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Minimum Flows for Ecosystem Health in Lowland Streams of the Coromandel: Wentworth, Stony, Whareroa, Waikawau and Waikanae

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Executive Summary

Managing the water resources of the Coromandel Peninsula 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 Coromandel streams. Site specific minimum flows were determined for five streams (Stony, Waikanae, Waikawau, Wentworth and Whareroa), and methods were investigated for predicting the flow requirements of lowland streams not directly surveyed. This research is intended as the third and last year of minimum flow investigations for the Coromandel area. It is complimentary to previous work, and focuses on lowland streams.

Potential instream ecological issues relating to flow include fish and invertebrate habitat, water temperature and dissolved oxygen. From previous research (Whenuakite, Wharekawa, Opitonui), oxygen and fish habitat are expected to be critical issues for lowland streams of the Coromandel area. The methods chosen to investigate these issues were WAIORA for oxygen modelling and RHYHABSIM for habitat modelling.

The recommended minimum flows for the assessed reaches are summarised in Table 1. Fish habitat is considered the critical issue in recommending minimum flows for Stony Stream, Waikanae Stream, Waikawau River and Whareroa Stream. Maintaining adequate dissolved oxygen concentrations was the critical issue for the Wentworth River. A repeat of oxygen modelling for the Wharekawa River determined that oxygen is not a critical issue for this river, so minimum flows determined in previous reports for fish habitat should be adopted as minimum flows for this river.

Predicting the flow requirements for lowland streams of the Coromandel area requires the consideration of both oxygen and habitat. For dissolved oxygen, a risk assessment key is provided for determining the need for more detailed investigations before recommending a minimum flow. This risk assessment procedure was proposed in previous reports was supported by further testing for this report. Flow requirements for fish habitat can be adequately predicted using equations developed based on the five-year low flow.

Table 1: Recommended minimum flows (m^3/s) are presented for each of the five Coromandel streams surveyed. The issue that determined the minimum flow (critical issue) is also noted (A-D). In the absence of an established protection level for the Waikato Region, the Environment Bay of Plenty method was used here. Should a more or less conservative protection level be adopted for the Waikato Region, this would change the minimum flows produced. Natural flow estimates are provided for each reach (Q_5 is the one in 5-year 7-day low flow, MALF is the 7-day mean annual low flow).

m^3/s	Stony Stream	Waikanae Stream	Waikawau River	Wentworth River	Whareroa Stream
Recommended minimum flow	0.053 [A]	0.038 [B]	0.039 [A]	0.123 [C]	0.029 [D]
Q_5	0.045	0.036	0.044	0.106	0.032
MALF	0.055	0.051	0.076	0.137	0.054
Median flow	0.16	0.12	0.20	0.48	0.14

A. Flow required to maintain 85% of maximum habitat for common bully.
B. Flow required to maintain 85% of habitat available at MALF for torrentfish.
C. Flow required to exceed the selected dissolved oxygen guideline of 6 g/m^3.
D. Flow required to maintain 85% of maximum habitat for shortfin eel.

1. Introduction

1.1 Study brief and background

Avoiding adverse ecological effects when allocating water requires information on the flow requirements of aquatic ecosystems. This report addresses the flow requirements for aquatic ecosystems in Coromandel streams. It builds on research completed by NIWA and Environment Waikato in previous years (Wilding 2007a, Wilding 2007b), and is intended as the third and last year of minimum flow investigations for the Coromandel area.

Issues that need consideration for flow requirements include fish and invertebrate habitat, water temperature, oxygen and contaminants. The relative importance of each of these issues is expected to vary between catchments and between reaches within a catchment. Grouping the reaches as upland or lowland habitat ensured the most efficient use of time and resources. Upland reaches were assessed in previous surveys, and habitat was found to be the critical issue. This investigation focused on lowland streams of the Coromandel where previous research indicated that both dissolved oxygen and fish habitat could be critical issues (Wilding 2007a, Wilding 2007b).

This report assesses the minimum flow requirements for aquatic ecosystems of selected Coromandel streams. Fish habitat and water quality were the focus of investigations. A method for extending these results to other streams was also investigated.

1.2 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 assessed reaches of the Wentworth River, Stony Stream and Whareroa Stream are also nominated as Indigenous Fishery Class, with tributaries in native forest areas nominated as Natural State (upstream of the assessed reaches). The Stony Stream is also classified as Trout Habitat (presumably because it is a tributary of the Tairua River). The Waikawau River and Waikanae Stream have Natural State classifications on some headwater tributaries, but the remainder of the catchments are not classed as Indigenous Fishery (despite multiple records of giant kokopu in sections of the Waikawau).

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). Fishery Class streams are believed to support a diverse range of fish species and fish habitats with significant conservation values or support significant recreational, traditional or commercial fisheries and are targeted for more specific policy (Section 3.2.3 Policy 7). The purpose of the Fishery Class is to maintain or enhance existing water quality and aquatic habitat. This includes consideration of the need to minimise changes in flow regimes that would otherwise prevent fish from completing their life cycle and/or maintaining self-sustaining populations, including migration and spawning. In addition, this policy identifies the need to maintain water temperatures and dissolved oxygen levels that are suitable for aquatic habitat and spawning.

The Regional Plan therefore identifies flow management objectives for the Wentworth, Stony and Whareroa to maintain or enhance existing water quality and aquatic habitat. For the Waikawau River and Waikanae Stream, the objectives are less protective, and focus more on avoiding direct effects on the ecosystem rather than maintaining the habitat of ecosystems.

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 were expected to vary with stream type. The effects of any in-river impoundments are outside the scope of this study, 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 mouths of the assessed streams are 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, hence depth requirements for fish passage were not investigated. Flow requirements for habitat and water quality are most likely to be critical issues. Flow requirements for stream invertebrates may be a critical issue for the assessed streams.

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.

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. 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).

1.3.2 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°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. The suitability curves were derived 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).

In New Zealand, a quantitative approach was taken to develop general habitat suitability criteria for a species using data collected from multiple rivers. Generally, species of native fish are found in similar habitats over a wide range of rivers. General habitat suitability curves have been developed for most native fish species (e.g., Figure 1.1), some of it published (e.g., Jowett & Richardson 1995; McCullough 1998) and some of it unpublished.

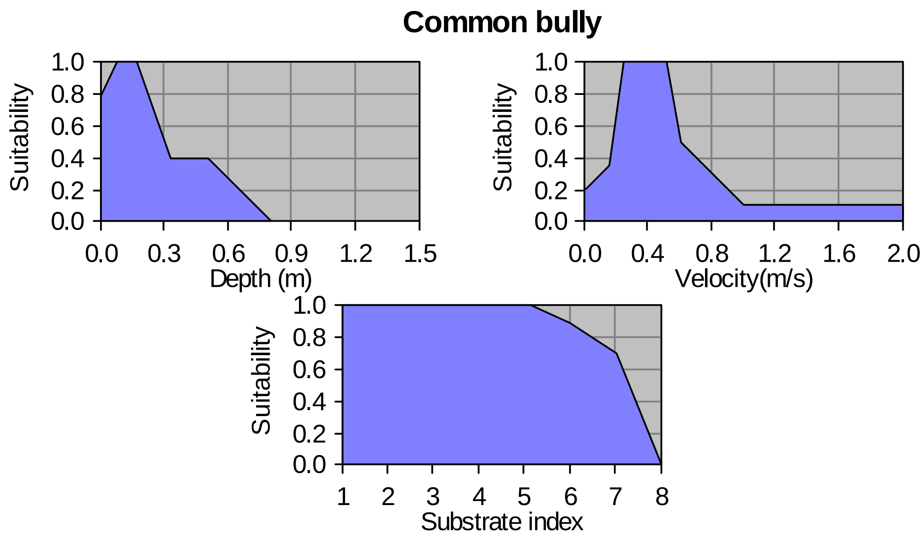


Figure 1.1: Habitat suitability curves for common bully, where suitability ranges from 0 (unsuitable) to 1 (optimal). Substrate index: 1=vegetation, 2=silt, 3=sand, 4=fine gravel, 5=gravel, 6=cobble, 7=boulder, 8=bedrock (Jowett & Richardson 1995).

1.3.3 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 area of suitable habitat. 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. HSI is average habitat suitability index, and is equivalent to 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.

WUA is 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 species. Flows can then be set so that they achieve a particular management goal.

1.3.4 Assessing Minimum Flow Requirements

There are two decisions to be made when assessing minimum flow requirements based on habitat modelling results; firstly, which species 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 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).

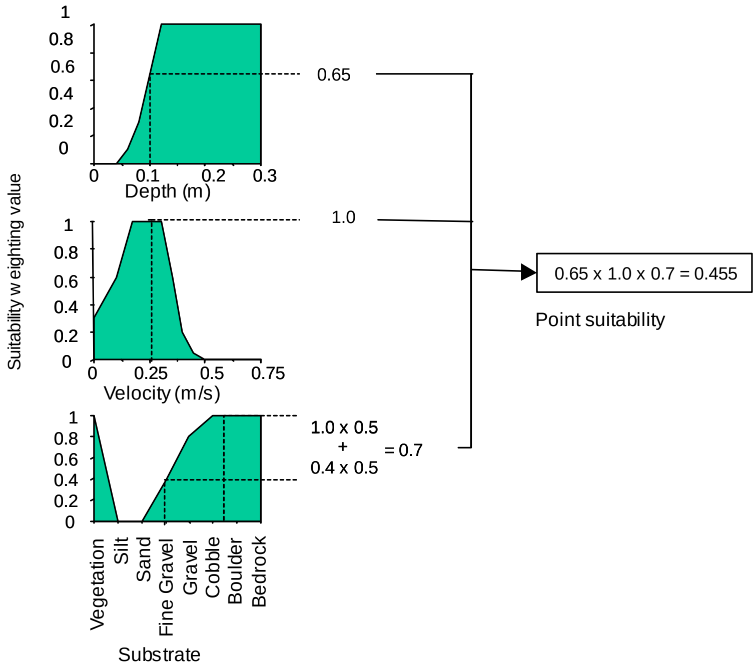


Figure 1.2: Calculation of habitat suitability for a fish species at a point with a depth of 0.1 m, velocity of 0.25 m/s, and substrate comprising 50% fine gravel and 50% cobble. The individual suitability weighting values for depth (0.65), velocity (1.0), and substrate (0.7) are multiplied together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

2. Sites and Methods

2.1 Study Sites

Survey reaches were selected to complement the lowland and midland sites surveyed in previous years (Wilding 2007a, Wilding 2007b). For habitat surveys, the intention was to expand the range of stream sizes covered in previous years (particularly the inclusion of small streams). For dissolved oxygen surveys, the intention was to cover a range of streams sizes and test the decision key presented in the previous Coromandel report (Box 2.1). Environment Waikato completed a GIS analysis of Coromandel Streams to identify streams where there is a higher risk of oxygen suppression, using the draft decision-key provided by Wilding (2007b) (Figure 2.1). Many of these catchments were visited to select five suitable sites (Figure 2.2).

Box 2.1: Decision key from Wilding (2007b). This key is tested and revised in this report, with a replacement key offered in Section 4.2.

The following key is offered to support the desktop selection of Coromandel streams that have a greater likelihood or risk of oxygen being a critical issue for determining minimum flow requirements.

- Low risk reaches

  - those at greater than 20 m elevation;

  or - reaches below 20 m elevation and with less than 2 km of stream length below this elevation (producing an average gradient >0.01 m/m).

- High risk reaches

  - if the stream length between the 20 m elevation contour line and the stream mouth is greater than 5 km, determine the point that is halfway between the 20 m contour line and the river mouth. High-risk reaches are located downstream of this point.

Reaches that do not meet either criterion (between 2 and 5 km of stream below 20 m elevation) could be classed as intermediate risk, or remain indeterminate awaiting further information (e.g., on-site inspection or better reach gradient estimates).

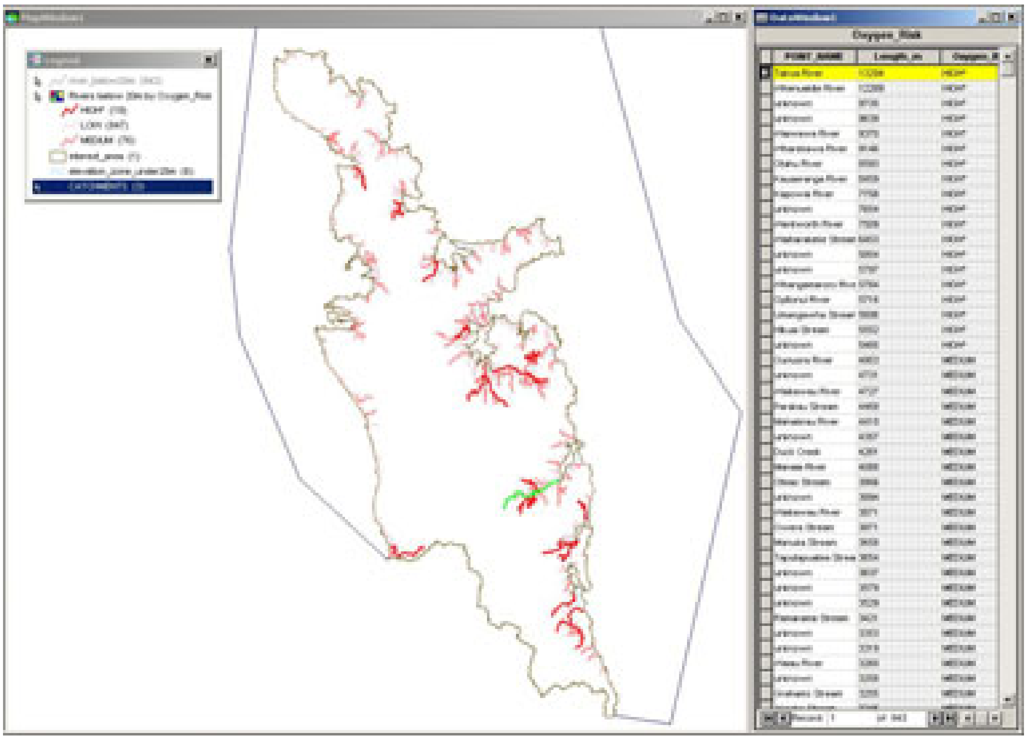


Figure 2.1: Sections of streams predicted to be at greater risk of oxygen suppression. Dark red streams are potentially high-risk streams, with lighter shades representing intermediate and low risk. Environment Waikato completed this desk-top evaluation using the decision key presented in Box 2.1.

Figure 2.2: Rivers and streams of the Coromandel area surveyed in 2007, as indicated by red arrows (NZMS242 Land Information New Zealand).

Stony Stream

This stream flows into the Tairua River a short distance upstream of State Highway 25 (Figure 2.3). The lower reach is relatively unshaded and there is some aquatic plant growth (Figure 2.4 and cover photo). Upstream of the tidal reach, aquatic plants are mostly limited to native charophytes. The substrate is fine sand and silt and predominantly run habitat. With half the catchment in pasture, Stony Stream is expected to receive more agricultural runoff than the other study sites. The total stream length below 20 m elevation is 10.5 km, including the Tairua River. Stony Stream is above of the halfway point between the coast and 20 m elevation, and therefore does not fall into the high-risk classification for oxygen suppression (6.6 km of the 10.5 km length below 20 m elevation is travelled by the Tairua River).

Both habitat and dissolved oxygen were assessed for Stony Stream. Habitat was assessed for a non-tidal reach, after determining the upstream extent of tidal influence. Dissolved oxygen monitoring was carried out within the freshwater tidal section.

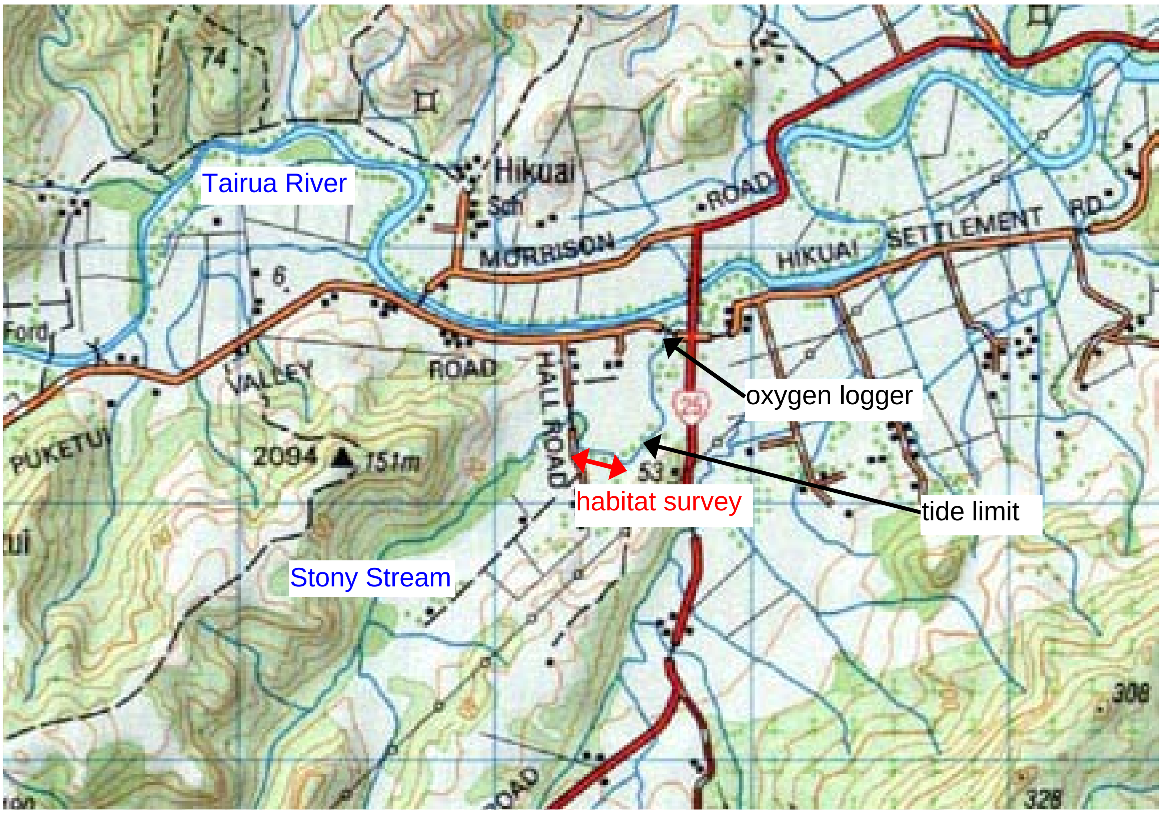


Figure 2.3: **Stony Stream**. Habitat was surveyed downstream of Hikuai Hall Rd (red arrow), and upstream of the measured tidal limit. Dissolved oxygen was monitored continuously at Puketui Valley Road. Tairua township is 10 km to the north-east.

Figure 2.4: **Stony Stream** (see also cover photo). The riparian area has been fenced and planted, but has not yet developed a closed canopy. Aquatic plants are visible (charophytes mainly).

Waikanae Stream

The Waikanae Stream flows into Waikawau Bay north of Kennedy Bay (Figure 2.5), from a predominantly forested catchment (80% forest and scrub). This stream has a short reach below 20 m elevation (3.7 km), so was expected to have a medium risk of oxygen suppression. The reach has sandy substrate, woody debris and occasional faster flowing runs (Figure 2.6). Riparian vegetation was sufficient to shade the stream. No aquatic plants were observed.

Both habitat and dissolved oxygen were assessed for the Waikanae Stream. Habitat was assessed for one non-tidal reach. The upstream extent of tidal influence was investigated and dissolved oxygen monitoring was carried out within the tidal section.

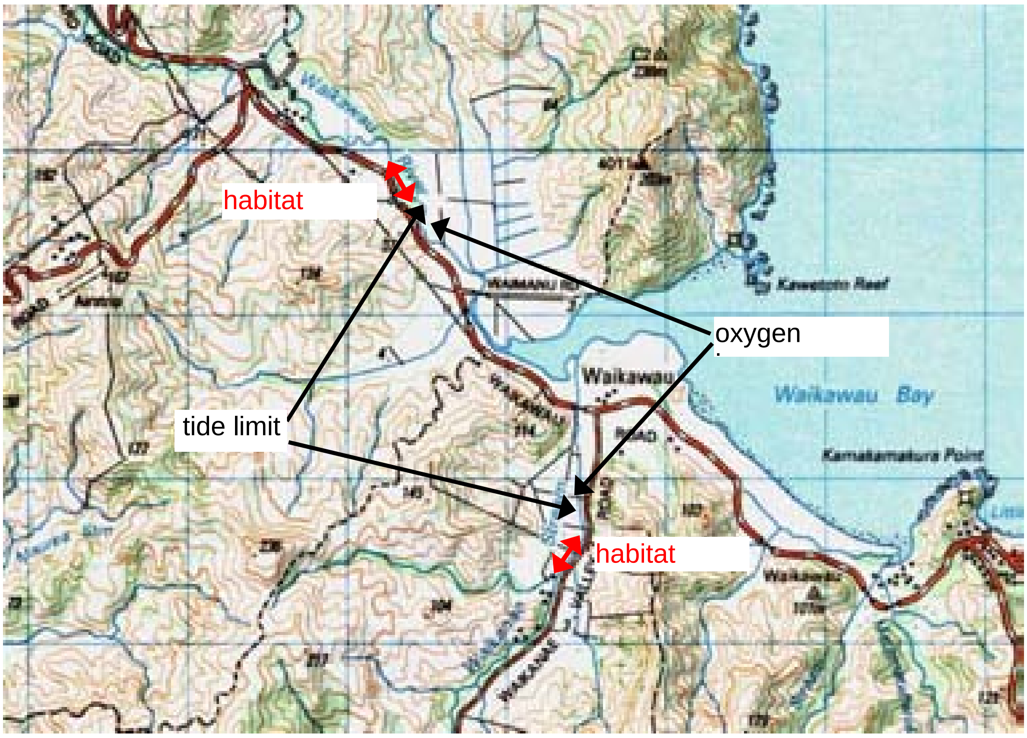


Figure 2.5: Both the **Waikanae Stream** and **Waikawau River** are shown on this map. The habitat survey reaches are indicated by red arrows. The tidal extent and oxygen monitoring sites are arrowed.

Figure 2.6: **Waikanae Stream**. The survey reach is predominantly pool habitat with occasional runs and fewer riffles.

Waikawau River (east coast)

There are two Waikawau Rivers in the Coromandel, which are distinguished here as east coast and west coast. The east coast Waikawau River flows into Waikawau Bay north of Kennedy Bay (Figure 2.5). A stream length of 4.7 km was measured below 20 m elevation (and therefore classed as a medium risk for oxygen suppression), producing mostly pool habitat with occasional runs flowing over gravel and/or woody debris (Figure 2.7). The catchment is predominantly forested (69% forest and scrub) and riparian vegetation affords reasonable shade to the stream for the pastoral sections visited. Few aquatic plants were observed.

Both habitat and dissolved oxygen were assessed for the lowland reach of this catchment. The extent of tidal reach was investigated. The reach that is tidal is more likely to have water quality issues hence dissolved oxygen monitoring was carried out here.

Figure 2.7: **Waikawau River** (east coast). The survey reach is predominantly pool habitat with occasional runs.

Wentworth River

The Wentworth River flows into the Whangamata Harbour via the Moanaanuanu Estuary (Figure 2.8), and is the largest of the streams surveyed for this report. The stream flows from forested headwaters (73% of the catchment), through farmland and subsequently the Whangamata golf course. Upstream of the golf course the stream is shaded by forest on the left-bank and, within the golf course, receives some shade from isolated trees. The substrate is mostly sand, with some gravel, occasional charophyte beds and woody debris (Figure 2.9).

Both habitat and dissolved oxygen were assessed for the Wentworth River. Habitat was assessed upstream of any tidal influence. Dissolved oxygen monitoring was carried out within the tidal section.

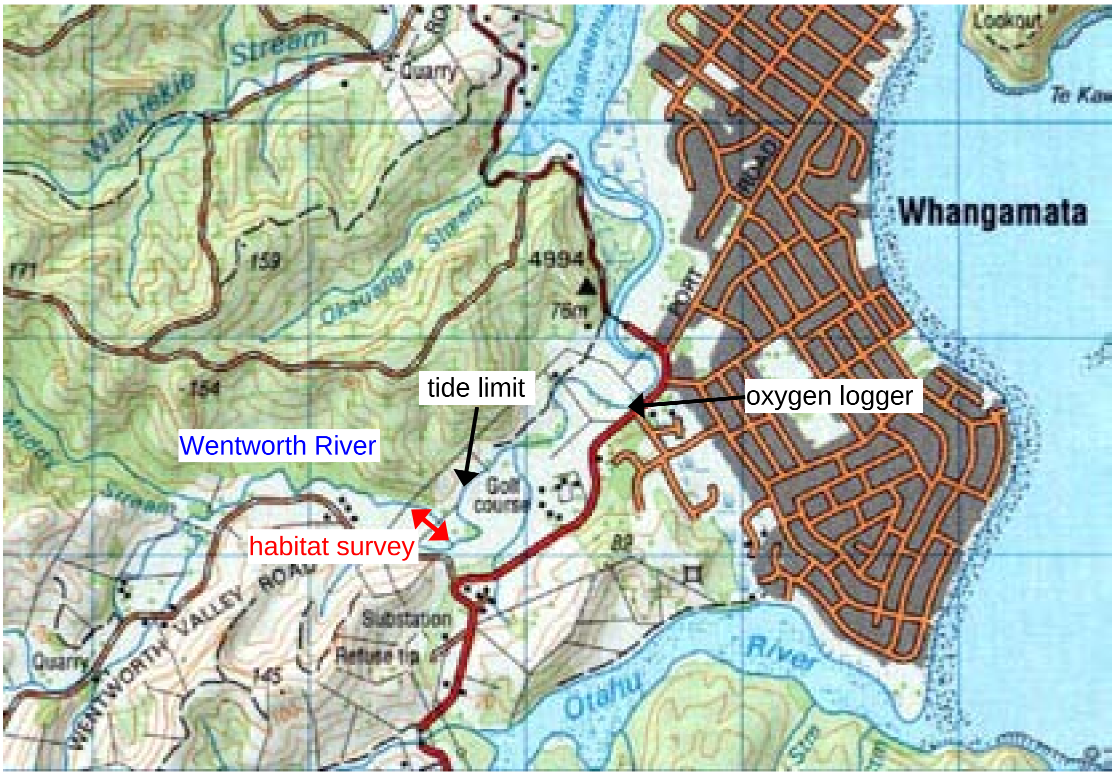


Figure 2.8: **Wentworth River**. Habitat was surveyed upstream of the golf course (red arrow). The measured tidal extent is indicated. Dissolved oxygen was monitored continuously below the golf course.

