%	60%	80%	60%	20%	0%	50%	0%	39%
Edges	20%	30%	20%	30%	40%	50%	30%	80%	38%

11. Appendix 5: Physical Habitat Data

Change in physical parameters with flow for the lowland and bedrock reaches combined. Area of riffle habitat is based only on the bedrock section (there was no riffle habitat in the lowland reach).





12. Appendix 6: Aquatic plant cover

Where aquatic plant communities differed either side of a road crossing, survey sites are denoted as upstream or downstream (u/s or d/s).

	Emergent				**Submerged**					
	Water celery	**Watercress**	***Polygonum***	**Sweet grass**	***Potamogeton crispus***	***Egeria densa***	***Lagarosiphon major***	***Myriophyllum***	***Elodea canadensis***	**Charophyte**
Whakapipi at SH22 (bedrock)	7%					7%				
Whakapipi lowland reach	30%	<1%	<5%	<5%	<1%	47%				
Whakapipi Ryders Rd									5%	30%
Whakapipi Barnaby Rd (u/s)	90%		5%	5%						
Whakapipi Ruebe Rd										
Tutaenui SH22						60%				
Tutaenui Hamilton Bridge (u/s)	10%									25%
Tutaenui Logan Rd	10%		10%		5%	5%				50%
Tutaenui trib. Golding Rd (u/s)	60%			5%			30%	5%		
Tutaenui Harrisville Rd		50%		15%	10%					