Figure 2.9: **Wentworth River**. The substrate is typically sandy and the stream lacks deep pools. Aquatic plant growth is limited.

Whareroa Stream

The Whareroa Stream flows into the north-end of Kennedy Bay (Figure 2.10). This stream has a forest catchment, with some pasture adjacent to the lowland reach (98% forest and scrub). Despite the short length of stream below 20 m elevation (2.7 km), the stream provides a lowland habitat reach with pools and woody-debris (Figure 2.11). Few aquatic plants were observed.

Both habitat and dissolved oxygen were assessed for the Whareroa Stream. Habitat was assessed over a non-tidal reach. The upstream extent of tidal influence was investigated and dissolved oxygen monitoring was carried out within the freshwater tidal section.

Figure 2.10: **Whareroa Stream**. This stream was surveyed below the Kennedy Bay Road bridge and the confluence with the Huakitoetoe Stream. The habitat survey reach is indicated by a red arrow and the tidal extent, a short distance below, is marked. Dissolved oxygen was monitored continuously within the tidal reach.

Figure 2.11: Whareroa Stream. Habitat ranges from shallow runs to occasional pools. A mix of native and exotic riparian vegetation (kanuka, nikau, blackberry) effectively shades the stream below the bush line.

Wharekawa River

Previous surveys of the Wharekawa River (Wilding 2007b) recommended that dissolved oxygen monitoring be repeated because the oxygen logger failed during the original survey. A dissolved oxygen logger was deployed in 2007 to support revised oxygen modelling. A flow recorder on the Wharekawa River provided the necessary flow data and enabled modelling using the habitat data collected in 2006. See Wilding (2007b) for further site information.

2.2 Fish and Invertebrate Community

For all reaches (excluding the Wharekawa), fish inhabiting shallow areas were caught by electric fishing, with fyke-nets used in deeper parts of the stream. An EFM 300 machine (Kainga battery powered backpack set) was used to fish an area of at least 50 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 potentially relevant to the surveyed reaches.

Benthic macroinvertebrates were sampled using a dip-net, 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 (Collier and Kelly 2005) was completed for each site.

2.3 Instream Habitat

RHYHABSIM was used to model habitat for fish and other biota in the study reaches. Habitat mapping was carried out for the Waikanae, Waikawau and Whareroa Stream to measure the percentage of riffle, pool and run habitat. Cross-section locations were 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 runs, plus wide and shallow runs. Habitat was more uniform in the Wentworth River and Stony Stream, and cross-sections were spaced evenly to represent the diversity of habitat within these streams. The number of cross-sections and the proportion of each habitat type are presented in Table 2.1 for each study reach.

Table 2.1: The number of cross-sections surveyed and habitat mapping results for each reach. The number of cross-sections (XS) per habitat type is also presented. More uniform habitat in the Stony Stream and Wentworth River negated habitat mapping, and cross-sections were spaced evenly at the nominated interval.

Reach	Number of cross-sections	Habitat mapping			Cross-section spacing
		% riffle	% run	% pool	
Stony Stream	15				15 m
Waikanae Stream	15	5% 2 XS	24% 6 XS	71% 7 XS	
Waikawau River	16	7% 4 XS	18% 4 XS	74% 8 XS	
Wentworth River	15				15 m
Whareroa Stream	15	0	52% 7 XS	48% 8 XS	

For each cross-section, water velocities, depths, and substrate composition were recorded. Water level was measured for each cross-section from a temporary staff gauge. Flows and levels were measured for the survey and on at least two other occasions 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 for the Waikanae, Whareroa, Waikawau and Wentworth (Appendix 3). The rating curves for Stony Stream were the most problematic, with its soft and mobile sediments presumably responsible for significant changes for some cross-sections (changes in profile or control level), combined with the greater accuracy required by the narrow range of calibration flows measured.

The Whareroa Stream also appeared to change shape, with March gaugings plotting as outliers. But the large number of gaugings before or shortly after the survey (4 in total) enabled good ratings to be produced without the two March gaugings. Rain on the day of the habitat survey (9/1/2007) increased flows slightly for the last few cross-sections surveyed (6% flow change estimated from regular water level measurements and repeat gaugings), and survey-flows were varied in the model to reflect this.

Different approaches can be used to determine minimum flow requirements from the plots of habitat (WUA) against flow, as discussed in Section 1.3.4. 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 for most species, except banded kokopu which are Criteria 2 species (95%) and giant kokopu Criteria 1 (100%)).

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

2.4 Dissolved Oxygen

Low oxygen levels and high stream temperatures are stressful to fish and other aquatic life (Dean and Richardson 1999), and reduced flows potentially exacerbate these levels. Data loggers were deployed in each of the five survey streams to monitor oxygen and temperature. In addition, a datalogger was deployed in the Wharekawa River, following recommendations for a repeat of this work from Wilding (2007b) (because of data logger problems in 2006).

The location, deployment period and type of logger used for each stream is summarised in Table 2.2. 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 highest and oxygen lowest. One logger failed, requiring a second deployment later in March (Waikanae Stream). Flow was measured at deployment and retrieval, with the nearest continuous flow recorder used to identify periods of high flow during the deployment period.

Earlier research indicated that tidal-reaches are at the greatest risk of oxygen suppression (Wilding 2007a, Wilding 2007b). Tidal extent was surveyed prior to logger deployment (see Section 2.5). Freshwater tidal sections were preferred, though results from some sites indicated saline intrusion. Loggers were attached to a waratah or existing structure, and placed in a flowing part of the stream (where possible).

For loggers that only measured percent dissolved oxygen, the Benson-Krause formula (Benson and Krause 1984) was used to convert these measurements to the concentration of dissolved oxygen, based on temperature.

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.

Table 2.2: Data loggers were deployed to measure dissolved oxygen and temperature in the five survey streams, plus the Wharekawa River. Deployment location and period are presented (see Section 2.1 for maps). Hydrolab datasondes used a Clark Cell membrane, with stirrer, to measure dissolved oxygen. The RBR TDO-2050 used an Oxygaurd membrane-covered galvanic cell (no stirrer required).

Stream	NZ metric grid-reference	Tidal (y/n)	Deployment period (measure interval)	Datalogger type	parameters
Stony	E2757704 N6454658	Y	23/1/07 to 6/2/07 (15 mins)	Hydrolab Datasonde DS4	%DO, temperature, pH, conductivity
Waikanae	E2735471 N6507933	Y	28/3/07 to 30/4/07 (15 mins)	RBR TDO-2050	%DO & temperature
Waikawau	E2734497 N6509586	Y	1/3/07 to 12/3/07 (10 mins)	RBR TDO-2050	%DO & temperature
Wentworth	E2764466 N6438621	Y	23/1/07 to 6/2/07 (15 mins)	Hydrolab Datasonde DS4	%DO, temperature, pH, conductivity
Whareroa	E2738388 N6501663	Y	1/3/07 to 12/3/07 (10 mins)	RBR TDO-2050	%DO & temperature
Wharekawa	E2763358 N6447449	Y	22/1/07 to 6/2/07 (20 mins)	Hydrolab Datasonde DS3	DO, %DO, temperature, pH, conductivity, depth

2.5 Tide and Aquatic Plant Survey

It was important to know the extent of tidal reach for the study sites. RHYHABSIM habitat surveys of tidal reaches were avoided because the model is based on the relationship between flow and depth, which is broken by tidal fluctuations. Oxygen monitoring targeted the upper tidal reaches because of the higher risk of oxygen suppression here.

Between five and ten wooden stakes were pushed into the stream bed at various points over the reach, at some time prior to high tide. Where possible, the tidal limit was narrowed down beforehand, from conversation with landowners or site inspection. The wooden stakes were typically spaced at least 100 m apart (see Appendix 4 for locations). A floating PVC tube was dropped over the stake and fine bark shavings dropped into the tube (Figure 2.12). 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. Tide height varies with time-scale (e.g., spring tides, storm surges), and surveys were intended to give a typical tidal range, rather than a maximum. The tidal limit (distance inland that the tide reaches) was typically defined as upstream of the first stake to experience a change in water level (allowing for flow recession of a few mm per day). Sometimes a short and steep section between stakes (e.g., a riffle) provided a point to describe as the tidal limit. Otherwise, the tidal limit was simply narrowed down to a section of stream between monitoring points.

Aquatic plants were surveyed as they are assumed to cause 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 2.12: 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 Natural flow estimates

Estimates of natural flow statistics are required to derive minimum flows using the Environment Bay of Plenty method. None of the study sites have continuous or long-term flow records. Therefore flow estimates were derived from nearby flow monitoring sites that have similar geology and climate.

The northern Coromandel sites (Waikanae, Waikawau, Whareroa) were referenced to flow records from the Opitonui River (site 11310, data supplied by Environment Waikato). A large number of gaugings were undertaken for the northern sites (Table 3.1) over a wide range of flows (when the Opitonui was flowing at 65% to 830% of mean annual low flow). A relationship was derived between the measured flow for each study reach and the corresponding flow in the Opitonui River (Figure 3.1). This relationship was then used to scale flow statistics from the Opitonui River, including Q_5 (1 in 5-year 7-day low flow) and MALF (mean annual 7-day low flow). Resultant flow statistics are summarised in Table 3.2.

Several approaches were used to determine median flows, with each approach referenced against the Opitonui River. One approach was to calculate median flow using the same approach as for Q_5 and MALF. This estimate was not relied on solely because of the low number of high-flow data points and the rapid changes in flow during freshes. So, in addition, REC database estimates (Snelder et al. 2004) of flow (mean flow and MALF) for each survey reach were used to scale the median flow for the Opitonui River[1]. The median flows produced by the different approaches were then averaged, and used for this investigation (Table 3.2).

Flow estimates for the northern sites are considered more accurate than the flow statistics derived for the Stony Stream. The REC database flow estimates for this catchment were disproportionately high (MALF specific discharge of 0.021 $m^3/s/km^2$, cf. Figure 3.2), so were not used. Flow measurements correlated best with Tairua and Wharekawa flows. The flow statistics used for this report (Table 3.2) were calculated as the average produced by correlations with the two flow monitoring sites (Tairua, Wharekawa).

[1] For example, the REC mean flow for the Waikawau was 30% of the REC mean flow for the Opitonui. The median flow for the Waikawau would then be calculated as 30% of the measured median-flow for the Opitonui (30% of 0.553 m^3/s is 0.157 m^3/s).

Flows in the Wentworth River were measured periodically by Environment Waikato at a ford upstream of the golf course (20 gaugings between 1991 and 1993 at E2760988, N6436045). Environment Waikato estimated flow statistics for the Wentworth based on these data. Flows for the Wentworth ford were correlated with the Tairua and Wharekawa Rivers, and the relationship was used to scale the flow statistics from these rivers (Q_5, MALF and median flow). The estimates derived from the two rivers (Tairua, Wharekawa) were averaged for the ford site. Paired gaugings at the ford site and lowland reach on the Wentworth River were carried out by Environment Waikato (4 measurements, summer 2001), and enabled scaling of flow statistics from the ford site to the lowland reach. Results are presented in Table 3.2.

Table 3.1: Flow measurements (m^3/s) recorded for the habitat survey (bold) and rating calibrations at each of the study reaches.

Date time (NZST)	Wentworth	Stony	Whareroa	Waikanae	Waikawau
11/12/06 12:00					0.0572
12/12/06 9:10				0.039	
12/12/06 13:50			0.034		
13/12/06 16:00	0.136				
14/12/06 10:00		0.05			
8/1/07 14:00				**0.035**	
9/1/07 10:30			**0.038**		
9/1/07 13:30			0.043		
9/1/07 13:50				0.0702	
9/1/07 14:40					0.1127
10/1/07 9:50				0.446	
10/1/07 10:20					0.834
10/1/07 12:40			0.376		
10/1/07 13:30				0.31	
10/1/07 14:10					0.452
11/1/07 11:20					**0.103**
23/1/07 8:40		**0.068**			
24/1/07 10:50	**0.201**				
6/2/07 14:40	0.172				
6/2/07 16:50		0.059			
1/3/07 11:10			0.030		
1/3/07 12:40				0.0382	
1/3/07 14:00					0.0418
12/3/07 13:50			0.027		
12/3/07 15:40				0.0336	
12/3/07 17:30					0.0413
28/3/07 15:20				0.0296	
30/4/07 12:00				0.0782	

Table 3.2: Natural flow estimates (m^3/s) for each survey reach. Q_5 is the one in five-year 7-day low flow; MALF is the 7-day mean annual low flow. Calculations methods are described in greater detail in Section 3.1 (REC flow data also used in calculation of median flows denoted with *).

Stream	Q_5	MALF	Median	Calculation
Stony	0.045	0.055	0.16	Correlation Tairua, Wharekawa (average)
Waikanae	0.036	0.051	0.12*	Opitonui correlation
Waikawau	0.044	0.076	0.20*	Opitonui correlation
Wentworth	0.106	0.137	0.48	Wharekawa & Tairua correlation
Whareroa	0.032	0.054	0.14*	Opitonui correlation

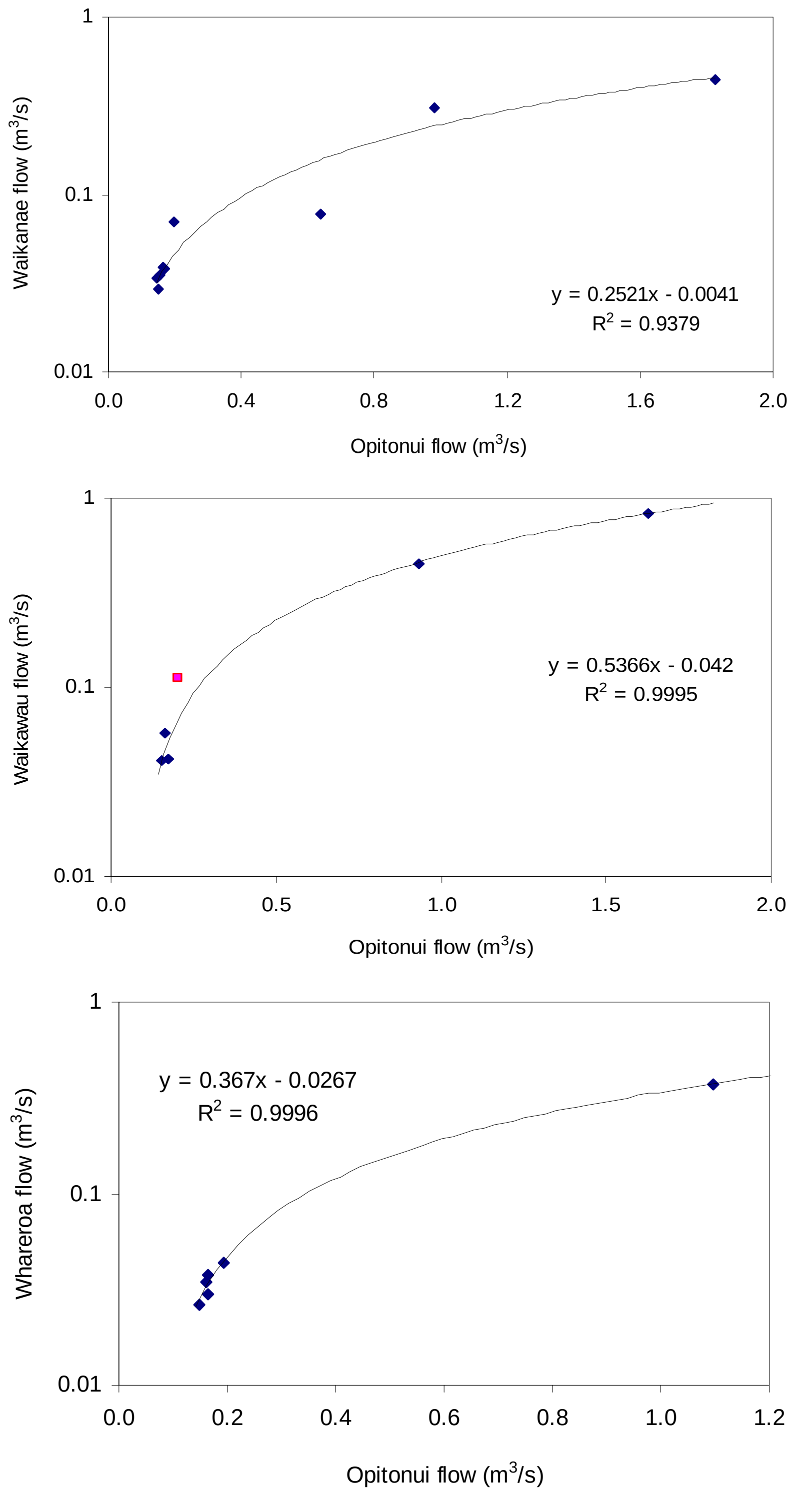


Figure 3.1: Flow relationship between the Opitonui River and three of the study reaches (Waikanae, Waikawau and Whareroa). The y-axes are plotted on a log-scale to clarify the scatter of points at low flows (trendlines would otherwise be linear). Only outliers that had a strong influence on the relationship were excluded from the fitted trendline (data point in red).

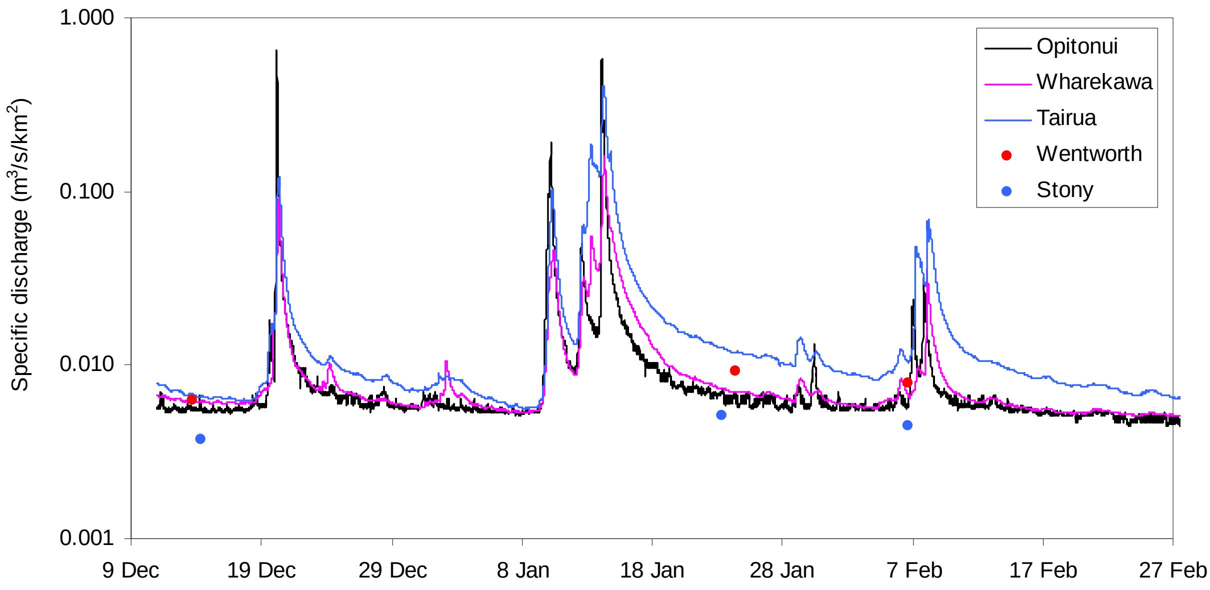


Figure 3.2: Flows during December-February 2007 are compared between sites, after dividing by the catchment area to produce a specific discharge (log scale). Flow measurements at two of the survey sites (Wentworth, Stony) are compared to Coromandel sites with continuous flow recorders (Opitonui, Wharekawa, Tairua). Stony Stream has a lower elevation catchment, hence is expected to intercept less rainfall than the other sites.

3.2 Fish and Invertebrate Community

Results are presented for electric fishing and fyke netting of the study sites (Table 3.3 and 3.4). Other species observed during the survey, or recorded in the New Zealand Freshwater Fish Database from the same reach, are also presented in the table. All potential inhabitants were included in the habitat modelling, but those species considered less likely to be resident (marked '?' in Table 3.3 and 3.4) were not used in determining the recommended minimum flow for each site.

All sites are within a short distance of the tidal reach, and hence have good access to the sea for migrant species. Fish communities were similar between sites, with redfin bully, giant bully, common bully, inanga, longfin and shortfin eel caught at most sites. As a point of interest, giant bully were exclusively caught using fyke nets, with electric fishing of same sections failing to reveal any. Two of the five streams supported small populations of torrentfish (Waikanae, Waikawau); these being the only two sites with some riffle habitat. No doubt torrentfish occur further upstream within all five catchments, where the habitat is more suitable. A single smelt was caught at one of the five sites (Waikawau). The mobility of this species can reduce its capture rate, but inanga are expected to be the dominant pelagic species in these small lowland streams.

Question remains over the apparent lack of large bodied galaxiids (giant kokopu and banded kokopu) from the lowland reaches. The absence of banded kokopu could reflect the size of the streams, with smaller streams (less than 0.01 m^3/s, with overhead shade) often a favourite of this species. Both the Whareroa and Waikawau Stream have multiple records of giant kokopu from upstream of the study reaches (New Zealand Freshwater Fish Database). The two fishing methods used for this study could reasonably be expected to detect giant kokopu if present (Bonnett and Sykes 2002). Previous surveys of near-tidal reaches in the Coromandel (Wilding 2007a, Wilding 2007b) also failed to detect giant kokopu, reducing the likelihood that these reaches represent preferred habitat.

Common bully were not caught in the Wentworth River study reach, despite records from further upstream and adjacent catchments. The fishing methods and effort were sufficient to detect a common bully population of any magnitude, so this species was not counted as resident.

Invertebrate sampling methods covered the range of stable habitats present, which ranged from marginal vegetation ("edge") and aquatic plants to woody debris and gravel riffles (Appendix 5). Only the Waikanae Stream had more than one of the ten samples collected from gravel riffles. The contribution from aquatic plants varied from 0% to 30% of samples (Appendix 5). The invertebrate community at most sites was dominated by shrimp (*Paratya curvirostris*), stick caddis (*Triplectides* sp.) and mudsnail (*Potamopyrgus* sp.) (Appendix 5). The mayfly *Zephlebia* sp. was common at most sites, which indicates reasonable water quality (for lowland streams). Greatest invertebrate diversity was recorded from the Waikanae Stream, which is at least partly attributable to greater proportion of riffle habitat sampled.

The large native snail *Melanopsis trifasciata* was recorded from three sites (Appendix 5) and probably occurs at the other two survey sites. Together with giant bully, *Melanopsis* is characteristic of the fauna inhabiting tidal and near-tidal freshwater reaches. Kakahi (*Hyridella* or freshwater mussel) and koura (crayfish) were encountered at several sites (Table 3.3).

Table 3.3: Number of fish and large invertebrates caught from three of the study sites. Electric fishing (EF) and fyke-nets were used at all sites. In addition to those caught, other fauna observed during the study are marked 'obs.'. 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 ('?'). The kokopu caught in the Waikawau River were juveniles (<50 mm), probably migrating upstream to resident habitats.

	Stony		**Waikanae**		**Waikawau**	
	23/1/07	24/1/07	9/1/07	9/1/07	11/1/07	11/1/07
	EF	Fyke	EF	Fyke	EF	Fyke
	50 m^2	5 trap-nights	50 m^2	5 trap-nights	50 m^2	5 trap-nights
Longfin eel	7	60	7	10	8	16
Shortfin eel	16	12	1		3	
Unident. eel	49		69		29	
Giant bully		1		1		3
Common bully		5		2	1	10
Redfin bully	104	7	69		75	
Torrentfish			6		2	
Common smelt	?		?		1	
Inanga	1	35	1		18	2
Banded kokopu						
Giant kokopu			?		?	
Unident. kokopu					3 juv.	
Lamprey	?		?		?	
Gambusia (intro.)	1					
Koura (crayfish)	1				2	
Kakahi (mussels)	Obs.				Obs.	
Shrimp	Abundant		Abundant		Abundant	

Table 3.4: Fish caught from two of the study sites (as per Table 3.3).

	Wentworth		Whareroa	
	23/1/07	24/1/07	11/1/07	10/1/07
	EF	Fyke	EF	Fyke
	55 m^2	5 trap-nights	50 m^2	5 trap-nights
Longfin eel	2	14	5	19
Shortfin eel	8	2	3	
Unident. eel	5		24	
Giant bully		4		1
Common bully	?		1	
Redfin bully	17	2	15	3
Torrentfish	?			
Common smelt	E		?	
Inanga	1	3	21	
Banded kokopu			?	
Giant kokopu			?	
Lamprey	?		?	
Gambusia (intro)				
Koura (crayfish)				1
Kakahi (mussels)				
Shrimp	Common		Abundant	

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 most species inhabiting the Stony Stream, low flows (MALF) provide near-maximum habitat (Figure 3.3). The relatively high flow at maximum habitat for species such as lamprey and banded kokopu are considered spurious - a likely product of inaccuracies in the rating curves, which were produced using a narrow range of calibration flows. The Environment Bay of Plenty method produced a minimum flow for Stony Stream of 0.053 m^3/s, based on common bully (Table 3.5). Points of inflection were derived for those species displaying a clear breakpoint, as opposed to a gradual reduction in habitat with flow (Table 3.5).

The Waikanae Stream provides near-maximum habitat at MALF for most species (Figure 3.4). Torrentfish, common smelt and large longfin eel can make use of greater flows. A relatively high number of torrentfish were caught at this site (6 over 50 m^2 of fished area), and therefore a site specific minimum flow based on torrentfish is appropriate (0.038 m^3/s). However, a minimum flow of 0.029 m^3/s (based on large longfin eel) is recommended for use in the interpolation analysis, as this better represents flow requirements in lowland streams that typically support few or no torrentfish. Several species displayed a clear point of inflection for the Waikanae Stream, and most are within the range of 0.03 to 0.035 m^3/s (Table 3.6).

The Waikawau Stream again provides near-maximum habitat at MALF for most species (Figure 3.5). Like the Waikanae Stream, torrentfish, common smelt and large longfin eel prefer higher flows. A minimum flow of 0.039 m^3/s is recommended for fish habitat, based on 85% of maximum habitat for common bully (Table 3.7). This represents a compromise of habitat for the few torrentfish that are resident in the lowland reach. A few species displayed points of inflection, including inanga at 0.034 m^3/s.

Most resident species prefer flows at or above MALF in the Wentworth River (Figure 3.6). The Environment Bay of Plenty method produced a minimum flow of 0.090 m^3/s for fish habitat in the Wentworth River, based on common smelt (Table 3.8).

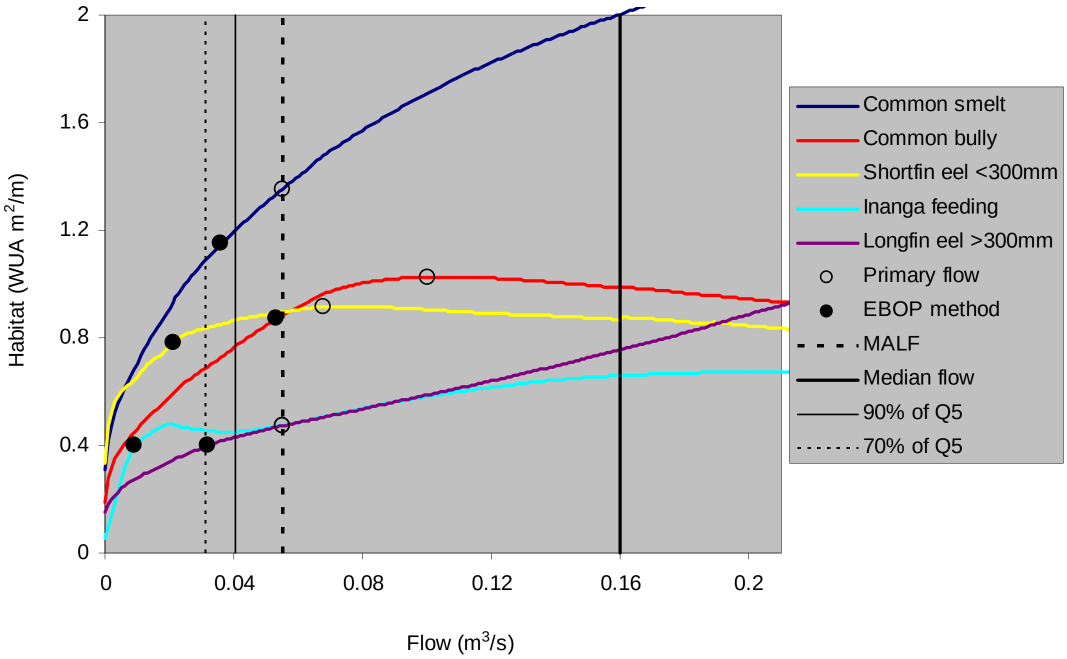
Despite the small size of the Whareroa Stream, MALF provides near-maximum habitat for most resident species of fish (Figure 3.7). The Environment Bay of Plenty produces a minimum flow of 0.040 m^3/s, based on common bully (Table 3.9). But only one common bully was caught in this reach (and it is common elsewhere), so a minimum flow based on shortfin eel is recommended in providing for resident fish populations at this site (0.029 m^3/s maintains 85% of maximum habitat for shortfin eel). If giant kokopu were later found to be resident in this reach, a higher minimum flow would be required. Some species display a point of inflection, including redfin bully at 0.025 m^3/s (Table 3.9).

Run habitat was modelled as an indicator of invertebrate habitat. Lowland streams, such as those surveyed for this study, offer little in the way of cobble riffle habitat.

Often stable organic substrate, such as logs and aquatic plants, represents the most productive habitat for benthic invertebrates. This is reflected in the type of invertebrates found in these streams, including stick caddis and the mayfly *Zephlebia* (Appendix 5). This is presented instead of modelled habitat changes (with flow) for individual invertebrate species because of concerns expressed by Jowett (2000) and Wilding (2007a) 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; see also Jowett et al. 1991).

Minimum flow requirements expected to maintain run habitat are presented in Table 3.10, using habitat protection levels of 70% and 85% of MALF. The proportion of run habitat at the primary flow that is maintained by the minimum flow requirement for fish habitat (Environment Bay of Plenty method) varied between 72% and 88% (Table 3.10).

The change in velocity, depth, width and the area of run habitat with flow are also plotted for each stream in Appendix 6. Velocity generally showed a gradual reduction with flow, declining more steeply than width or depth.



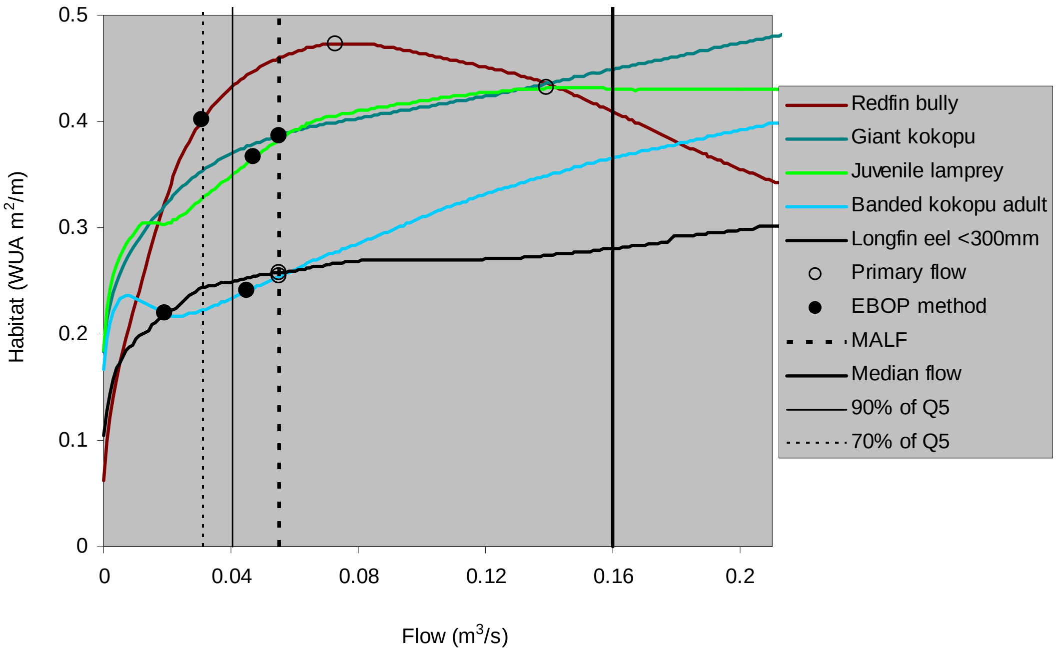


Figure 3.3: The change in habitat with flow for various species and life stages of fish in the **Stony Stream** (two graphs are used to allow presentation of each species on an appropriate scale). Using the Environment Bay of Plenty method, the primary flow is the available-habitat value to which the 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 3.5: Results derived from the habitat-flow response data for the **Stony Stream** (as plotted in Figure 3.3). 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 at 95% and giant kokopu at 100%). Species and life stages marked * are not expected to reside in this reach, and are included for reference only. Flow requirements for banded kokopu and lamprey are suspect, as a consequence of rating curve problems for Stony Stream (italicised figures). Habitat protection levels afforded by existing and historic allocation methods are also presented (90% & 70% of Q_5 flow, respectively). 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 (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
Stony Stream	(Q_5 0.045 m^3/s, MALF 0.055 m^3/s, median flow 0.16 m^3/s)				
Common smelt*	>1	0.036		80%	88%
Common bully	0.100	0.053	0.07	67%	74%
Shortfin eel	0.068	0.021		91%	94%
Inanga	0.218	0.009	0.02	96%	95%
Longfin eel >300mm	>1	0.032		83%	91%
Redfin bully	0.073	0.031	0.03	85%	91%
Juvenile lamprey	*>1*	*0.055*	*0.03*	*91%*	*96%*
Longfin eel <300mm	0.139	0.047		76%	81%
Giant kokopu*	0.249	0.045		87%	92%
Banded kokopu*	*0.51*	*0.019*		*95%*	*97%*

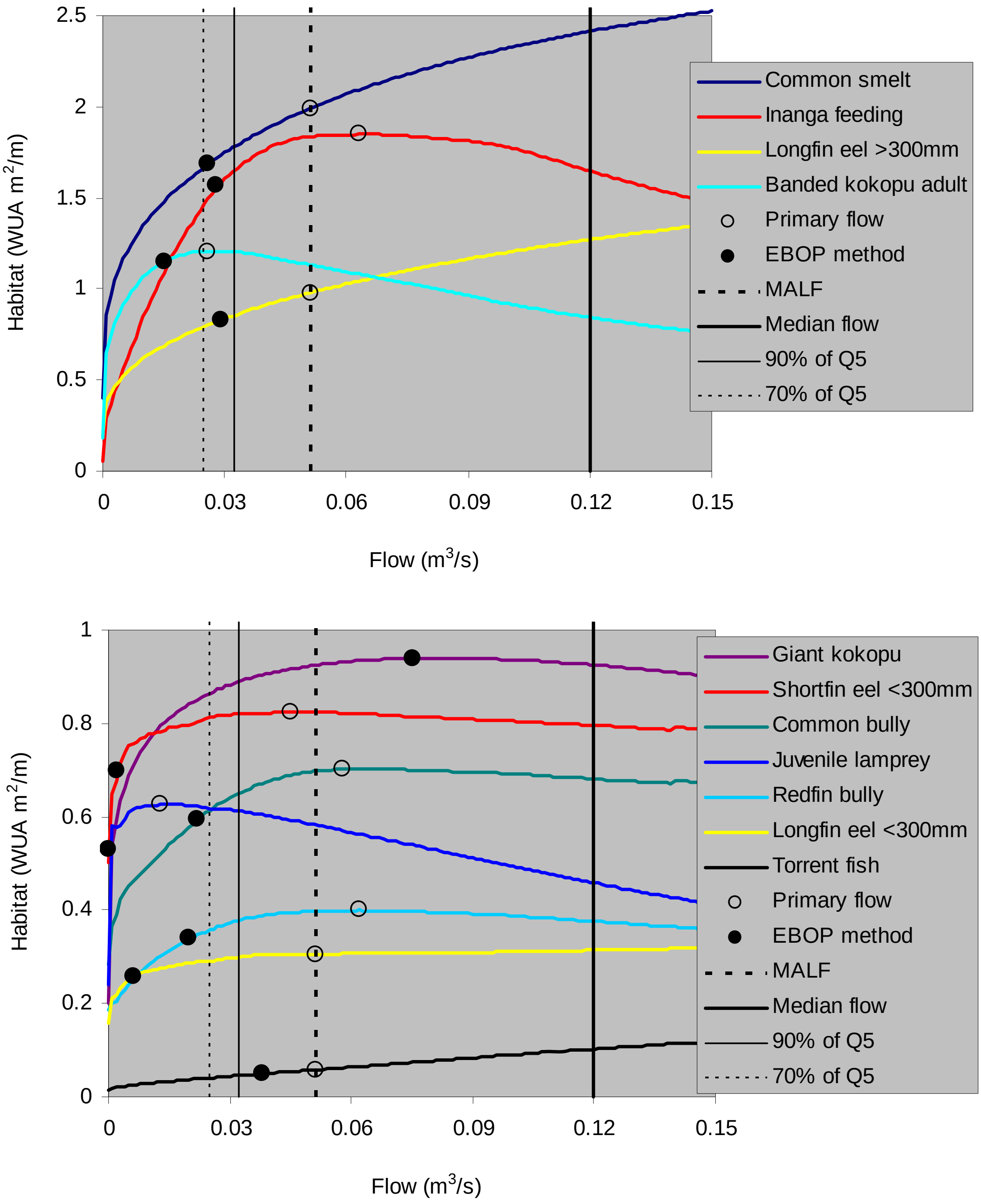


Figure 3.4: The change in habitat with flow for various species and life stages of fish in the **Waikanae Stream**. Otherwise as per Figure 3.3.

Table 3.6: Results derived from the habitat-flow response data for the **Waikanae Stream** (as plotted in Figure 3.4). Otherwise as per Table 3.5.

	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**
Waikanae Stream	(Q_5 0.036 m^3/s, MALF 0.051 m^3/s, median flow 0.12 m^3/s)				
Common smelt	0.5	0.026		84%	89%
Inanga	0.063	0.028	0.03	79%	89%
Longfin eel >300mm	>0.7	0.029		81%	87%
Banded kokopu*	0.026	0.015		100%	100%
Giant kokopu*	0.075	0.075		92%	95%
Shortfin eel	0.045	0.002	0.01	99%	99%
Common bully	0.058	0.022	0.033	87%	92%
Juvenile lamprey	0.013	0		99%	98%
Redfin bully	0.062	0.02	0.03	89%	95%
Longfin eel <300mm	>0.7	0.006	0.035	95%	98%
Torrent fish	0.52	0.038		71%	79%

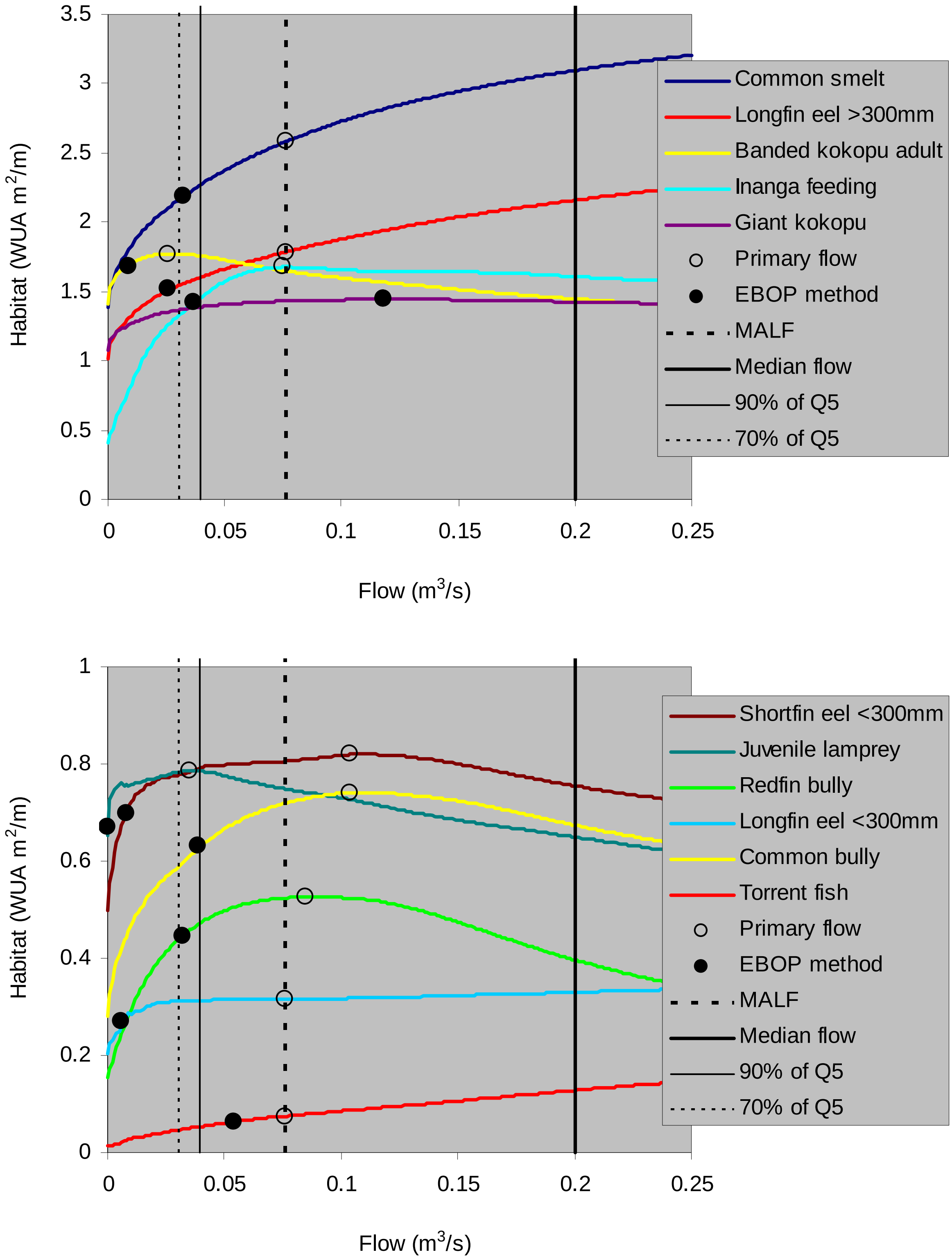
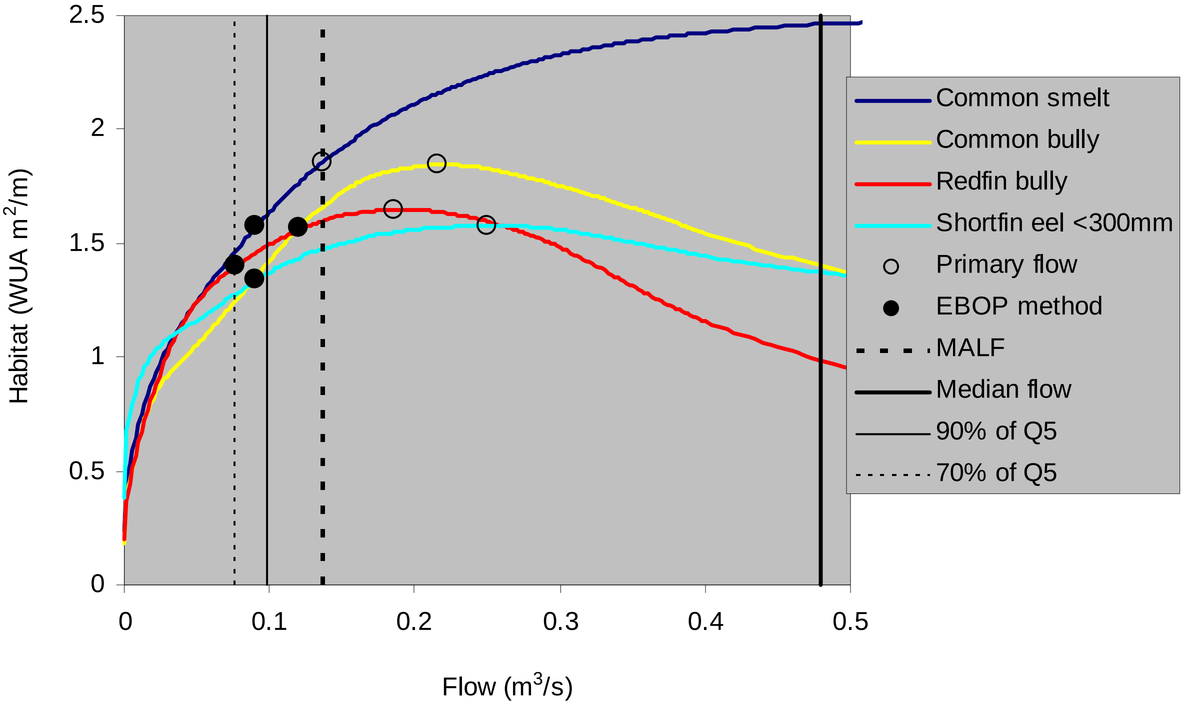


Figure 3.5: The change in habitat with flow for various species and life stages of fish in the **Waikawau River**. Otherwise as per Figure 3.3.

Table 3.7: Results derived from the habitat-flow response data for the **Waikawau River** (as plotted in Figure 3.5). Otherwise as per Table 3.5.

	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
Waikawau River	(Q_5 0.044 m^3/s, MALF 0.076 m^3/s, median flow 0.2 m^3/s)				
Common smelt	0.55	0.032		83%	88%
Longfin eel >300mm	>1	0.026		86%	90%
Banded kokopu*	0.026	0.009		100%	99%
Inanga	0.075	0.037	0.034	79%	86%
Giant kokopu*	0.118	0.118		95%	96%
Shortfin eel	0.104	0.008	0.02	95%	96%
Juvenile lamprey	0.035	0		99%	100%
Redfin bully	0.085	0.032		82%	88%
Longfin eel <300mm	>1	0.006	0.02	99%	99%
Common bully	0.104	0.039		85%	89%
Torrent fish	0.46	0.054		61%	71%



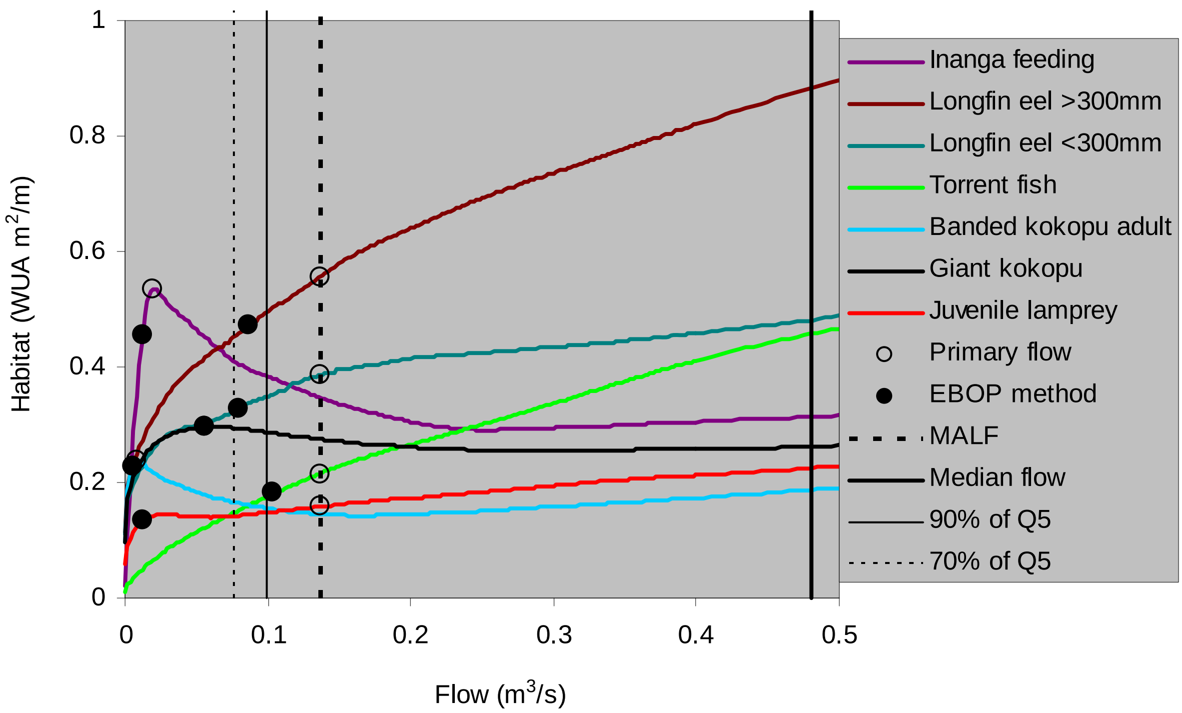
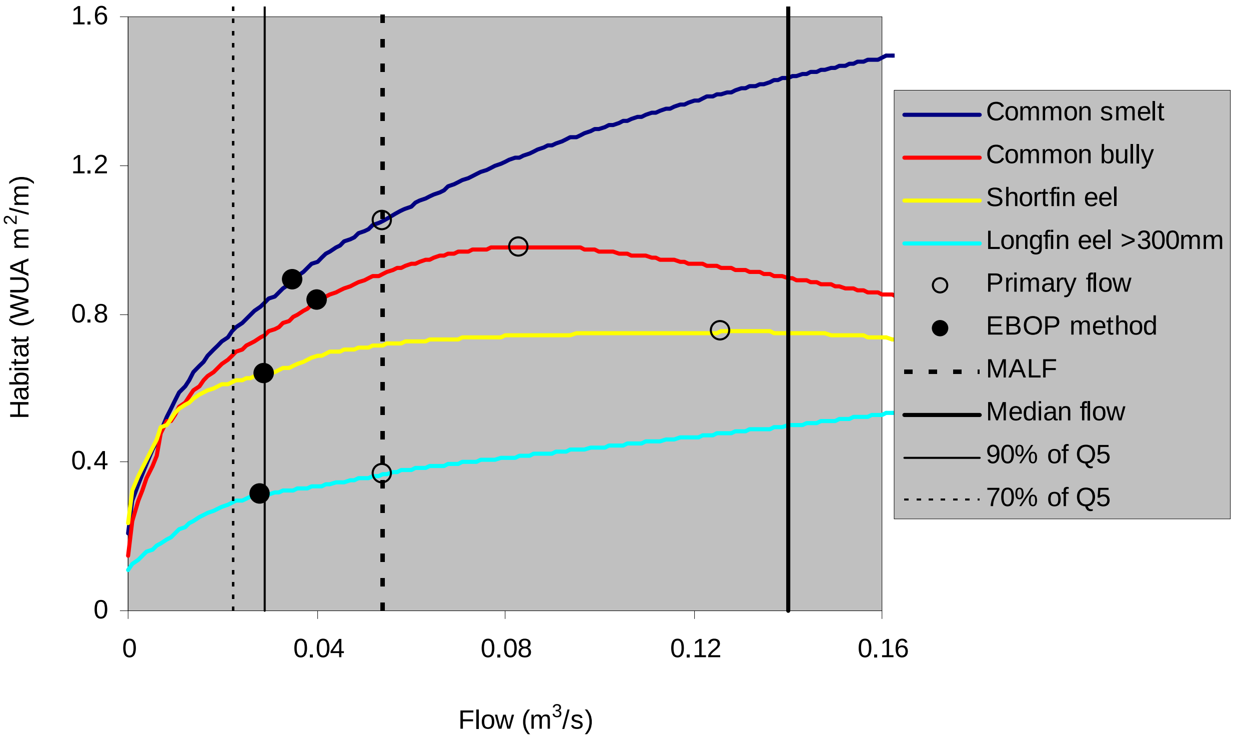


Figure 3.6: The change in habitat with flow for various species and life stages of fish in the **Wentworth River**. Otherwise as per Figure 3.3.

Table 3.8: Results derived from the habitat-flow response data for the **Wentworth River** (as plotted in Figure 3.6). Otherwise as per Table 3.5.

	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
Wentworth River	(Q_5 0.106 m^3/s, MALF 0.137 m^3/s, median flow 0.48 m^3/s)				
Common smelt	0.6	0.090		78%	86%
Common bully*	0.216	0.120	0.17	67%	75%
Redfin bully	0.186	0.076		84%	89%
Shortfin eel	0.25	0.090		80%	86%
Inanga	0.02	0.013	0.016	77%	73%
Longfin eel >300mm	>1	0.086		81%	87%
Longfin eel <300mm	>1	0.080		83%	89%
Torrent fish*	0.71	0.104		67%	79%
Banded kokopu*	0.008	0.005	0.005	70%	66%
Giant kokopu*	0.056	0.056		100%	98%
Juvenile lamprey	>1	0.012		90%	93%



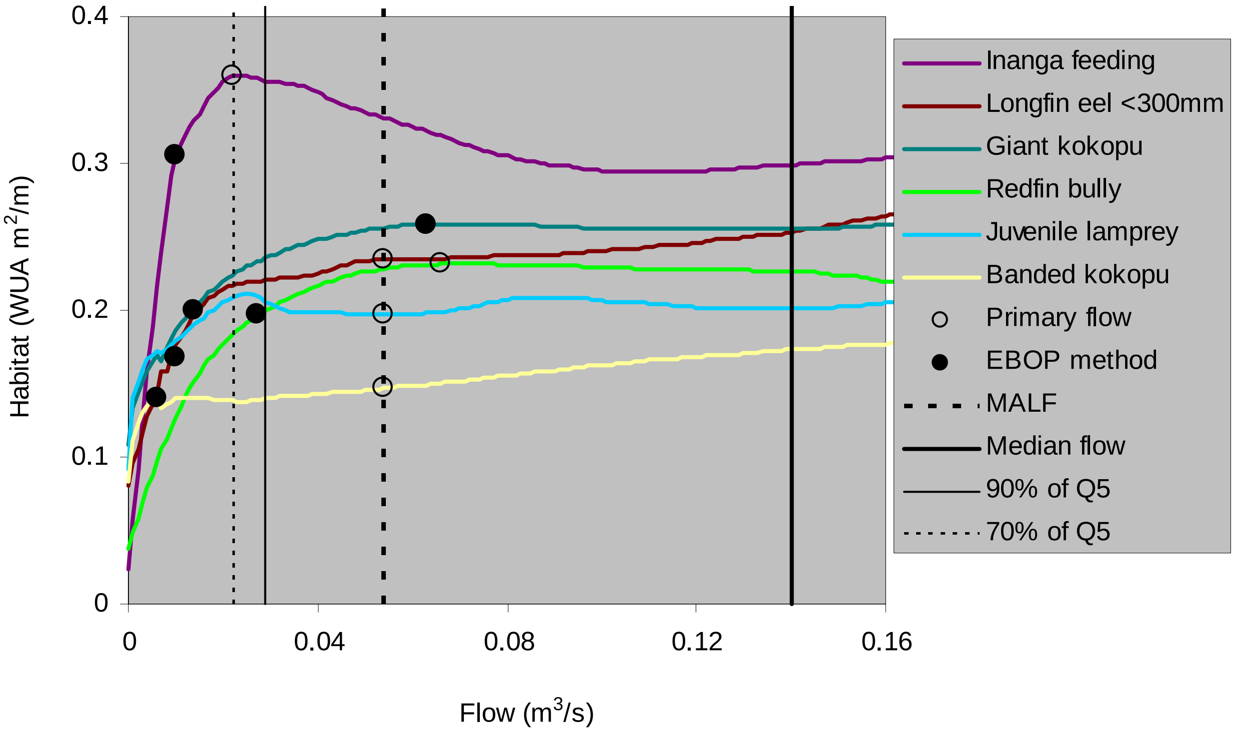


Figure 3.7: The change in habitat with flow for various species and life stages of fish in the **Whareroa Stream**. Otherwise as per Figure 3.3.

Table 3.9: Results derived from the habitat-flow response data for the **Whareroa Stream** (as plotted in Figure 3.7). Otherwise as per Table 3.5.

	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
Whareroa Stream	(Q_5 0.032 m^3/s, MALF 0.054 m^3/s, median flow 0.14 m^3/s)				
Common smelt*	0.6	0.035		72%	78%
Common bully	0.084	0.040		70%	75%
Shortfin eel	0.109	0.029		82%	84%
Longfin eel >300mm	>0.5	0.028		79%	85%
Inanga	0.021	0.010	0.011	100%	99%
Longfin eel <300mm	>0.5	0.014	0.015	92%	94%
Giant kokopu*	0.061	0.063		88%	92%
Redfin bully	0.062	0.027	0.025	80%	86%
Juvenile lamprey	0.023	0.010		99%	98%
Banded kokopu*	0.197	0.006		95%	95%
Torrent fish*	0.198	0.039		61%	68%

Table 3.10: Flows required (m^3/s) to maintain 70% and 85% of run habitat available at MALF (mean annual low flow). Run habitat is used as a surrogate for invertebrate habitat. *The protection level that is afforded for run habitat, by the flow requirement determined for fish habitat, is also presented (site specific minimum flow as recommended in Section 3.3). A smoothing function was run for all reaches to remove the effect of 'bumps' in the modelling results (plotted data is presented in Appendix 6).

Stream	Q_5	Flow for 70% habitat	Flow for 85% habitat	Prot. Level from min. flow for fish habitat*	Prot. level at 70% of Q_5	Prot. level at 90% of Q_5
Stony	0.045 m^3/s	0.039 m^3/s	0.046 m^3/s	88%	54%	74%
Waikanae	0.036 m^3/s	0.027 m^3/s	0.035 m^3/s	90%	67%	78%
Waikawau	0.044 m^3/s	0.024 m^3/s	0.037 m^3/s	86%	79%	87%
Wentworth	0.106 m^3/s	0.084 m^3/s	0.114 m^3/s	73%	76%	62%
Whareroa	0.032 m^3/s	0.026 m^3/s	0.042 m^3/s	73%	65%	73%

3.4 Tide and Aquatic Plant Survey

The upstream extent of tidal influence was assessed for each stream. This focussed on the freshwater tide, produced by streamflow backing up as sea-level increases. Salt water penetrates a distance upstream as an undercurrent or salt wedge (salt water is heavier than fresh), but not as high as the freshwater tide. Water level fluctuation was measured at various points over one tidal cycle, so producing a tidal extent on that day, rather than a maximum tidal extent. Results are presented in Table 3.11, including the limit of tidal extent (grid-references for a point or section of stream), the oceanic high-tide water-level when surveyed (from the NIWA tide forecaster) and how typical that tide was (expressed as a percentile of high tide levels for that month).

For the Stony Stream, two tides were surveyed including a small and a large tide (33%ile and 100%ile for high tide levels). The bigger tide extended an extra 300 m upstream, and is useful in demonstrating the variability that could apply to the results for other sites.

Table 3.11: Results from the tidal survey of five Coromandel streams. Tidal height is given as metres above sea level as well as a percentile of high-tide levels for that calendar month. The survey tide is described by the date and time (DST) of the high tide event.

	Tidal extent (NZMS grid-reference)	**High-tide level (m ASL)**	**High-tide percentile**	**Survey tide (d/m/yy h:mm)**
Stony Stream	E2757584 N6454179	0.67 m	33%	13/12/06 13:52
	E2757503 N6454171	0.97 m	100%	23/1/07 10:47
Waikanae Stream	E2735509 N6507756	0.85 m	58%	11/12/06 12:22
Waikawau River	E2734343 N6509822	0.85 m	58%	11/12/06 12:22
Wentworth River	E2763695 N6438288	0.66 m	34%	13/12/06 13:52
Whareroa Stream	E2738395 N6501826	0.85 m	58%	11/12/06 12:22

Aquatic plant growth varied between sites, but coverage was generally low (Table 3.12). All reaches were surveyed mid to late summer, when plant growth would be close to its full potential. The habitat survey reach of Stony Stream had native charophytes covering 10% of the channel width, on average. Overhanging grasses and emergent vegetation lined the banks, with woody debris also providing stable substrate for invertebrates and cover for fish. Closer to the Tairua River confluence, aquatic plants were more prolific (approximately 50% cover) including *Potamogeton* and *Elodea canadensis*.

Few aquatic plants were observed in the other four streams, with occasional patches of charophytes and emergents (e.g., *Polygonum*).

Table 3.12: Aquatic plant cover expressed as an average proportion of the wetted-channel width. Fifteen cross-sections were surveyed for each stream.

	Charophyte	*Potamogeton crispus*	Emergent
Stony Stream	10%		2%
Waikanae Stream	0%		
Waikawau River	<1%		3%
Wentworth River	<1%		<1%
Whareroa Stream	<1%	3%	

3.5 Dissolved oxygen and temperature

Stony Stream

Dissolved oxygen concentrations in Stony Stream showed a marked diurnal pattern, with an average range between 5.9 and 10.6 g/m^3 about a mean of 7.7 g/m^3 (Figure 3.8). The average water temperature was 18.7 °C (maximum recorded temperature 24.6 °C). Data from the period 1 to 3 February was used to avoid any tidal influence or significant flow changes (a small fresh occurred 29-30 January). The average flow between 1 and 3 February was 0.047 m^3/s (Tairua flows scaled by 4.5% to reproduce measured flows for Stony Stream).

A tidal fluctuation in water level of approximately 80 mm was observed at the oxygen monitoring site. This had a small effect, reducing dissolved oxygen concentrations by 0.35 g/m^3 on average (derived by plotting residuals from the diurnal pattern against time since low tide).

The computer programme WAIORA was used to predict the effect of flow on oxygen concentrations. The model was calibrated using oxygen monitoring data and RHYHABSIM habitat data (the nine slowest flowing cross-sections were selected to better represent the tidal reach). The predicted oxygen concentrations assume an average water temperature of 20 °C, which is close to that observed (19.5 °C for the total monitoring period). Aquatic plants were nominated as the most important primary produces upstream of the monitoring site, with extensive beds of *Elodea canadensis* and charophytes (Section 3.4). Respiration and reaeration rates produced by the model were relatively high (Table 3.13), even after adopting a 1 hour lag period (the observed lag between solar noon and maximum oxygen ranged between 0 and 30 minutes).

Dissolved oxygen (24-hour minimum) is expected to decline rapidly at flows less than MALF (Figure 3.9). Flow requirements to achieve nominal oxygen values were derived from these results (Table 3.14). The flow requirement for habitat (0.053 m^3/s) would maintain oxygen concentrations above 5 g/m^3.

Waikanae Stream

Dissolved oxygen concentrations displayed little diurnal variation in the Waikanae Stream, with an average range of 0.5 g/m^3 about a mean of 7.4 g/m^3 (Figure 3.10). Maximum oxygen concentrations occurred mid-morning (09:45) in contrast to oxygen depleted streams, which would be closer to their minimum at this time. Instead of being driven by photosynthesis, temperature appears to be the primary driver of the small diurnal fluctuation in oxygen observed in the Waikanae Stream (Figure 3.10), by changes to the saturation point. Flow during the monitoring period averaged 0.083 m^3/s (cf. MALF 0.051 m^3/s).

A tidal fluctuation in water level of approximately 20 mm was observed at the oxygen monitoring site. This had a small effect, reducing dissolved oxygen concentrations at high tide by 0.31 g/m^3 on average.

The effect of flow changes on oxygen was not modelled. The WAIORA model attempts to balance respiration and photosynthetic oxygen production against flow-related reaeration. Because diurnal oxygen-fluctuation in the Waikanae Stream is not driven by photosynthesis, WAIORA is not an appropriate model. This also means that oxygen is unlikely to be a critical issue for determining flow requirements. With an absolute-minimum oxygen concentration of 4.7 g/m^3 (high tide) and a 1-percentile of 5.5 g/m^3 (for the period 28 March to 30 April), aquatic life is not expected to be oxygen limited.

Waikawau River

Dissolved oxygen was monitored in the tidal reach of the Waikawau River at a point experiencing seawater intrusions. The observed water-level fluctuation between high and low tide was approximately 300 mm (11 December 2006), and the datalogger results show plumes of warm water (overlaid on the diurnal pattern) that coincide with high tide (Figure 3.11). Saltwater is heavier than freshwater, forming a salt wedge below freshwater flows. The oxygen sensor was calibrated for freshwater, hence measurements of the salt wedge are not accurate. Further, oxygen concentrations within the salt-wedge (Figure 3.12) are presumably not a product of river flow (more likely a product of estuarine conditions). Periods of seawater intrusion were therefore removed from the data record prior to analysis (data between 5 hours and 10 hours 40 minutes after low tide).

After removing the seawater intrusions, the residual diurnal-fluctuation of oxygen concentrations was relatively small (average range of 0.6 g/m^3) about a mean of 7.2 g/m^3 (Figure 3.13). This is in spite of high water temperatures (average 20.7 ºC, maximum 23.9 ºC) and low river flows during the monitoring period (average 0.042 m^3/s, or 95% of Q_5). It is therefore not surprising that predicted flow requirements for oxygen were relatively low (Figure 3.14, Table 3.14). Maintaining oxygen concentrations (24-hour minimum) above 6 g/m^3 requires half the flow recommended for fish habitat (Table 3.7), and therefore oxygen is not a critical issue for the Waikawau River.

Wentworth River

Like the Waikawau River, sea water intrusions were also detected in the Wentworth River. These were shorter lived and produced both positive and negative spikes in temperature (Figure 3.15) and oxygen (Figure 3.16). During tidal inundation, dissolved oxygen fluctuated +/- 1.6 g/m^3 (between a 5%ile to 95%ile). The datalogger deployed in the Wentworth River also measured conductivity, confirming that these intrusions were salty (conductivity > 10,000 µS). Tidal fluctuations in water level of 420 mm were observed at the oxygen monitoring site (13 December 2006).

After removing the seawater intrusions, the residual diurnal-fluctuation of oxygen concentrations had a range of 1.3 g/m^3 about a mean of 7.2 g/m^3 (Figure 3.17). Water temperatures were high (average 20.5 ºC, maximum 24.6 ºC) while river flows averaged 0.19 m^3/s (cf. MALF 0.15 m^3/s).

The response of dissolved oxygen to flow was modelled using WAIORA (using 6 cross-sections from the habitat survey that were slower flowing). The model produced a relatively high respiration rate and reaeration coefficient in calibrating to the observed conditions (Table 3.13). However, these are similar to values produced for the Opitonui River (Wilcock et al. 1998, Wilding 2007b). Both rivers have relatively low biomasses of aquatic plants and periphyton. The modelling results do not predict a steep decline in oxygen concentrations until flows drop below 0.1 m^3/s (Figure 3.18). The flow required to maintain oxygen concentrations greater than 6 g/m^3 exceeds the flow requirement for fish habitat (Table 3.8 and Table 3.14). The flow requirement for fish habitat (0.090 m^3/s) maintains oxygen concentrations greater than 5 g/m^3. Because of the low biomass of large aquatic plants, the WAIORA model was also run assuming benthic algae dominated the plant biomass. This estimated flows as low as 0.025 m^3/s would maintain oxygen concentrations greater than 6 g/m^3.

Whareroa Stream

Dissolved oxygen in the Whareroa Stream displayed similar characteristics to Waikanae Stream, with little diurnal variation (average range 0.5 g/m^3) about a relatively high mean of 8.4 g/m^3 (Figure 3.19). Maximum oxygen concentrations occurred mid-morning (10:00 am) indicating that temperature, rather than photosynthesis, was responsible for the small diurnal oxygen fluctuation (Figure 3.19), by changes to the saturation point. Flow during the monitoring period (1 to 12 March 2007) was very low (average 0.028 m^3/s, cf. Q_5 0.032 m^3/s). The stream benefits from extensive shading of the catchment and study reach, producing cool stream temperatures (average 17.7 °C, maximum recorded 19.6 °C).

A tidal fluctuation in water level of 230 mm was estimated for the oxygen monitoring site (from tidal measurements 11/12/06). This had a small effect, reducing dissolved oxygen concentrations at high tide by 0.19 g/m^3 on average.

The effect of flow changes on oxygen was not modelled. The WAIORA model attempts to balance respiration and photosynthetic oxygen production against flow-related reaeration. The limited diurnal oxygen-fluctuation and lack of aquatic plants means that WAIORA is not an appropriate model for this stream. This also means that oxygen is not likely to be a critical issue for determining flow requirements. With an absolute-minimum oxygen concentration of 7.1 g/m^3 (high tide) and a 1-percentile of 7.65 g/m^3 (1 to 12 March), aquatic life is not expected to be oxygen limited.

Wharekawa River

Oxygen was monitored in the Wharekawa River in a repeat of the work conducted in 2006. It was hoped to achieve a better representation of oxygen conditions during summer baseflows, after previous modelling indicated oxygen was a potentially critical issue (Wilding 2007b). The oxygen logger was redeployed during summer (22 January to 6 February 2007), under low flow conditions (average flow 0.309 m^3/s, cf. MALF 0.32 m^3/s, Q_5 0.265 m^3/s). Oxygen measurements were corrected for an apparent loss of calibration over the monitoring period (from measurements at recovery).

Despite low flow conditions and relatively warm river temperatures (average 20.9 °C, maximum 23.4 °C), dissolved oxygen concentrations remained high with an average diurnal range of 0.7 g/m^3 about a mean of 7.4 g/m^3 (Figure 3.20). Overlain on this diurnal pattern (which excludes high tide data) is a tidal pattern that reduced oxygen concentrations by 0.93 g/m^3 on average at high tide (Figure 3.21). Water levels increased by 530 mm at high tide at this site (from Wilding 2007b), but no seawater intrusion was detected (from conductivity and temperature results).

The response of dissolved oxygen to flow was modelled using WAIORA. Habitat data from the midland reach was used (excluding riffle cross-sections to better represent the tidal reach). The model produced similar values for respiration rate and reaeration coefficient to those produced for the Wharekawa River by Wilcock et al. (1998). These are several orders of magnitude lower than those produced by Wilding (2007b), therefore the recommendation to repeat this work was justified. The modelling results predict that oxygen concentrations (24-hour minimum) would remain high at flows greater than 0.2 m^3/s (Figure 3.22). The flow required to maintain oxygen concentrations (24-hour minimum) greater than 6 g/m^3 (Table 3.14) are less than the flow requirements for fish habitat in the midland reach (0.265 m^3/s from Wilding 2007b). Oxygen is therefore not a critical issue for the Wharekawa River.

Table 3.13: Coefficients calculated by WAIORA from oxygen monitoring data. These are used to predict the effect of flow on dissolved oxygen. The Waikanae and Whareroa were not modelled because they did not display a diurnal oxygen pattern from photosynthesis (peak DO before solar noon).

Stream	Community respiration $g[O_2]/m^3/day$	Production / respiration ratio	Reaeration coefficient /day	Peak DO lag
Stony	98.3	0.53	26.7	1 hour
Waikanae	NA	NA	NA	-2.5 hours
Waikawau	7.26	0.17	3.57	3.5 hours
Wentworth	36.6	0.21	16.3	1.5 hours
Whareroa	NA	NA	NA	-2.5 hours
Wharekawa	6.61	0.24	3.40	3.75 hours

Table 3.14: Predicted flow requirements to achieve various dissolved oxygen concentrations (24-hour minimum concentration), modelled using WAIORA.

Stream	Q_5	2 g/m^3 DO	3 g/m^3 DO	4 g/m^3 DO	5 g/m^3 DO	6 g/m^3 DO
Stony	0.045 m^3/s	0.022 m^3/s	0.025 m^3/s	0.031 m^3/s	0.041 m^3/s	0.06 m^3/s
Waikanae	0.036 m^3/s	NA	NA	NA	NA	NA
Waikawau	0.044 m^3/s	0.012 m^3/s	0.014 m^3/s	0.017 m^3/s	0.021 m^3/s	0.027 m^3/s
Wentworth	0.106 m^3/s	0.049 m^3/s	0.058 m^3/s	0.068 m^3/s	0.086 m^3/s	0.123 m^3/s
Whareroa	0.032 m^3/s	NA	NA	NA	NA	NA
Wharekawa	0.265 m^3/s	0.099 m^3/s	0.114 m^3/s	0.137 m^3/s	0.168 m^3/s	0.208 m^3/s

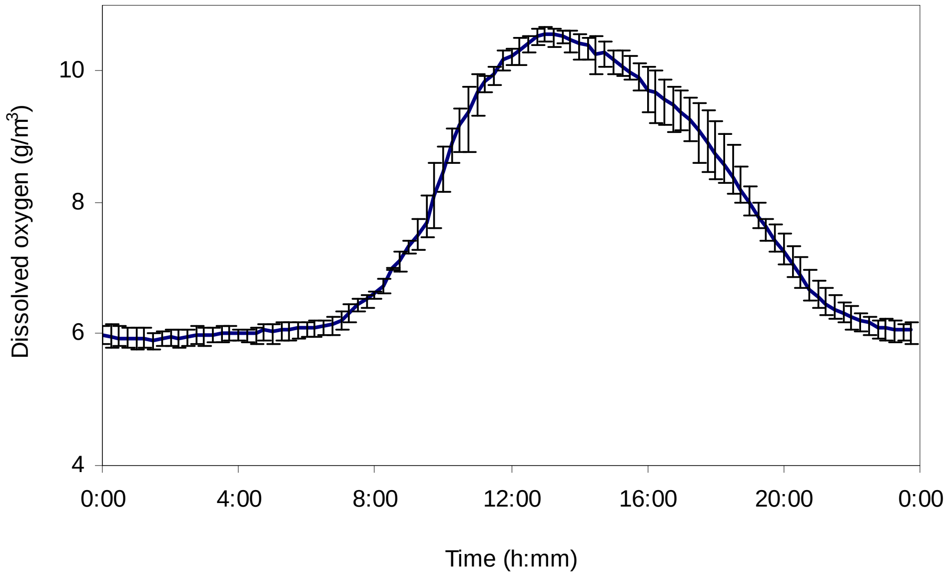


Figure 3.8: Dissolved oxygen concentrations in the tidal reach of **Stony Stream**. Oxygen concentrations were averaged for each time of day over the selected period (1 to 3 February) to give the average 24-hour cycle of dissolved oxygen. Error bars show the maximum and minimum for each time of day.

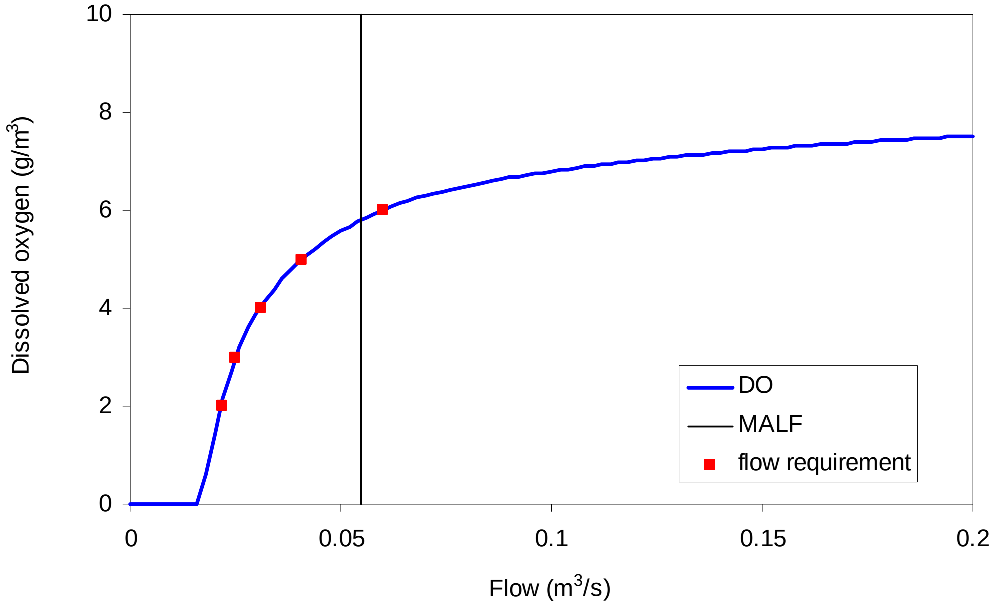


Figure 3.9: Predicted effect of reduced flow on dissolved oxygen concentrations (24-hour minimum) for **Stony Stream**. The MALF (mean annual low flow) is plotted, in addition to the flow requirements for nominal oxygen thresholds (as presented in Table 3.14).

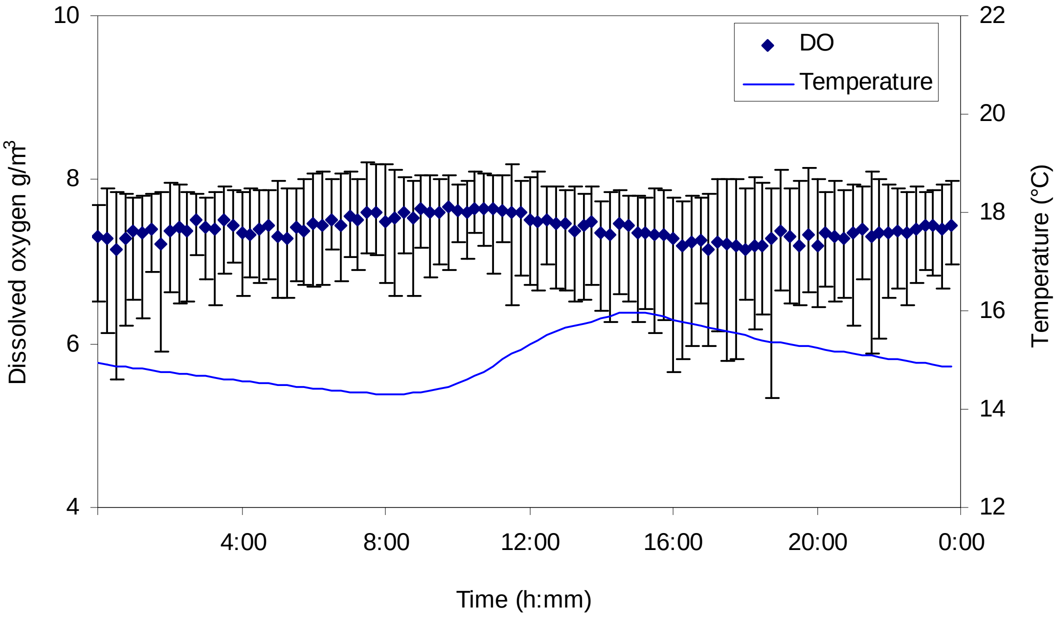


Figure 3.10: Dissolved oxygen concentrations in the tidal reach of **Waikanae Stream**. Oxygen concentrations were averaged for each time of day over the monitoring period (6-18 April) to give the average 24-hour cycle of dissolved oxygen (excludes high flow data 27 March to 5 April and declining stream temperatures 19 to 30 April). Error bars show the maximum and minimum for each time of day. Temperature is also presented on this graph (average for each time of day) as a likely driver of oxygen concentrations and because of the late deployment (datalogger deployed in autumn, cf. summer for other sites).

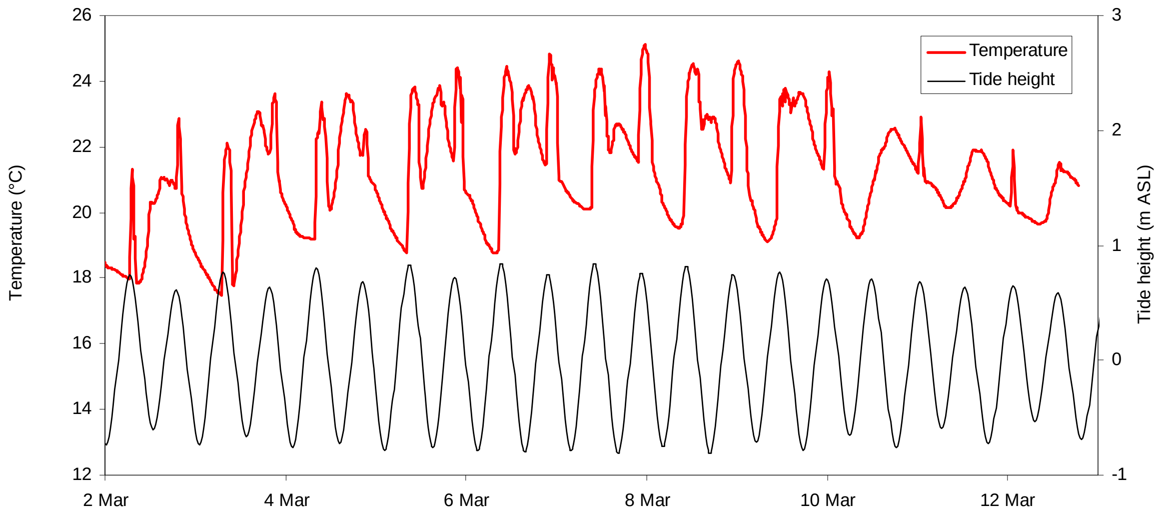


Figure 3.11: Temperature results for the **Waikawau River** (March 2007) indicate tidal influxes, with warm water intrusions at high tide (tidal data for Waikawau Bay from the NIWA tide forecaster).

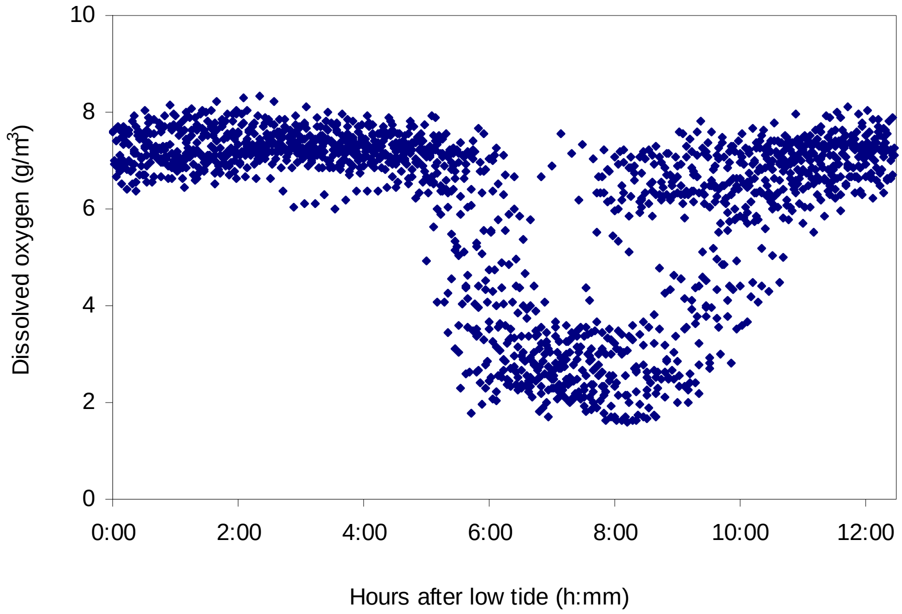


Figure 3.12: Dissolved oxygen is plotted against hours after low tide for the **Waikawau River**. The tidal cycle is about 12 hours and 30 minutes, hence low tide occurs at either end of this time scale, with high tide producing lower concentrations of dissolved oxygen. Salt water influxes likely affected sensor calibration at high tide.

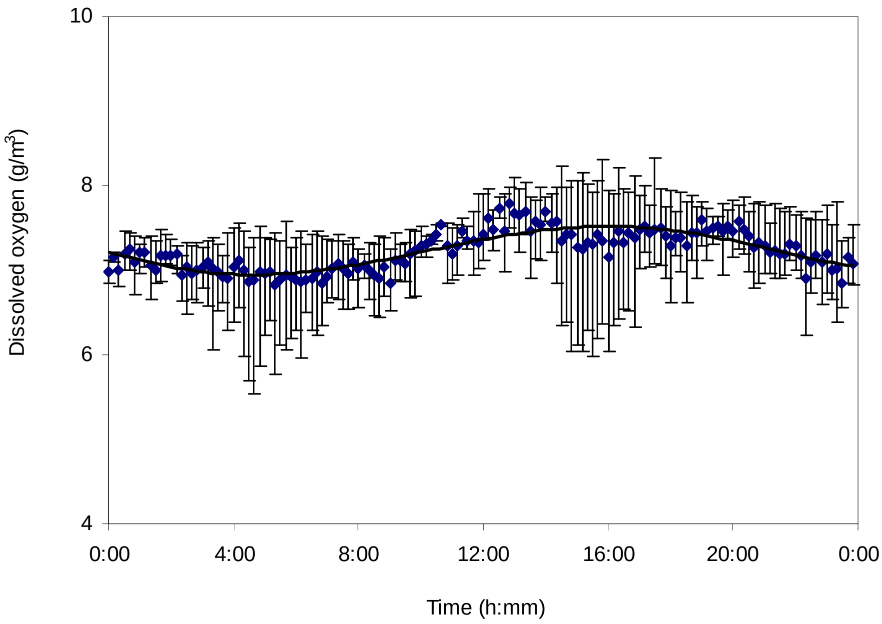


Figure 3.13: Dissolved oxygen concentrations in the tidal reach of the **Waikawau River**. Oxygen concentrations were averaged for each time of day over the monitoring period (1 to 12 March 2007) to give the average 24-hour cycle of dissolved oxygen (excludes high tide data, between 5 hours and 10 hours 40 minutes after low tide). Error bars show the maximum and minimum for each time of day. A polynomial trendline (5th order) was fitted for the calculation of modelling parameters (e.g., time of maximum DO).

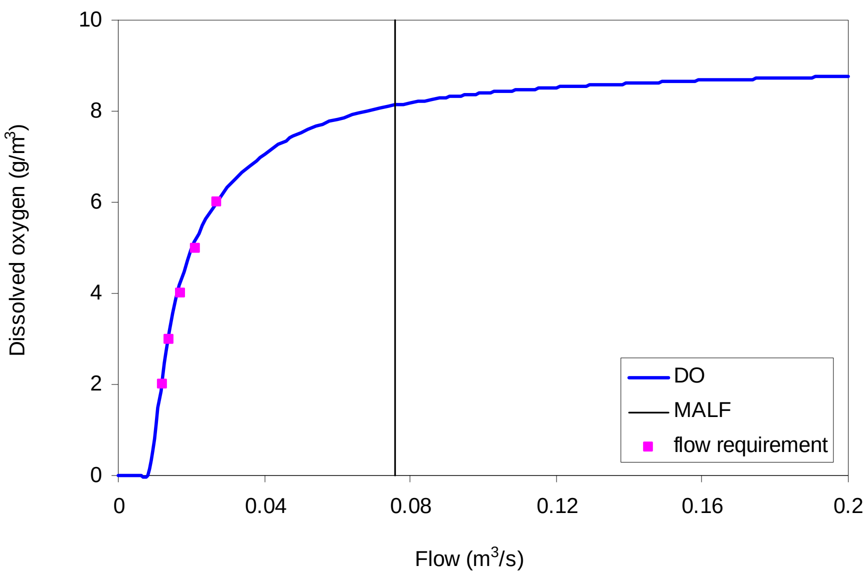


Figure 3.14: Predicted effect of reduced flow on dissolved oxygen concentrations (24-hour minimum) for **Waikawau River**. The MALF (mean annual low flow) is plotted, in addition to the flow requirements for nominal oxygen thresholds (as presented in Table 3.14).

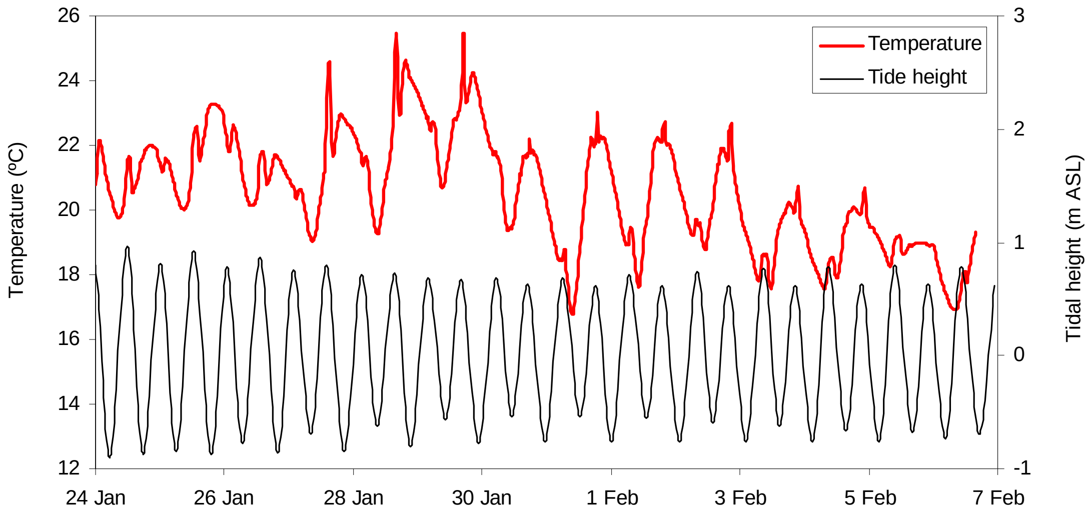


Figure 3.15: Temperature results for the **Wentworth River** (Jan/Feb 2007) indicate tidal influxes, with a temperature signature (warm or cold) at high tide (tidal data for Whangamata Harbour entrance were produced by the NIWA tide forecaster).

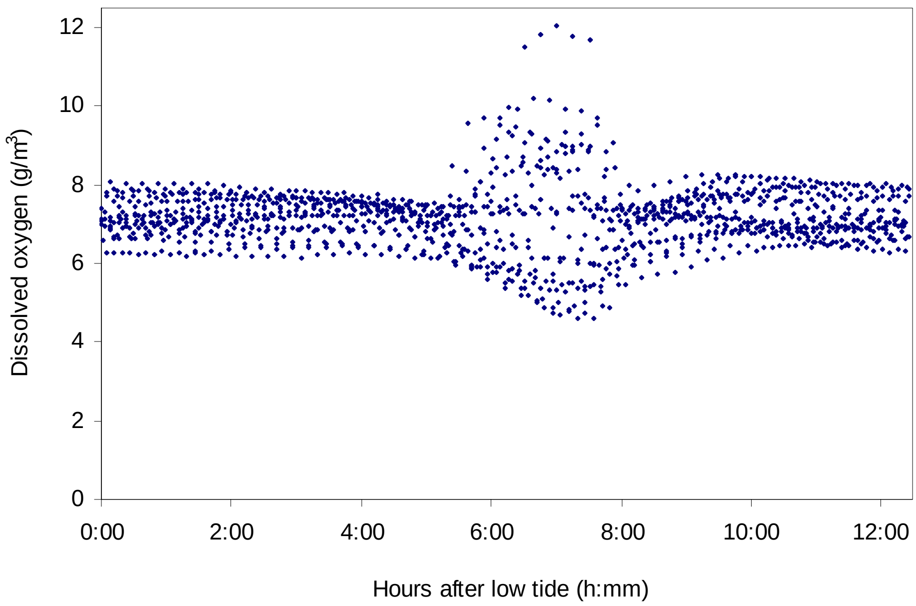


Figure 3.16: Dissolved oxygen is plotted against hours after low tide for the **Wentworth River**. The tidal cycle is about 12 hours 30 minutes, hence low tide occurs at either end of this time scale, with high tide associated with variable concentrations of dissolved oxygen. Salt water influxes at high tide likely affected sensor calibration.

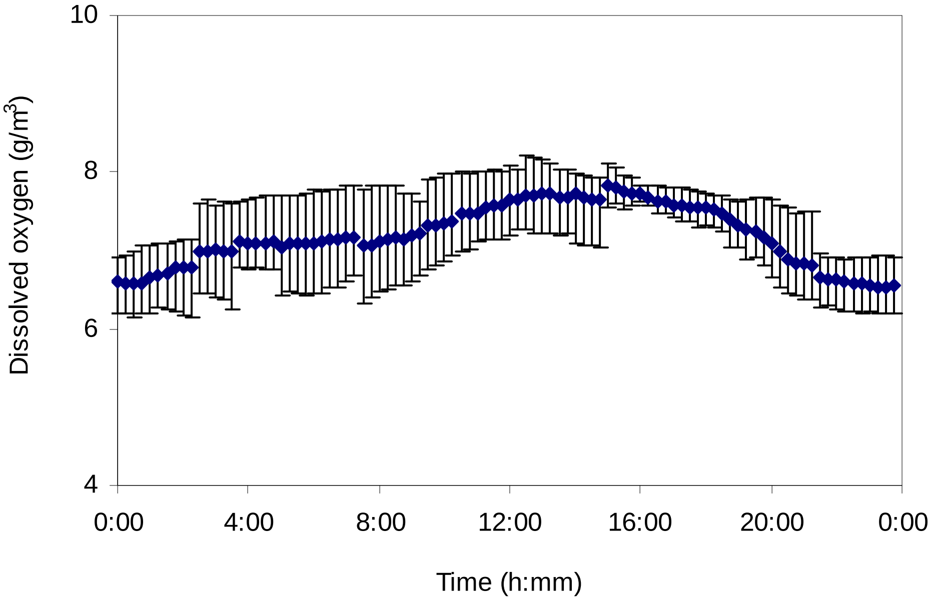


Figure 3.17: Dissolved oxygen concentrations in the tidal reach of **Wentworth River**. Oxygen concentrations were averaged for each time of day over the monitoring period (Jan-Feb) to give the average 24-hour cycle of dissolved oxygen (excludes high tide data, between 5 hours and 10 hours after low tide, and conductivity >250 µS). Error bars show the maximum and minimum for each time of day.

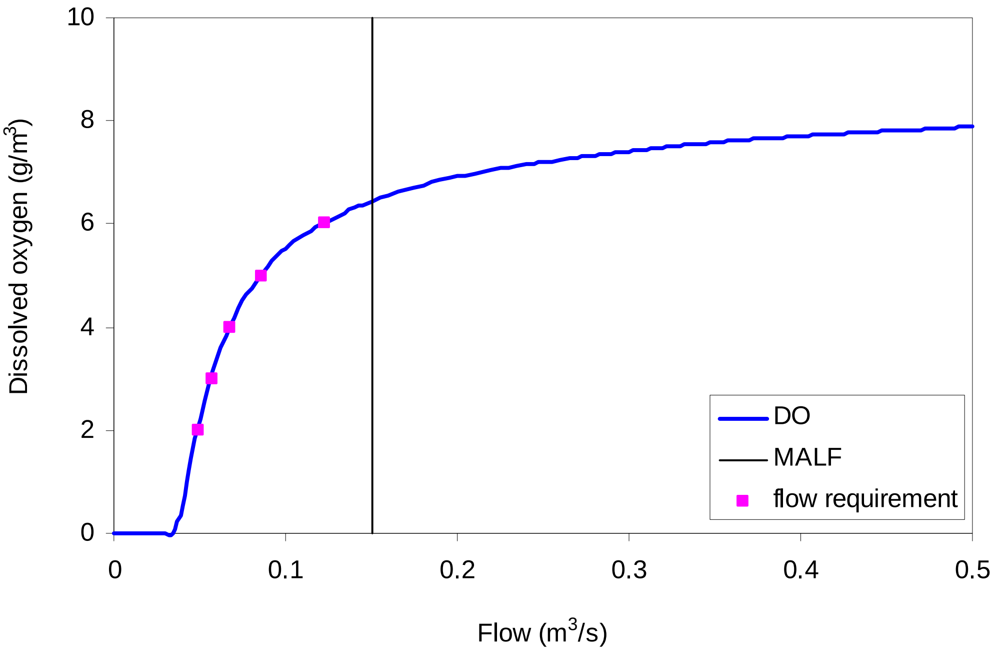


Figure 3.18: Predicted effect of reduced flow on dissolved oxygen concentrations (24-hour minimum) for **Wentworth River**. The MALF (mean annual low flow) is plotted, in addition to the flow requirements for nominal oxygen thresholds (as presented in Table 3.14).

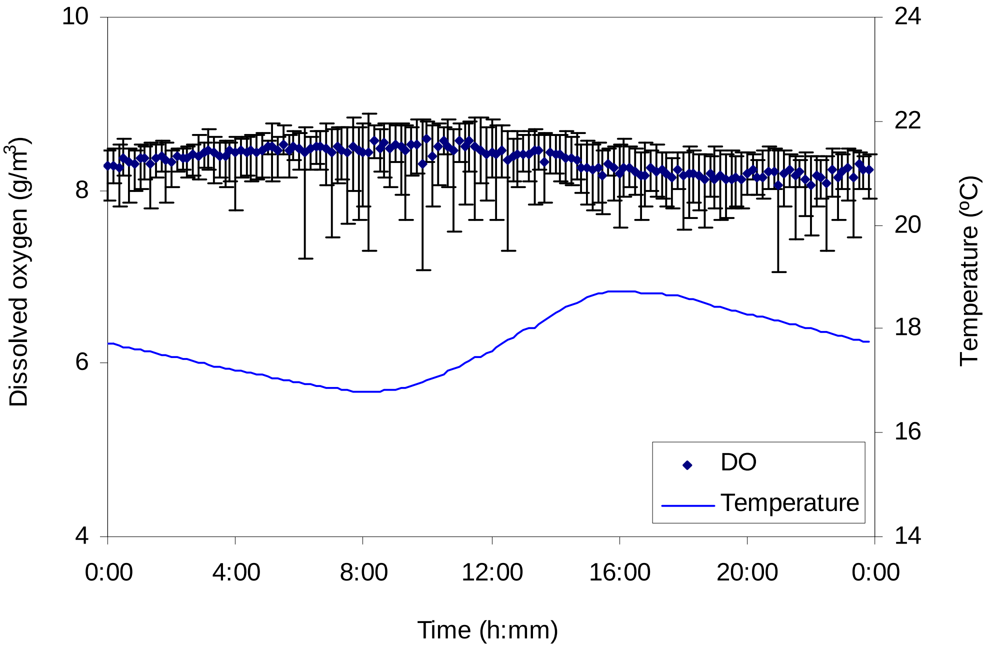


Figure 3.19: Dissolved oxygen concentrations in the tidal reach of **Whareroa Stream**. Oxygen concentrations were averaged for each time of day over the monitoring period (March) to give the average 24-hour cycle of dissolved oxygen. Error bars show the maximum and minimum for each time of day. Temperature is also presented on this graph (average for each time of day) as a likely driver of oxygen concentrations.

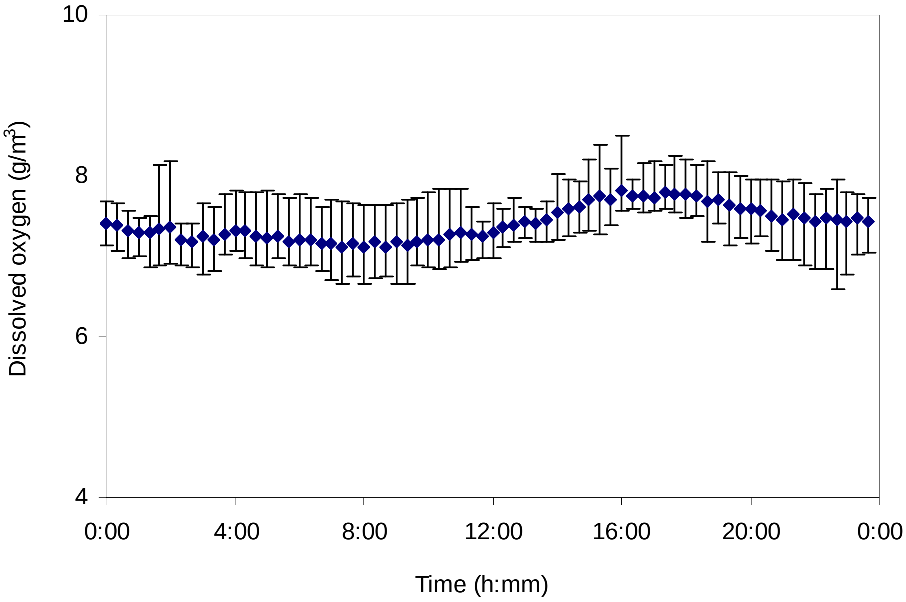


Figure 3.20: Dissolved oxygen concentrations in the tidal reach of **Wharekawa River**. Oxygen concentrations were averaged for each time of day over the monitoring period (March) to give the average 24-hour cycle of dissolved oxygen (excludes high tide data, between 5 hours and 8 hours 15 minutes after low tide, and depth >8m). Error bars show the maximum and minimum for each time of day. Data corrected for calibration shift (detected at recovery).

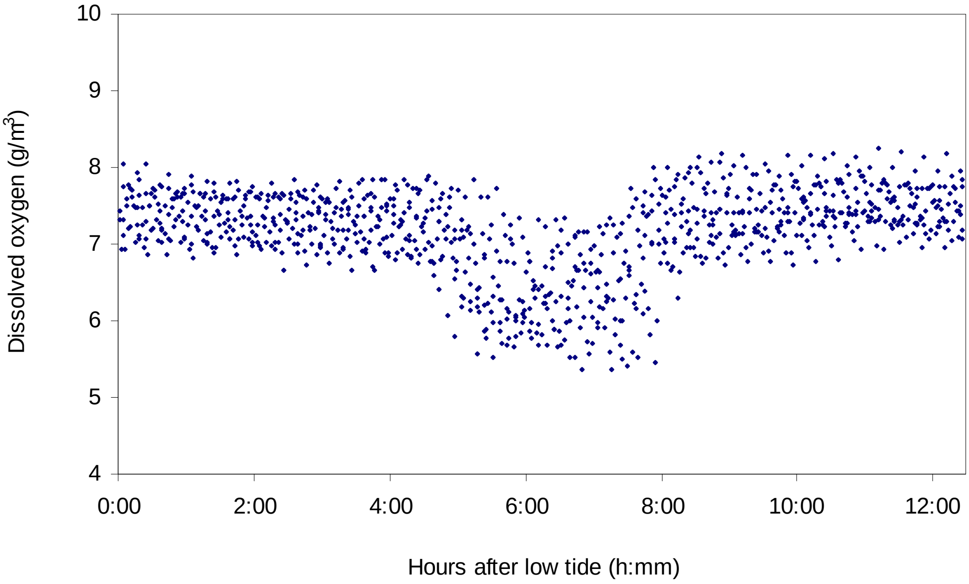


Figure 3.21: Dissolved oxygen is plotted against hours after low tide for the **Wharekawa River**. The tidal cycle is about 12 hours 30 minutes, hence low tide occurs at either end of this time scale, with high tide indicated by lower concentrations of dissolved oxygen.

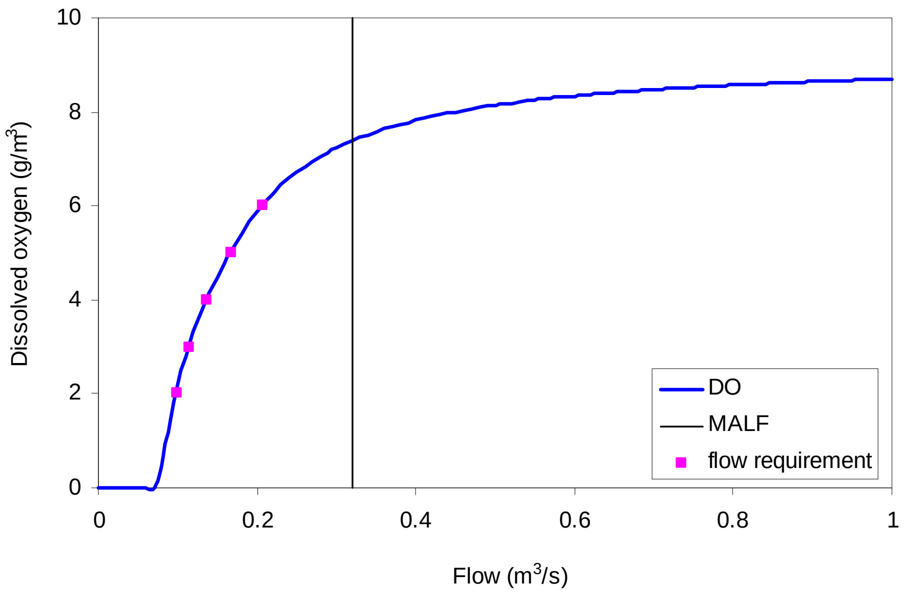


Figure 3.22: Predicted effect of reduced flow on dissolved oxygen concentrations (24-hour minimum) for **Wharekawa River**. The MALF (mean annual low flow) is plotted, in addition to the flow requirements for nominal oxygen thresholds (as presented in Table 3.14).

3.6 Applying results to other Coromandel streams

3.6.1 Habitat

The ability to predict the minimum flow requirements for other streams, based on hydrological statistics, would avoid the need to undertake full habitat surveys for every reach potentially affected by abstraction. Wilding (2002) found that such a method was feasible for areas of the Bay of Plenty. Equations were also successfully developed for upland streams of the Coromandel by Wilding (2007b). The generalised flow requirements for lowland streams of the Coromandel were investigated for this report. Lowland streams are distinguished from upland streams by a lower gradient, finer sediment (typically sand rather than cobble) and predominantly pool/run habitat (riffles are common in upland reaches). The five sites surveyed for this report compliment the four lowland sites surveyed previously (Whenuakite, Wharekawa, Opitonui, Wharekawa – see Appendix 7 for data summary).

The flow requirements for fish habitat in the nine lowland Coromandel streams were plotted against Q_5 (Figure 3.23). The results provide a close relationship, and the predictive equation is therefore considered an accurate descriptor of flow requirements for habitat in lowland reaches of the Coromandel area (minimum flow = 0.698 x (Q_5 to the power of 0.915)).

The minimum flows for lowland streams were derived using an 85% protection level, which maintains 85% of available habitat. Available habitat is defined as the primary flow (see Section 2.3 for the derivation of primary flow). The primary flow increases more steeply with MALF than the minimum flow (Figure 2.24).

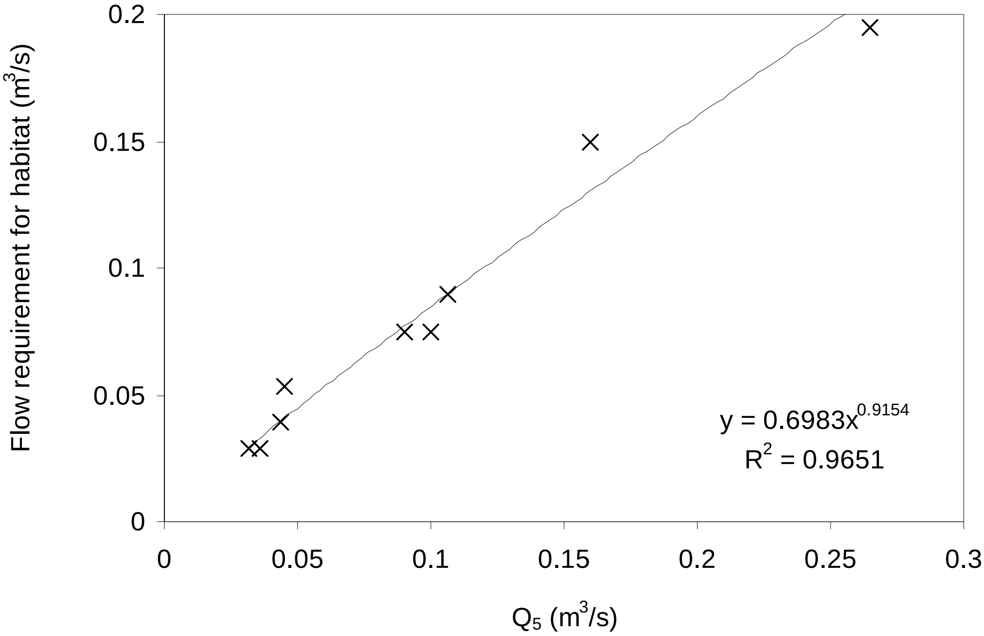


Figure 3.23: Minimum flows for fish habitat are plotted against Q_5 (five-year low flow) for lowland reaches of the Coromandel area.

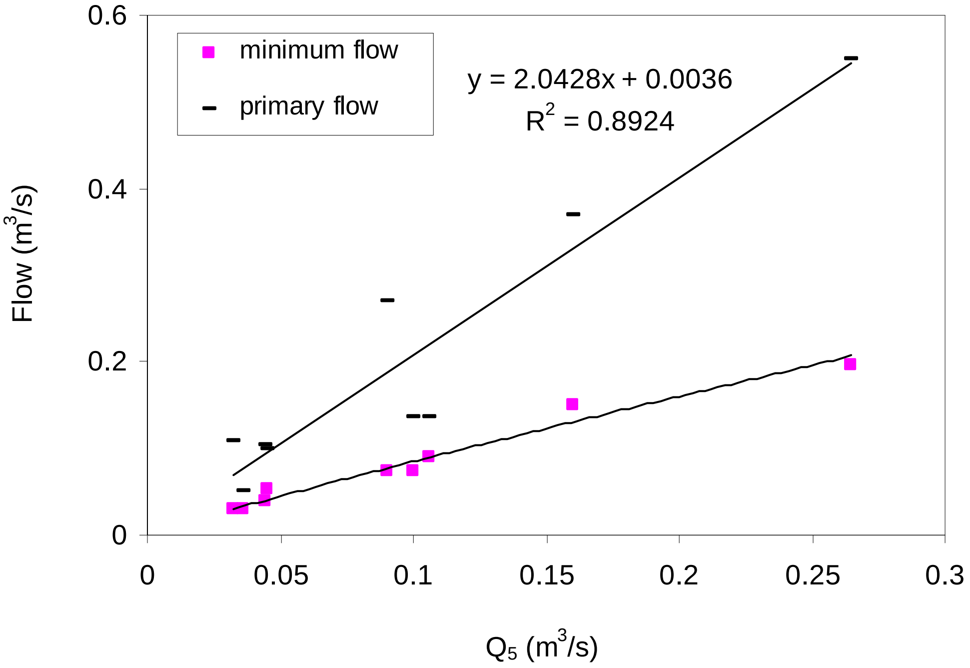


Figure 3.24: A comparison of the minimum flow with the primary flow (calculated using the Environment Bay of Plenty method), both plotted against the Q_5 for each lowland reach. The equation for the primary flow trendline is also presented. Put simply, the primary flow is the value for available habitat to which the protection level is applied to derive the minimum flow (Section 2.3 describes the primary flow in detail.).

3.6.2 Oxygen

Wilding (2007b) investigated potential predictors for identifying reaches where dissolved oxygen is potentially a critical issue. Stream gradient was investigated as a predictor, as measured by the distance from the stream mouth to the 20 m contour line (on topographical maps). A stream length greater than 5 km to the 20 m contour was proposed as an indicator of high-risk streams, with less than 2 km below 20 m altitude indicating low-risk streams (see Box 2.1). The intention is not to predict the flow requirements for oxygen, but where oxygen could be a critical issue requiring further investigation (i.e., where the flow requirement for oxygen could be higher than the flow requirement for fish habitat).

Streams were investigated for this report to further test and refine the key. Dissolved oxygen was modelled for seven reaches in total. Five of these were surveyed for this report (Waikanae, Waikawau, Whareroa, Stony, Wentworth). The Wharekawa River was re-modelled using oxygen data collected in 2007 and habitat data from 2006 (as presented in Wilding 2007b). The Whangamaroro River was modelled based on oxygen monitoring by Environment Waikato (March 2007) and habitat data from Wilding (2005).

The results reinforce the key proposed by Wilding (2007b), with streams below the 5 km cut-off maintaining oxygen concentrations greater than 6 g/m^3 (Figure 3.25). Streams with 5 to 10 km of stream below 20 m elevation all met the 4 g/m^3 guideline, but some required greater flows to achieve the 6 g/m^3 guideline (flows greater than the minimum flow requirement for fish habitat).

The same sites were also plotted as a flow requirement proportional to Q_5 (Figure 3.26). This is useful in demonstrating the relationship between stream gradient and oxygen suppression.

Environment Waikato monitored dissolved oxygen at an additional three sites to provide a dataset for testing the risk assessment key (Kaueranga, Waiwawa and Waiau). If monitoring was carried out during low flows (~MALF), then observed 24-hour minima could be compared to appropriate oxygen guidelines. Failure to meet the guidelines would indicate oxygen is potentially a critical issue for that reach. For monitoring that did not coincide with low flows, a significant diurnal-fluctuation in oxygen concentrations would be a more appropriate indicator of potential oxygen issues. These data provide a qualitative test of the risk assessment key, as flow requirements for dissolved oxygen or habitat were not determined.

Results from the three sites are presented in Appendix 8. The Kauaeranga and Waiau River were presumably monitored under low flow conditions (6 to 22 March 2007), with flows at monitored sites ranging from 65% to 125% of MALF (Opitonui, Wharekawa, Tairua, Tapu). The Whenuakite River was also used as a reference site, because oxygen is documented as a critical issue here (Wilding 2007a). Oxygen in the Whenuakite River dropped below 2 g/m^3 each day during this period. It is therefore reasonable to compare the observed 24-hour minima for the Kauaeranga and Waiau directly to oxygen guidelines. The Kauaeranga River maintained high oxygen concentrations over the monitoring period (Appendix 8), so oxygen is unlikely to be a critical issue here. However, the Waiau River dropped slightly below the 6 g/m^3 guideline for dissolved oxygen (average 24-hour minimum 5.88 g/m^3) and displayed marked diurnal fluctuations in dissolved oxygen (range 7.38 g/m^3). Flow estimates for this site range from 90% to 125% of MALF (based on Opitonui and Tapu correlations respectively). Flow requirements to maintain oxygen over 6 g/m^3 could be about MALF, which would exceed the predicted flow requirement for fish habitat ($<Q_5$). Therefore, dissolved may be a critical issue for the Waiau River if applying the higher oxygen standard (cf. 4 g/m^3). Oxygen suppression was not nearly as marked compared

to the Whenuakite River during the same period (see Appendix 8). With a stream length of 3.88 km below the 20 m contour, this river falls into the intermediate risk category (between 2 and 5 km below 20 m elevation).

The Waiwawa River was monitored during April, and certainly oxygen conditions at the reference site (Whenuakite River) had improved by this time (24-hour minimum dissolved oxygen increased from 1 g/m^3 in March to 5.7 g/m^3 in April). Direct comparison to the guideline values is therefore not appropriate. Instead diurnal oxygen fluctuations are a more appropriate indicator of oxygen being a potential issue. There was a measurable fluctuation in dissolved oxygen (1.47 g/m^3), about a high average of 9.29 g/m^3 of oxygen. Dissolved oxygen cannot be ruled out as a critical issue for this site, though it does seem unlikely. With a distance of 9.4 km to the 20 m contour, the Waiwawa River is classed as a high risk stream for low oxygen.

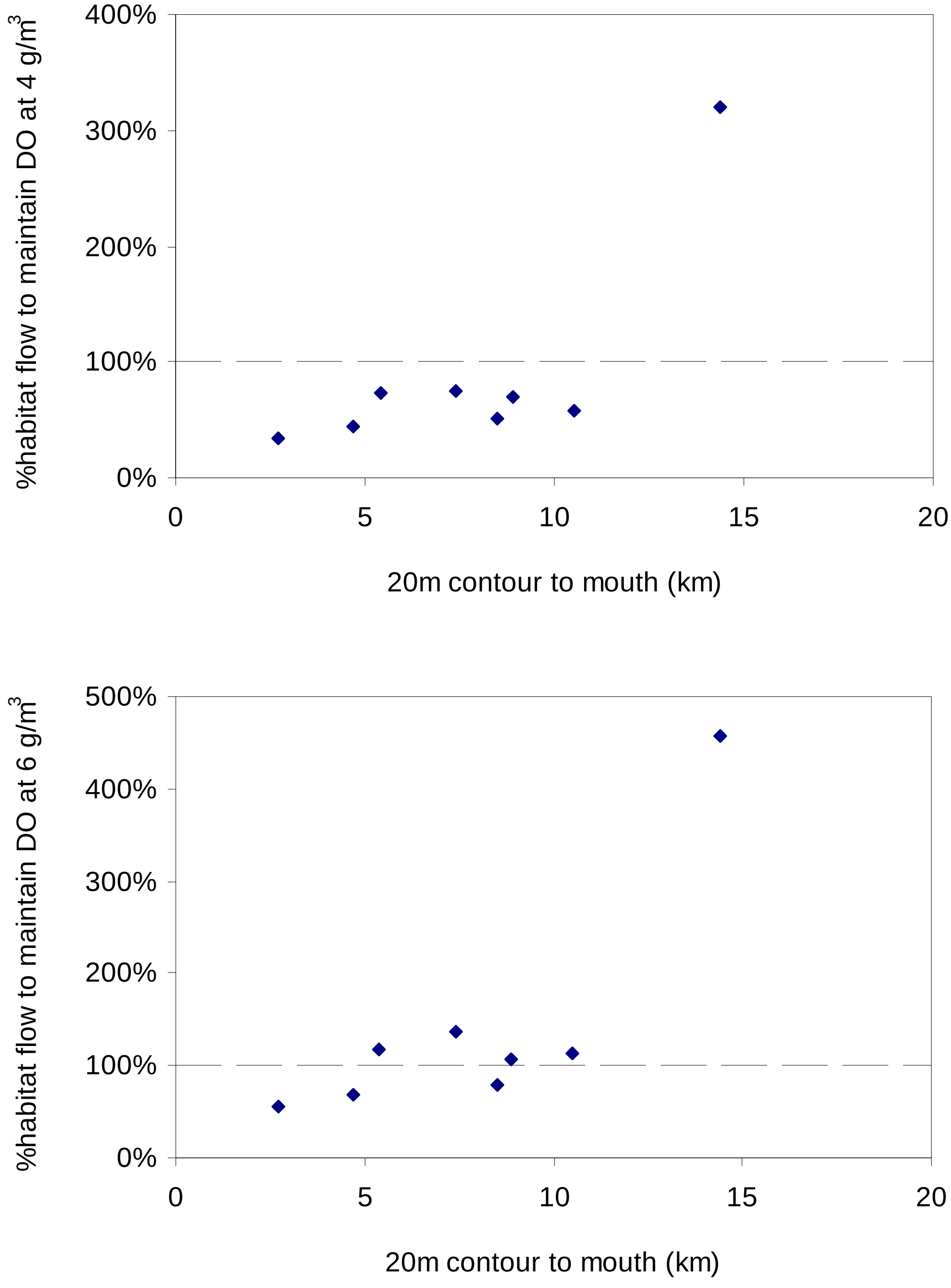
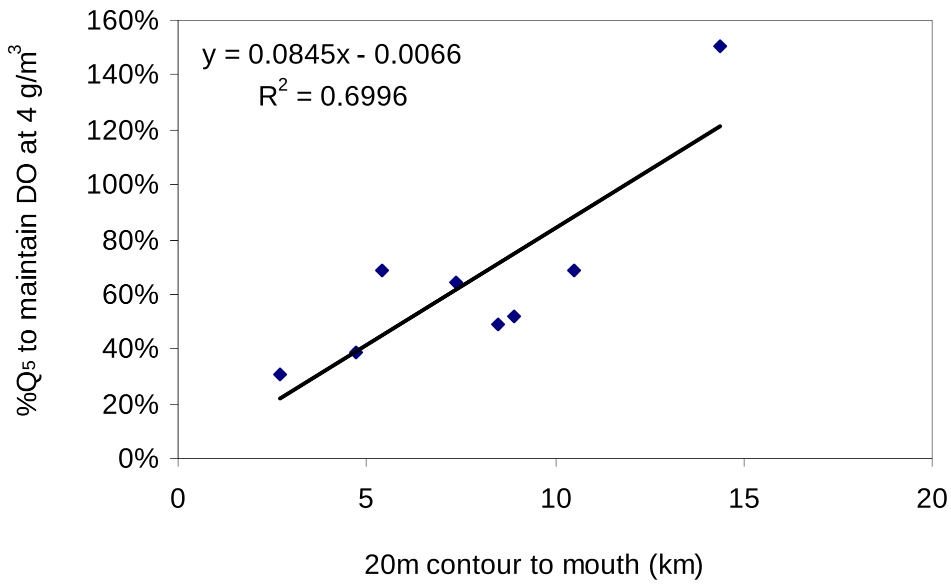


Figure 3.25: At sites where the flow requirement for dissolved oxygen exceeds the flow requirement for fish habitat, and so exceed 100% on the y-axis, oxygen is a critical issue for determining the minimum flow. This is plotted against a measure of stream gradient, using the stream length between the mouth and the 20 m altitude contour line (longer the distance, the lower the gradient). The two graphs present two guidelines for dissolved oxygen (4 and 6 g/m^3 as a 24-hour minimum).



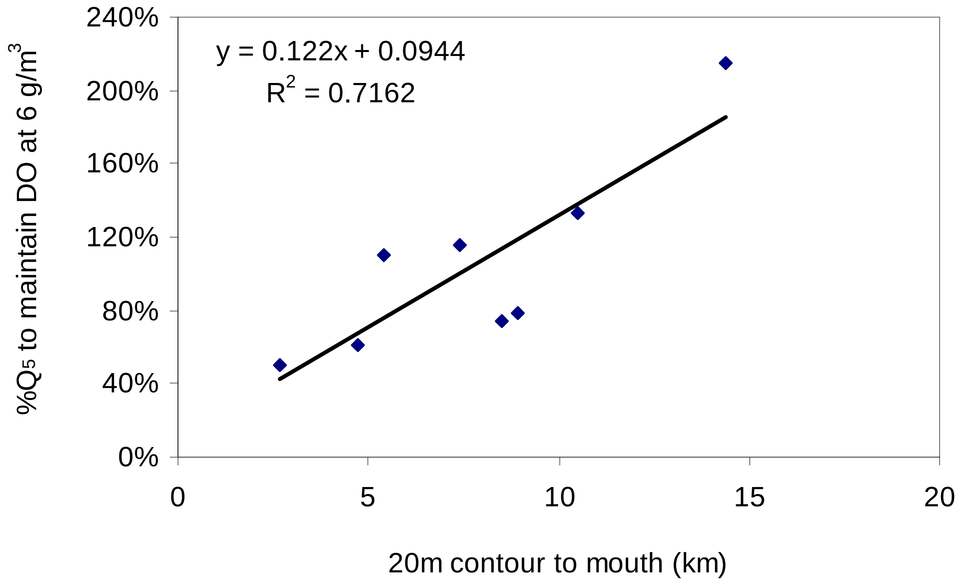


Figure 3.26: The relationship between stream gradient and oxygen suppression. Flow requirements for dissolved oxygen in tidal reaches are plotted as a proportion of Q_5. The stream length between the mouth and the 20 m contour line is used as a measure of gradient (longer the distance, the flatter the gradient).

4. Discussion

4.1 Minimum flow recommendations

Habitat and dissolved oxygen were assessed to determine the recommended minimum flow for ecosystem health of five Coromandel streams (Stony, Waikanae, Waikawau, Wentworth, Whareroa). The Wharekawa River was assessed previously (Wilding 2007b), but oxygen modelling was repeated in 2007 following recommendations from the previous report.

Deciding how much flow is required to maintain aquatic habitat will primarily be determined by two factors; how habitat changes with flow and what level of habitat protection is considered adequate. The Environment Bay of Plenty method sets out a predefined level of habitat protection (scaled according to ecosystem significance) to ensure consistent decision-making across the region (as described in Section 2.3 and Appendix 1). This method was used to derive the minimum flows for fish habitat, as presented in Table 4.1. Should the Waikato Region decide a more or less conservative protection level is acceptable, then this would change the minimum flow. The same principle also applies to choosing a guideline for dissolved oxygen – the desired level of protection, and the way oxygen changes with the flow, will determine the flow requirement to achieve this guideline (derivation of oxygen guidelines was described by Wilding 2007b).

With the level of protection predetermined for each issue, the following discussion for each stream compares the flow requirement for each issue in order to determine the recommended minimum flow. Results in this section refer to specific reaches of each stream (described in Section 2.1).

Stony Stream

Flow requirements for fish habitat in the Stony Stream were relatively high. Both the habitat modelling and natural flow statistics have a wider margin of error for the Stony Stream, because of the narrow flow range measured, which increased the susceptibility to any changes in the soft stream bed. Based on the available data, common bully have the highest flow requirement at 0.053 m^3/s (using the Environment Bay of Plenty method and a protection level of 85%).

Dissolved oxygen is potentially a critical issue for the Stony Stream, depending on which oxygen guideline is applied. The flow requirement to maintain dissolved oxygen concentrations above 4 g/m^3 (as a 24-hour minimum) is 0.031 m^3/s, and 0.06 m^3/s to exceed 6 g/m^3 of oxygen. The lower guideline value was recommended for application to highly modified catchments in the Coromandel area (Wilding 2007b). Half of the Stony catchment is pastoral, compared to 42% of the catchment of the Whenuakite River. Both could be considered highly modified catchments by Coromandel standards (though both are classed indigenous fishery by the Waikato Regional Plan – see Section 1.2). Adopting the lower oxygen guideline means that habitat is the critical issue, and the recommended minimum flow is 0.053 m^3/s. By default, this flow maintains oxygen concentrations over 5 g/m^3.

Waikanae Stream

The flow requirement for fish habitat, produced using the Environment Bay of Plenty method, was 0.038 m^3/s (Table 4.1). This is based on 85% of habitat at MALF for torrentfish. Even in the lowland reach there were several gravel riffles where torrentfish were caught. Flow requirements for invertebrates were lower than fish habitat (Table 4.1).

Monitoring indicated that oxygen concentrations in the Waikanae Stream were relatively high. There was no apparent afternoon peak in oxygen, suggesting little production or consumption by aquatic plants. For this reason, oxygen is not considered a critical issue for the Waikanae Stream. The recommended minimum flow for this reach is therefore based on flow requirements for fish habitat, at 0.038 m^3/s.

Waikawau River

The recommended minimum flow for fish habitat in the Waikawau River (lowland reach) is 0.039 m^3/s (Table 4.1). This flow maintains 85% of maximum habitat for common bully. A higher flow would be required to provide for torrentfish in this reach (0.054 m^3/s), but too few torrentfish reside in this reach (compared to nearby upland reaches) to justify the extra flow provision. The flow requirement for dissolved oxygen was relatively low at 0.027 m^3/s (Table 4.1), based on the higher 6 g/m^3 oxygen guideline.

Flow requirements for fish habitat are higher than for oxygen and invertebrate habitat, and therefore determines the recommended minimum flow of 0.039 m^3/s (Table 4.1).

Wentworth River

The flow requirement estimated for fish habitat in the Wentworth River was 0.090 m^3/s (Table 4.1). This was derived using the Environment Bay of Plenty method, providing 85% of habitat at MALF for common smelt. The flow requirement to exceed 6 g/m^3 of dissolved oxygen is greater than the flow requirement for fish habitat, and is also expected to maintain adequate invertebrate habitat (Table 4.1). The oxygen guideline of 6 g/m^3 is appropriate for this largely forested catchment (73% forest), so the recommend minimum flow is based on this guideline (0.123 m^3/s). However, a minimum flow based on fish habitat (0.090 m^3/s) offers a valid alternative for water managers, as it maintains relatively high oxygen concentrations (> 5 g/m^3) and a protection level of 73% for invertebrate habitat.

Whareroa Stream

As for the Waikanae Stream, dissolved oxygen concentrations remained high during the monitoring period, with little diurnal fluctuation. This well-shaded stream supports a small biomass of plants and receives little agricultural input (98% forest), so oxygen consumption through respiration is expected to be small. The flow requirement for fish habitat is therefore the critical issue for the Whareroa Stream. Common bully had the highest flow requirement of the fish expected to occur here (0.04 m^3/s required to maintain 85% of maximum habitat). The lowland reach does support a resident population of common bully of any magnitude (one caught, despite use of appropriate methods). The recommended minimum flow for fish habitat is therefore 0.029 m^3/s, based on shortfin eel. This flow is would maintain 73% of invertebrate habitat (percent of run habitat at MALF).

Wharekawa

Revised oxygen modelling for this report demonstrates that fish habitat is the critical issue for the Wharekawa River. A minimum flow of 0.208 m^3/s would maintain oxygen concentrations greater than 6 g/m^3. This flow is less than the flow requirement for fish habitat determined by Wilding (2007b) for both the midland and upland reaches (0.265 m^3/s and 0.405 m^3/s respectively). Therefore flow requirements should be based on fish habitat rather than dissolved oxygen.

4.2 Applying results elsewhere

The potential for applying results from the minimum flow investigations completed so far to other lowland streams in the Coromandel area was investigated (Section 3.6). Previous research for upland reaches found habitat was the critical issue, and equations were derived to predict flow requirements for unstudied reaches (Wilding 2007b). For lowland reaches, both habitat and dissolved oxygen are potentially critical issues for setting minimum flows. Therefore, applying results to as yet unstudied reaches will require consideration of both issues. Lowland streams are distinguished from upland streams by a lower gradient, finer sediment (typically sand rather than cobble) and predominantly pool/run habitat (riffles are common in upland reaches).

Habitat for lowland reaches

Flow requirements for fish habitat in lowland streams of the Coromandel area provided a good relationship with Q_5 (Section 3.6.1). Flow requirements for fish habitat were derived using the Environment Bay of Plenty method and a protection level of 85%. The equation allows a greater reduction in flow (minimum flow = 698 x (Q_5 to the power of 0.915); units are m^3/s), compared to upland streams. The original equations produced for upland streams by Wilding (2007b) used MALF as the predictor (minimum flow = 0.8127 x MALF). To allow direct comparison to the results of this report, the upland streams were replotted against Q_5 (Appendix 9). This demonstrates a higher flow requirement for upland reaches. So in terms of habitat at least, lowland reaches should not be a limiting factor for allocation of water from upland reaches.

Dissolved oxygen

A decision key was proposed by Wilding (2007b) for identifying reaches where oxygen was a potentially critical issue, and therefore requiring further investigation (reproduced in Box 2.1). Results from subsequent modelling generally support this key (Section 3.6.2). The reaches where oxygen was a critical issue all fell into the high-risk category (distance from the coast to the first 20 m contour is greater than 5 km). Stony Stream deviated from the expectation that reaches further inland than half-way between the coast and the 20 m contour are not at risk of oxygen suppression. The revised decision key therefore excludes this component.

Oxygen monitoring of the Waiau River indicated oxygen may be a critical issue, if applying the higher dissolved oxygen guideline (6 g/m^3). This is the only intermediate risk stream (streams with 2 to 5 km below 20 m elevation) to show signs of oxygen suppression. The tidal reach experienced large diurnal fluctuations in dissolved oxygen, dipping below the 6 g/m^3 guideline (average 24-hour minimum 5.88 g/m^3). This suggests the intermediate risk class should be retained in the decision key. In managing the intermediate risk streams, we could simply use the flow requirements for fish habitat and accept some risk of oxygen dropping below guideline concentrations in these streams. Alternatively, these streams could be treated as high-risk streams, requiring site-specific oxygen investigations.

The key was therefore revised as follows, to support the desktop selection of Coromandel streams that have a greater likelihood or risk of oxygen being a critical issue for determining minimum flow requirements.

- Low risk reaches

  - those at greater than 20 m elevation;

  or - reaches below 20 m elevation and with less than 2 km of stream length below this elevation (producing an average gradient >0.01 m/m).

- High risk reaches

  - reaches below 20 m elevation and with more than 5 km of stream length below this elevation.

Reaches that do not meet either criterion (between 2 and 5 km of stream below 20 m elevation) are classed as intermediate risk.

The key would potentially trigger site specific investigations when setting instream flow requirements. Site-specific investigations would likely take the form of continuous oxygen monitoring, preferably during summer/early-autumn. If low-flow conditions were present during monitoring (~MALF) then observed daily minima could be compared to appropriate oxygen guidelines. If the guidelines are not met, then oxygen modelling work should be carried out to determine a flow requirement (e.g., using the WAIORA method, with flow measurements and depth profiles). Monitoring may not always coincide with low flows, in which case a significant diurnal-fluctuation in oxygen concentrations could be used as a trigger for oxygen modelling.

Table 4.1: Recommended minimum flows (m^3/s) are presented for each of the five Coromandel streams surveyed, in addition to issue-specific minimum flows that the recommendations are based on. Oxygen monitoring results for the Waikanae and Whareroa Streams indicated oxygen was not a critical issue. Otherwise, minimum flows are specified (m^3/s) and the protection levels used to derive them are given in the footnotes. In the absence of an established protection level for the Waikato Region, the Environment Bay of Plenty method was used here. Should a more or less conservative protection level be adopted for the Waikato Region, this would change the minimum flows produced. Natural flow estimates are provided for each reach (Q_5 is the one in 5-year 7-day low flow, MALF is the 7-day mean annual low flow).

m^3/s	Stony Stream	Waikanae Stream	Waikawau River	Wentworth River	Whareroa Stream	Wharekawa River (midland)
Dissolved oxygen	0.031 [A]	Not critical	0.027 [B]	0.123 [B]	Not critical	0.208 [B]
Fish habitat	0.053 [C]	0.038 [D]	0.039 [C]	0.090 [E]	0.029 [F]	0.265 [G]
Invertebrate habitat	0.046 [H]	0.035 [H]	0.037 [H]	0.114 [H]	0.042 [H]	0.08 [G]
Recommended minimum flow	0.053	0.038	0.039	0.123	0.029	0.265
Q_5	0.045	0.036	0.044	0.106	0.032	0.265
MALF	0.055	0.051	0.076	0.137	0.054	0.32
Median flow	0.16	0.12	0.20	0.48	0.14	0.81

A. Flow required to exceed the selected dissolved oxygen guideline of 4 g/m^3.
B. Flow required to exceed the selected dissolved oxygen guideline of 6 g/m^3.
C. Flow required to maintain 85% of maximum habitat for common bully.
D. Flow required to maintain 85% of habitat available at MALF for torrentfish.
E. Flow required to maintain 85% of habitat available at MALF for common smelt.
F. Flow required to maintain 85% of maximum habitat for shortfin eel.
G. From Wilding (2007b).
H. Flow required to maintain 85% of run habitat available at MALF.

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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[2]	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).

[2] 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

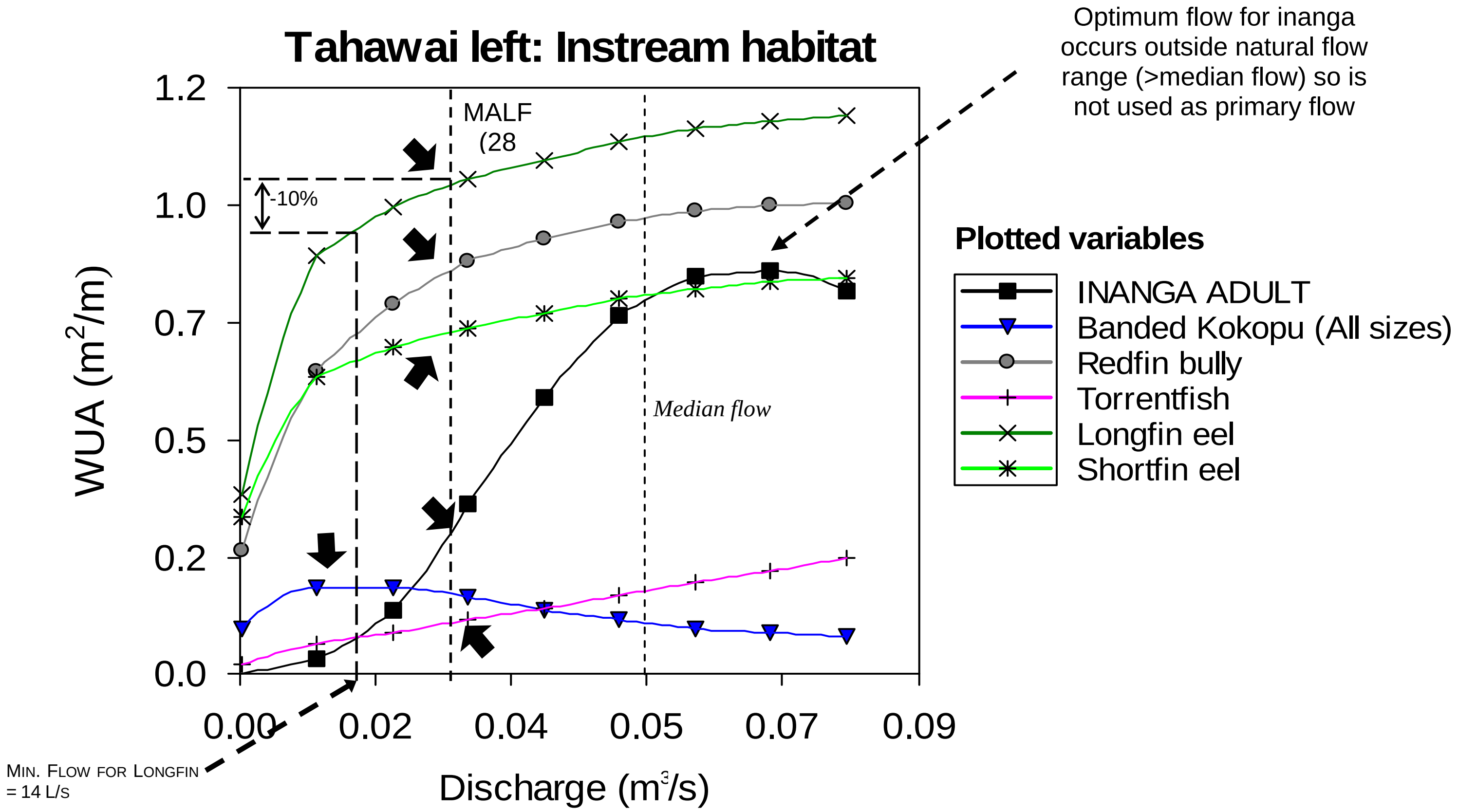
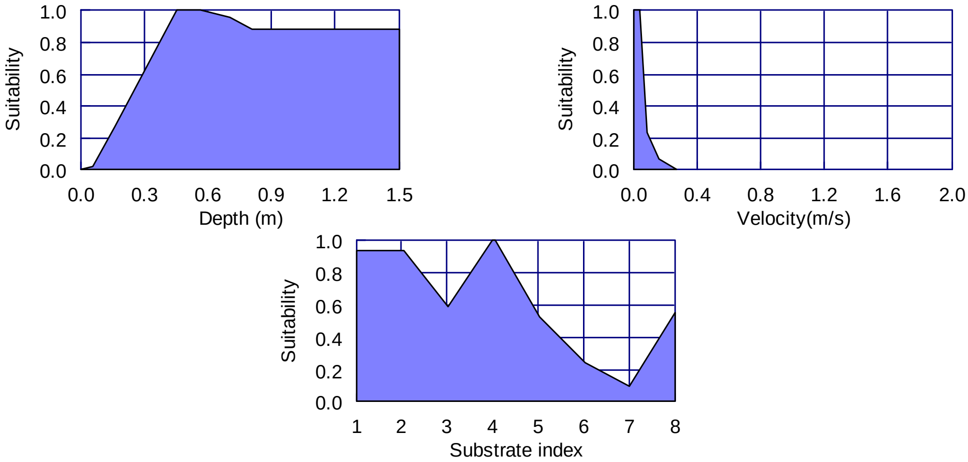


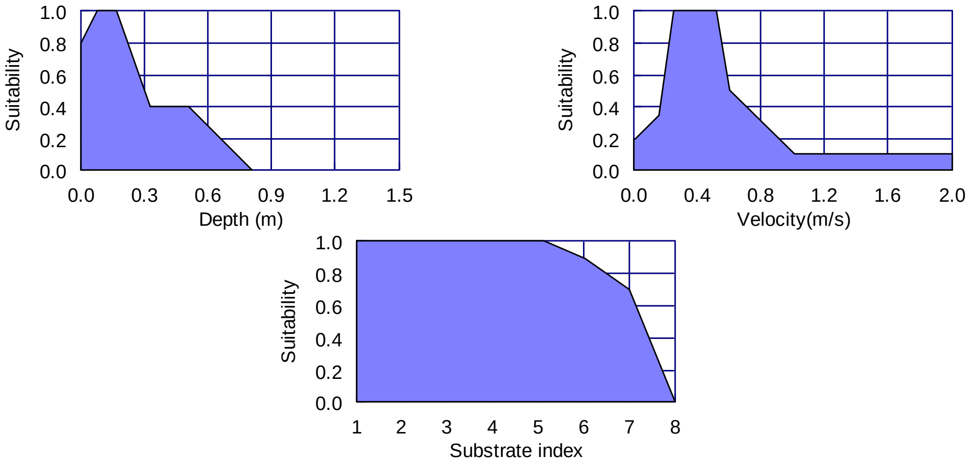
Figure 1: Modelled habitat for the Tahawai Stream (western BOP) expressed as habitat (WUA m^2/m) versus flow. Primary flows determined using established criteria are arrowed for each species. Minimum flow calculation for longfin eel illustrated. Note, this is presented as an example only, as taxa and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

8. Appendix 2 Habitat Suitability Curves

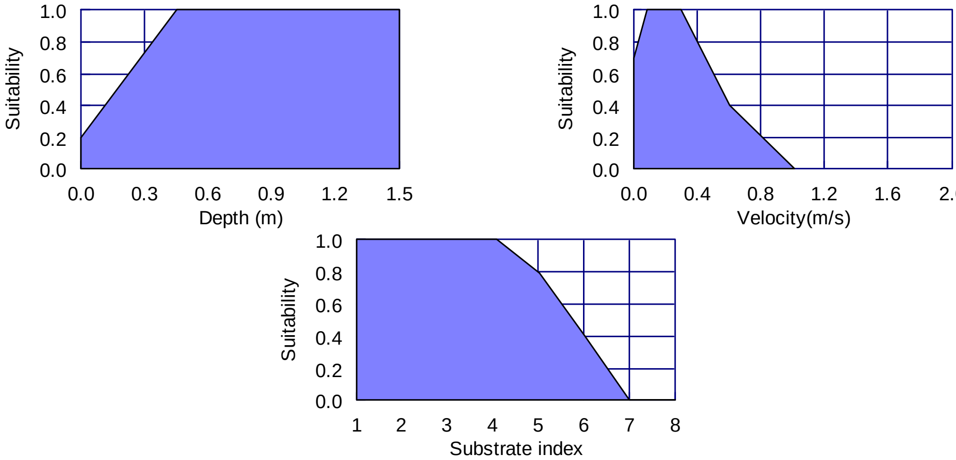
Banded Kokopu 1+ (McCullough 1998)



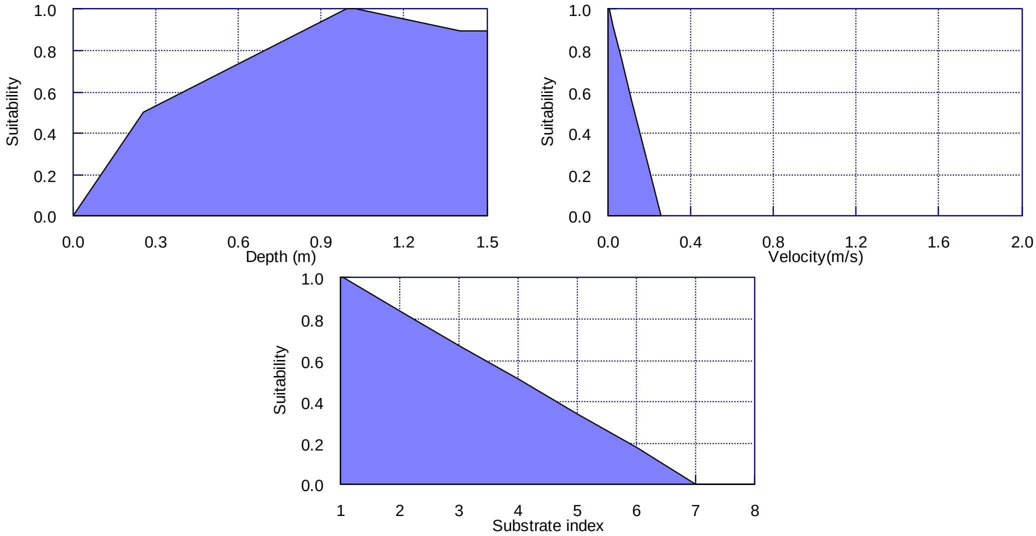
Common bully (Jowett & Richardson 1995)



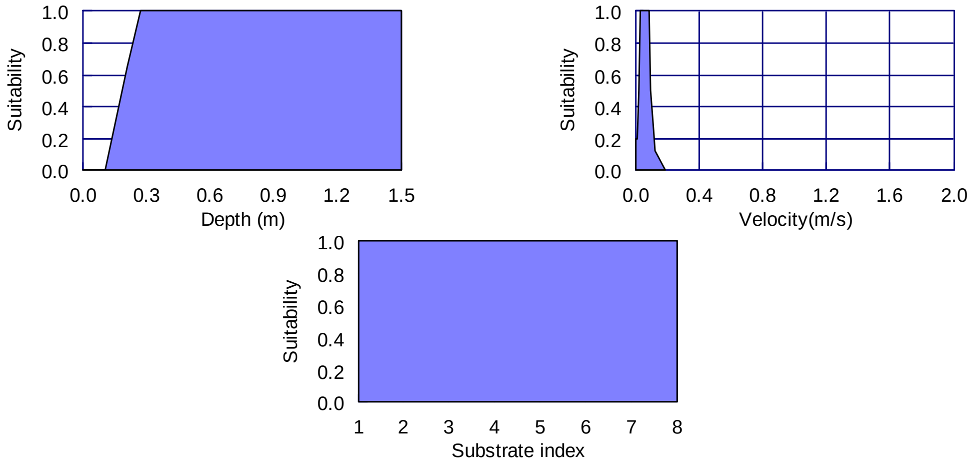
Common smelt



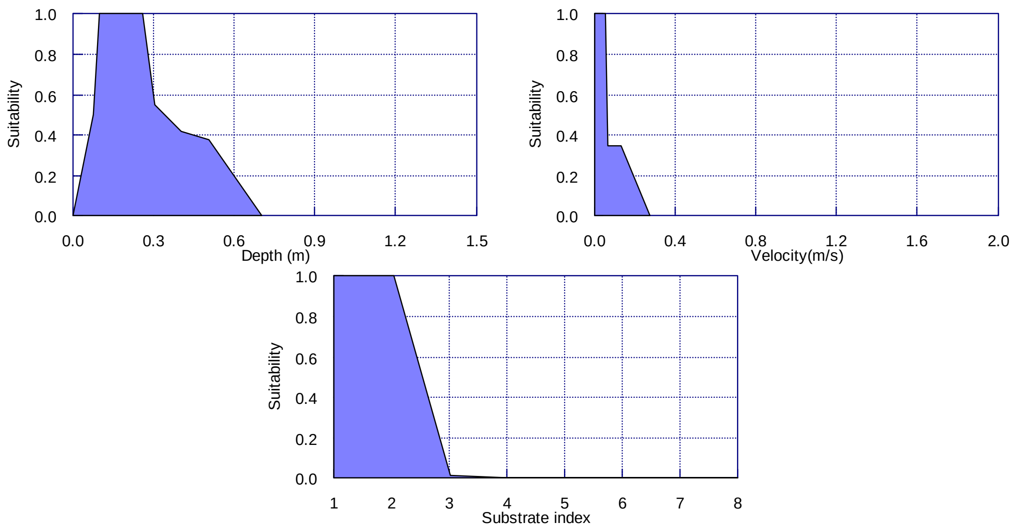
Giant kokopu (smoothed data from Bonnett & Sykes 2002)



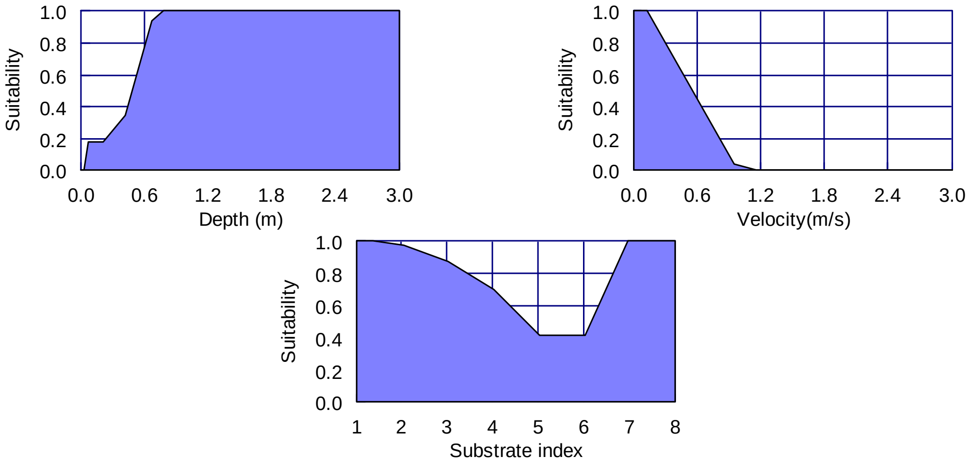
Inanga feeding (Jowett 2002)



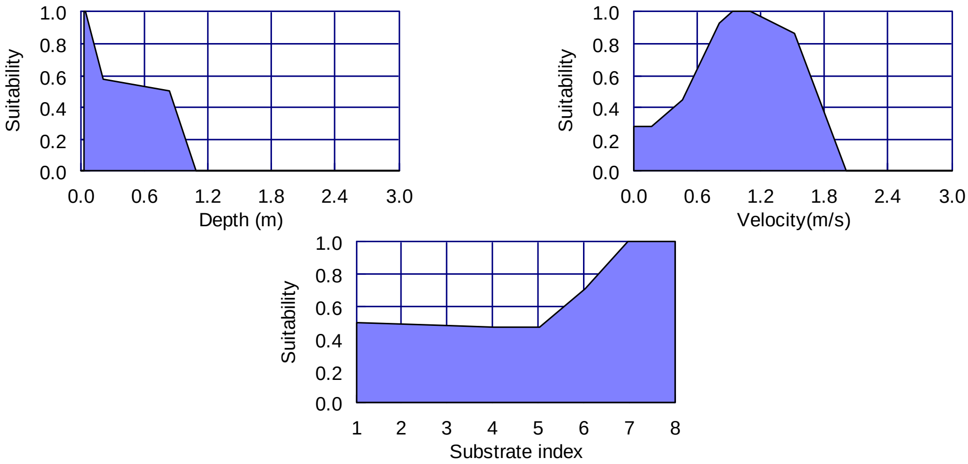
Juvenile lamprey (Jellyman & Glova 2002)



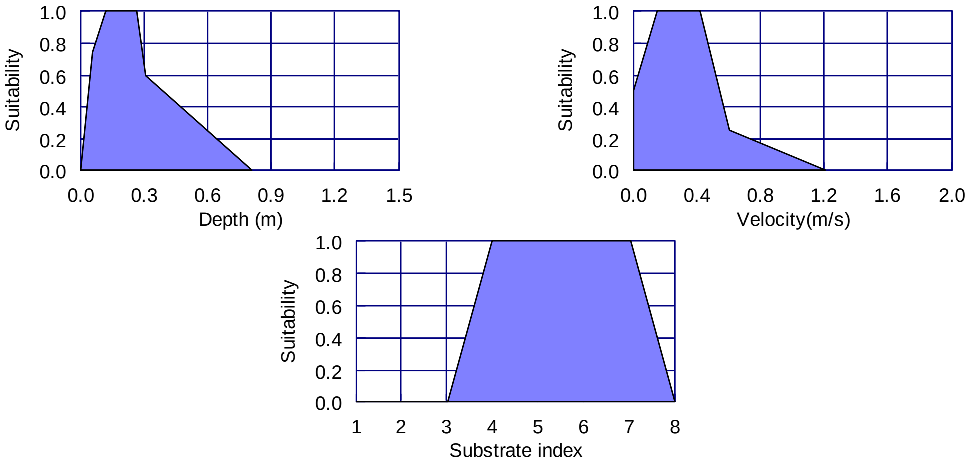
Longfin eels >300 mm (Jellyman et al. 2003)



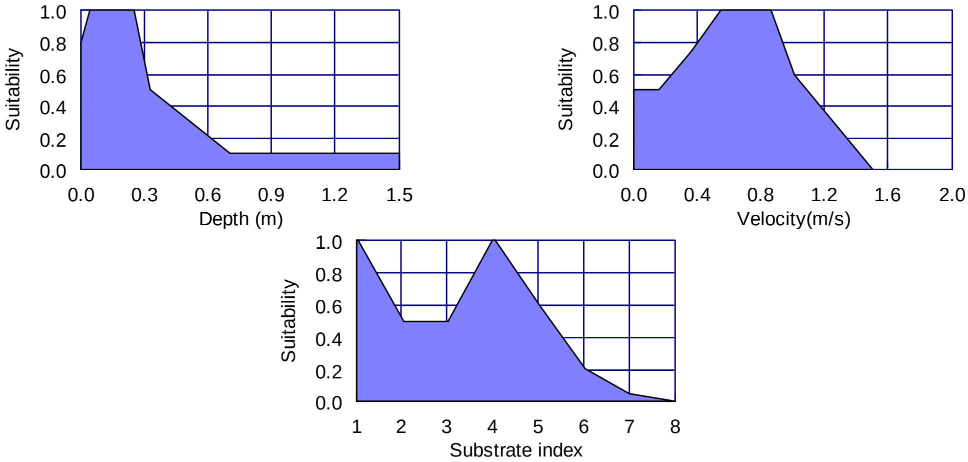
Longfin eels <300 mm (Jellyman et al. 2003)



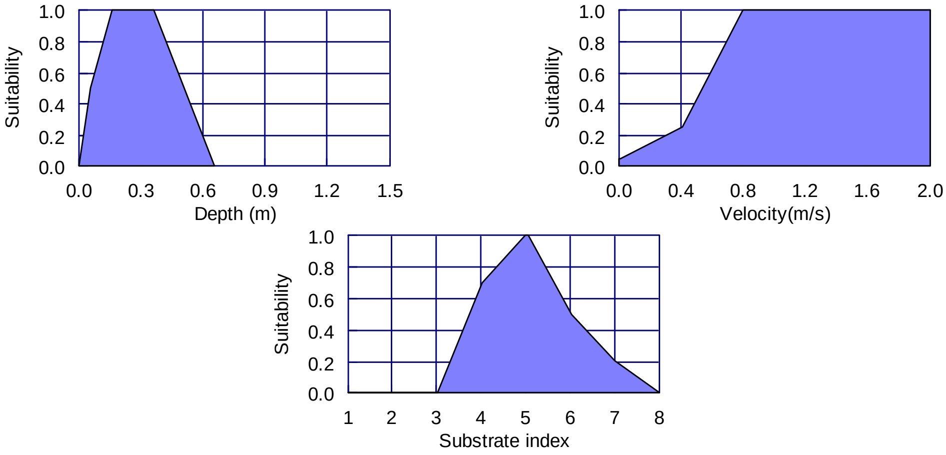
Redfin bully (Jowett & Richardson 1995)



Shortfin eel <300mm (Jowett & Richardson 1995)



Torrentfish (Jowett & Richardson 1995)



9. Appendix 3: Rating curve changes.

Changes to the default rating curves (as produced from the raw data) are detailed for each reach (entries were only included in this table where changes to the default were necessary). 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). The default rating gave the best ratings for this study. Rating exponents normally fall within the range of 2.5 to 3.5 and were adjusted up or down if well outside this range.

Cross-section	Calculated exponent	Nominated exponent	Other changes
Stony Stream			
3			Used hydraulic rating
12			Deleted SZF
13			Used hydraulic rating Outlier gauging deleted (14/12/06).
14			Deleted SZF Outlier gauging deleted (14/12/06).
15			Outlier gauging deleted (14/12/06).
Waikanae Stream			
			No changes necessary
Waikawau Stream			
6			Outlier gauging deleted (11/12/06).
Wentworth River			
2			Deleted SZF
3			Deleted SZF
13	0.93	2.5	
Whareroa Stream			
1-15			Deleted March gaugings (suspect change in channel shape)
4			Used hydraulic rating
9b			Deleted outlier gauging (9/1/07 14:20). Use hydraulic rating.
10			Used hydraulic rating.

10. Appendix 4 GPS locations for survey sites

Metric grid-references recorded from Garmin e-trex GPS units. These are given for tide survey stakes and habitat survey cross-sections (see Table 2.2 for dissolved oxygen logger locations).

Stream	Peg	Easting	Northing	notes
Stony	tide peg 1	2757703	6454358	<tide limit
Stony	tide peg 2	2757639	6454563	
Stony	tide peg 3	2757690	6454622	
Stony	tide peg 4	2757709	6454655	
Stony	tide peg 5	2757731	6454709	
Stony	tide peg 6	2757741	6454736	
Stony	tide peg 7	2757674	6454286	
Stony	tide peg 8	2757478	6454198	
Stony	tide peg 9	2757584	6454179	
Waikanae	tide peg 1	2735487	6508123	
Waikanae	tide peg 2	2735501	6508055	
Waikanae	tide peg 3	2735499	6508009	
Waikanae	tide peg 4	2735490	6507965	
Waikanae	tide peg 5	2735486	6507912	
Waikanae	tide peg 6	2735497	6507817	
Waikanae	tide peg 7	2735506	6507746	<tide limit
Waikawau	tide peg 1	2734300	6509884	
Waikawau	tide peg 10	2734864	6509134	
Waikawau	tide peg 2	2734336	6509820	
Waikawau	tide peg 3	2734353	6509758	
Waikawau	tide peg 4	2734373	6509698	
Waikawau	tide peg 5	2734521	6509639	
Waikawau	tide peg 6	2734486	6509537	
Waikawau	tide peg 7	2734516	6509462	
Waikawau	tide peg 8	2734571	6509423	
Waikawau	tide peg 9	2734635	6509422	
Wentworth	tide peg 1	2764425	6438623	
Wentworth	tide peg 10	2763676	6438057	
Wentworth	tide peg 2	2764292	6438726	
Wentworth	tide peg 3	2764189	6438718	
Wentworth	tide peg 4	2764181	6438611	
Wentworth	tide peg 5	2764064	6438557	
Wentworth	tide peg 6	2763853	6438441	
Wentworth	tide peg 7	2763695	6438289	<tide limit
Wentworth	tide peg 8	2763677	6438206	
Wentworth	tide peg 9	2763767	6438159	
Whareroa	tide peg 1	2738395	6501826	<tide limit
Whareroa	tide peg 2	2738424	6501686	
Whareroa	tide peg 3	2738413	6501647	
Whareroa	tide peg 4	2738475	6501595	
Whareroa	tide peg 5	2738518	6501533	

Stream	Habitat cross-section	Easting	Northing
Stony	XS1	2757398	6454202
Stony	XS2	2757416	6454199
Stony	XS3	2757429	6454196
Stony	XS4	2757440	6454197
Stony	XS5	2757449	6454203
Stony	XS6	2757469	6454205
Stony	XS7	2757483	6454195
Stony	XS8	2757496	6454183
Stony	XS9	2757503	6454171
Stony	XS10	2757514	6454161
Stony	XS11	2757526	6454154
Stony	XS12	2757539	6454145
Stony	XS13	2757560	6454129
Stony	XS14	2757562	6454156
Stony	XS15	2757572	6454168
Waikanae	XS1	2735352	6507400
Waikanae	XS2	2735354	6507398
Waikanae	XS3	2735367	6507404
Waikanae	XS4	2735387	6507438
Waikanae	XS5	2735389	6507439
Waikanae	XS6	2735393	6507444
Waikanae	XS7	2735408	6507462
Waikanae	XS8	2735412	6507465
Waikanae	XS9	2735422	6507478
Waikanae	XS10	2735423	6507481
Waikanae	XS11	2735429	6507496
Waikanae	XS12	2735432	6507497
Waikanae	XS13	2735439	6507501
Waikanae	XS14	2735450	6507514
Waikanae	XS15	2735455	6507523
Waikawau	XS1	2734269	6509969
Waikawau	XS2	2734273	6509952
Waikawau	XS3	2734285	6509931
Waikawau	XS4	2734294	6509912
Waikawau	XS5	2734291	6509916
Waikawau	XS6	2734291	6509910
Waikawau	XS7	2734296	6509894
Waikawau	XS8	2734300	6509885
Waikawau	XS9	2734304	6509879

Stream	Habitat cross-section	Easting	Northing
Waikawau	XS10	2734306	6509847
Waikawau	XS11	2734308	6509833
Waikawau	XS12	2734308	6509831
Waikawau	XS13	2734329	6509823
Waikawau	XS14	2734337	6509822
Waikawau	XS15	2734343	6509822
Waikawau	XS16	2734356	6509772
Wentworth	XS1	2763565	6438209
Wentworth	XS5	2763594	6438169
Wentworth	XS10	2763603	6438118
Wentworth	XS15	2763645	6438063
Whareroa	XS2	2738449	6501932
Whareroa	XS3	2738441	6501924
Whareroa	XS4	2738442	6501920
Whareroa	XS5	2738436	6501914
Whareroa	XS6	2738424	6501887
Whareroa	XS7	2738421	6501895
Whareroa	XS8	2738418	6501897
Whareroa	XS9	2738412	6501874
Whareroa	XS9b	2738404	6501862
Whareroa	XS10	2738399	6501855
Whareroa	XS11	2738400	6501850
Whareroa	XS12	2738384	6501844
Whareroa	XS13	2738387	6501840
Whareroa	XS14	2738388	6501834
Whareroa	XS15	2738395	6501823

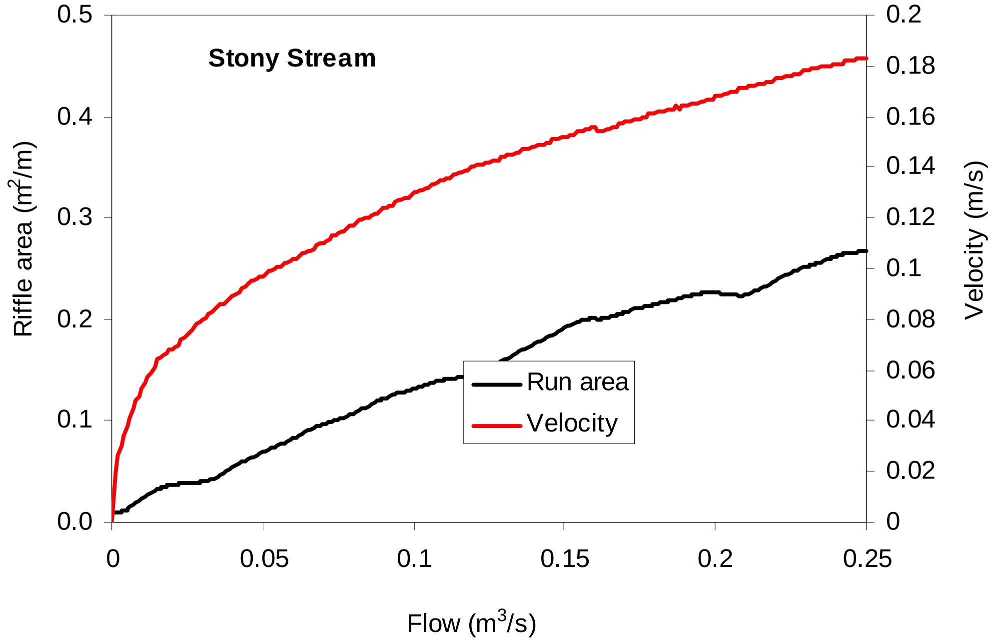
11. Appendix 5 Invertebrate Data

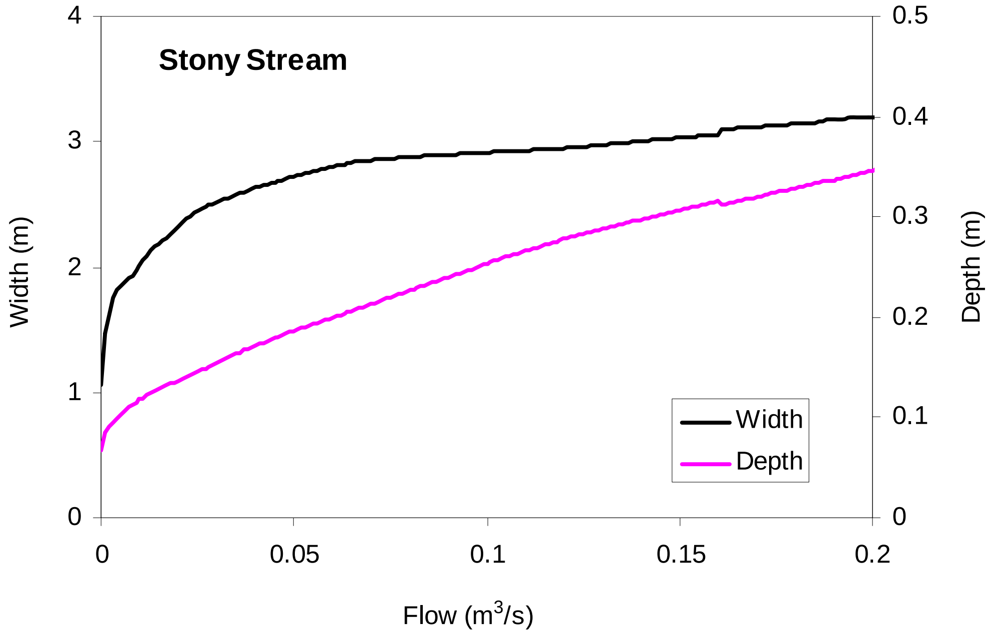
P = rare taxa observed after 200 animal fixed-count.

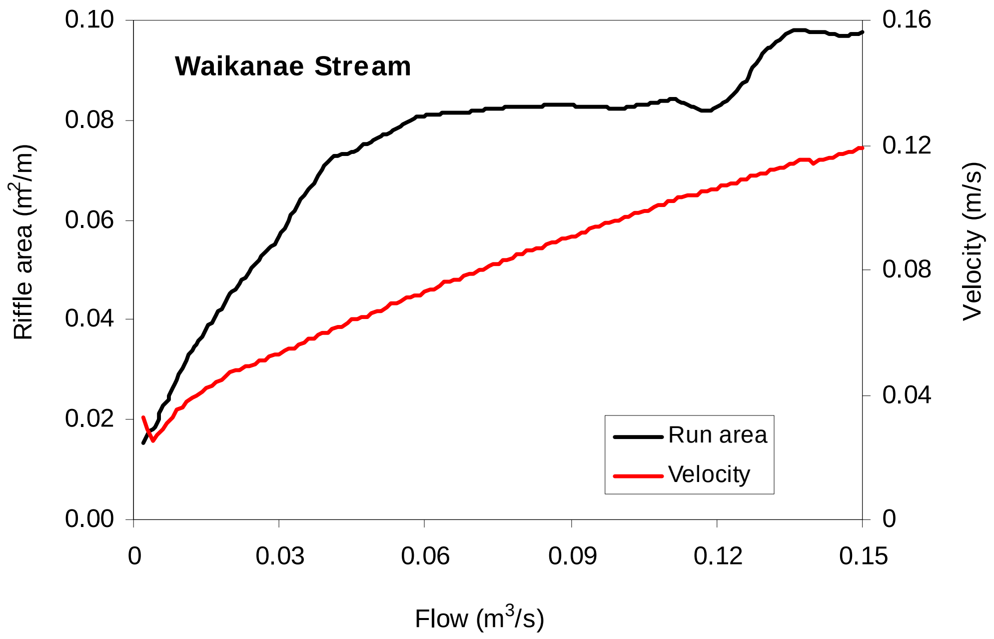
	Stony	Wentworth	Waikawau	Waikanae	Whareroa	average
EPHEMEROPTERA (Mayflies)						
Austroclima		1		1	4	1.2
Coloburiscus				2		0.4
Deleatidium			1	2	2	1
Zephlebia	10	27	p	10	19	13.2
PLECOPTERA (Stonefly)						
Zelandobius				2	3	1
TRICHOPTERA (Caddisfly)						
Hudsonema		1				0.2
Hydrobiosis				1		0.2
Oecetis	1	2				0.6
Olinga				p		0
Oxyethira		4				0.8
Psilochorema			p			0
Pycnocentrodes			3	p		0.6
Triplectides	23	40	56	91	35	49
MEGALOPTERA (Dobsonfly)						
Archichauliodes				1	1	0.4
COLEOPTERA (Beetles)						0
Elmidae	p	2	12	11	3	5.6
Hydraenidae			p	p		0
Hydrophilidae			p	p		0
Ptilodactlidae					1	0.2
Scirtidae				1		0.2
DIPTERA (Two winged flies)						
Austrosimulium		14		9	3	5.2
Empididae				p		0
Eriopterini				p	p	0
Hexatomini				1		0.2
Paradixa			p	5	16	4.2
Tanyderidae				p		0
Chironomidae orthoclads	1	1	p	13	3	3.6
Chironomidae tanytarsini				15	10	5
Chironomidae tanypodinae	p			1		0.2
Chironomidae Chironomus	1					0.2
Chironomidae Polypedilum	2	1		9	2	2.8
ODONATA (Damselflies & Dragonflies)						
Antipodochlora					1	0.2
Xanthocnemis	p		1			0.2
MOLLUSCA (Snails)						
Melanopsis		1	1		1	0.6

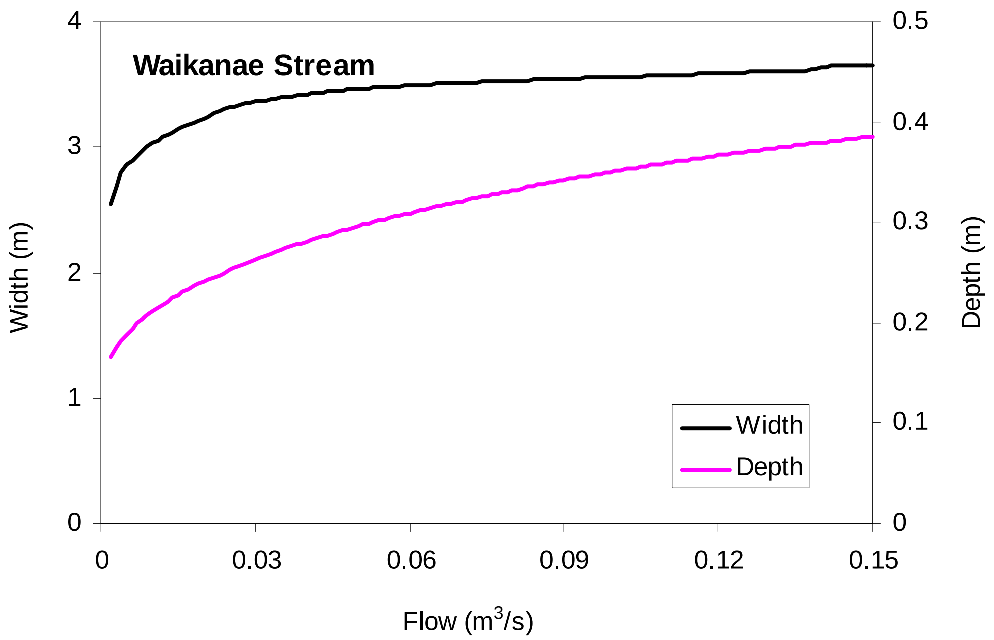
	Stony	Wentworth	Waikawau	Waikanae	Whareroa	average
Potamopyrgus	86	27	41	1	67	44.4
Sphaerium	2					0.4
Hyridella			p			0
OLIGOCHAETA (Worms)	p	3	2			1
PLATYHELMINTHES (Flatworms)	1					0.2
CRUSTACEA						
Amphipoda					12	2.4
Paratya	92	92	142	49	18	78.6
Isopoda				p		0
ACARINA (MITES)	1	2		1		0.8
NEMERTEA (proboscis worms)	1	p	1	p		0.4
no. of taxa	16	16	17	29	19	19.4
no. of taxa (excl. rare)	12	15	10	20	18	15
%EPT	15%	34%	23%	48%	31%	30%
Habitats Sampled						
Stones	0%	0%	10%	20%	10%	8%
Wood	30%	30%	40%	50%	40%	38%
Aquatic plants	30%	20%	20%	0%	10%	16%
Edges	40%	50%	30%	30%	40%	38%

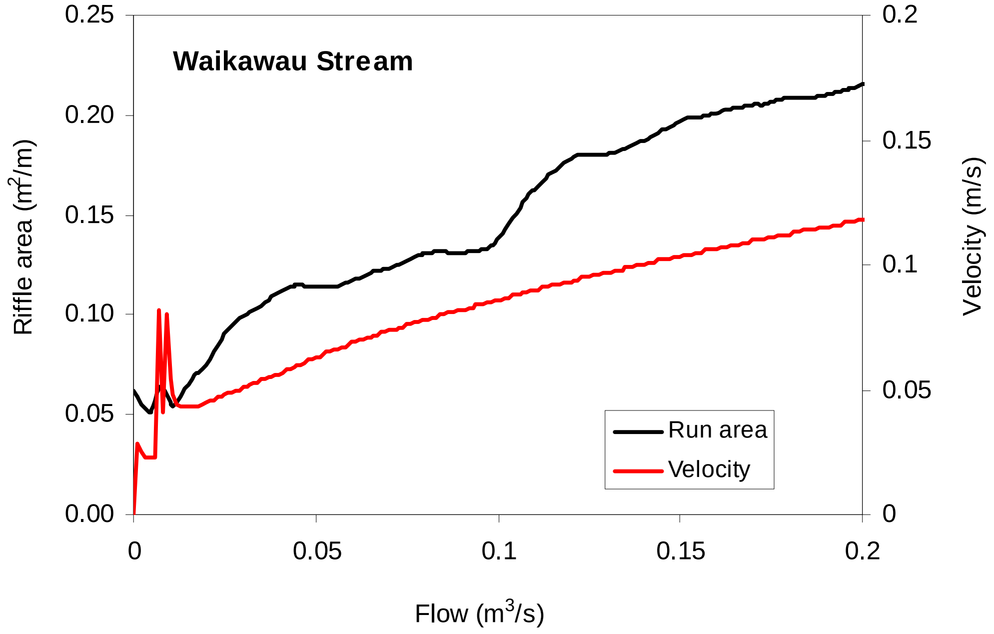
12. Appendix 6 Physical Habitat Data

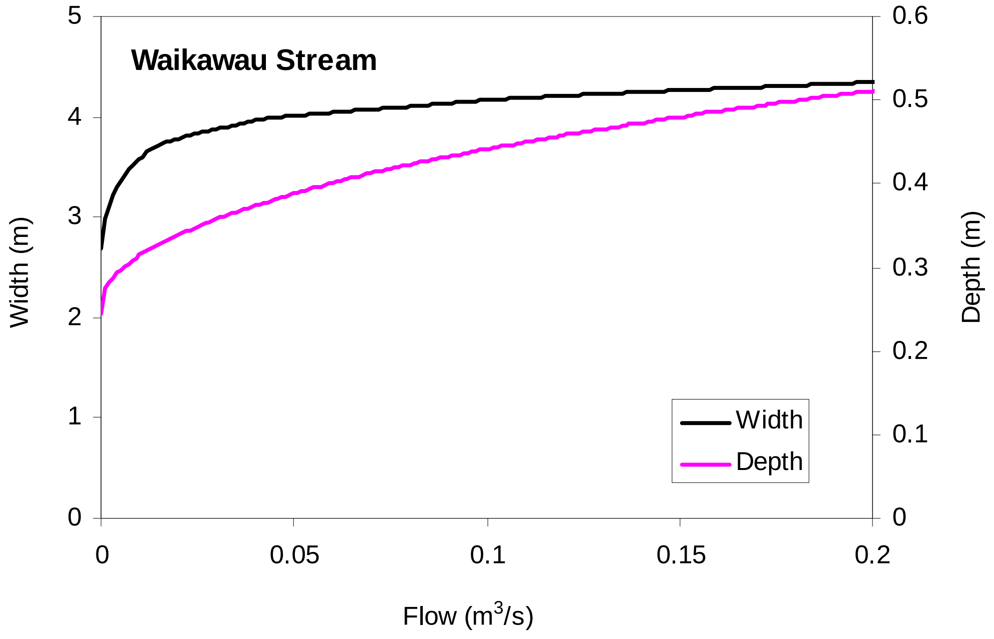


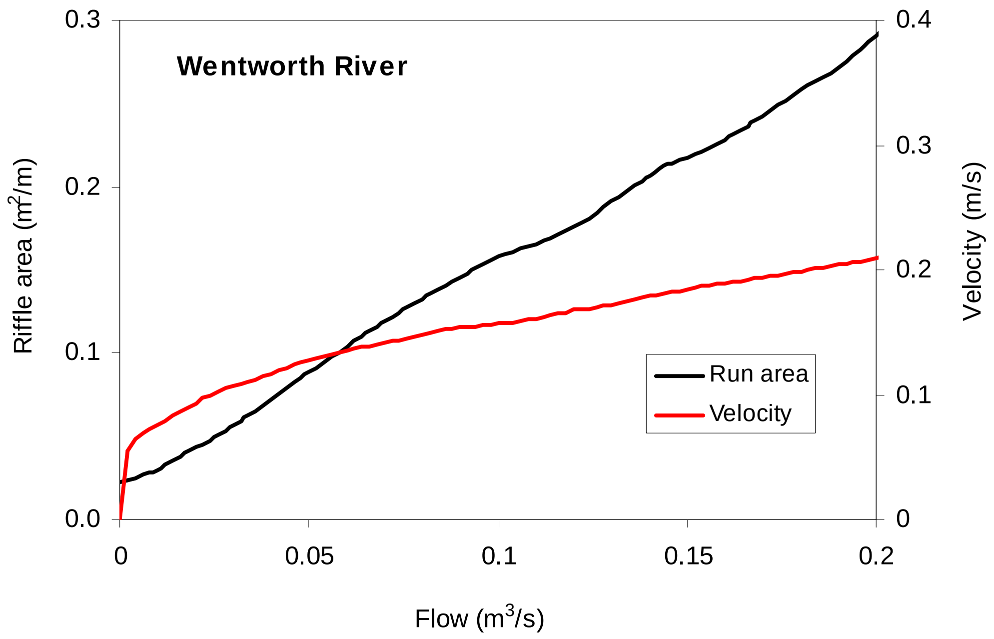


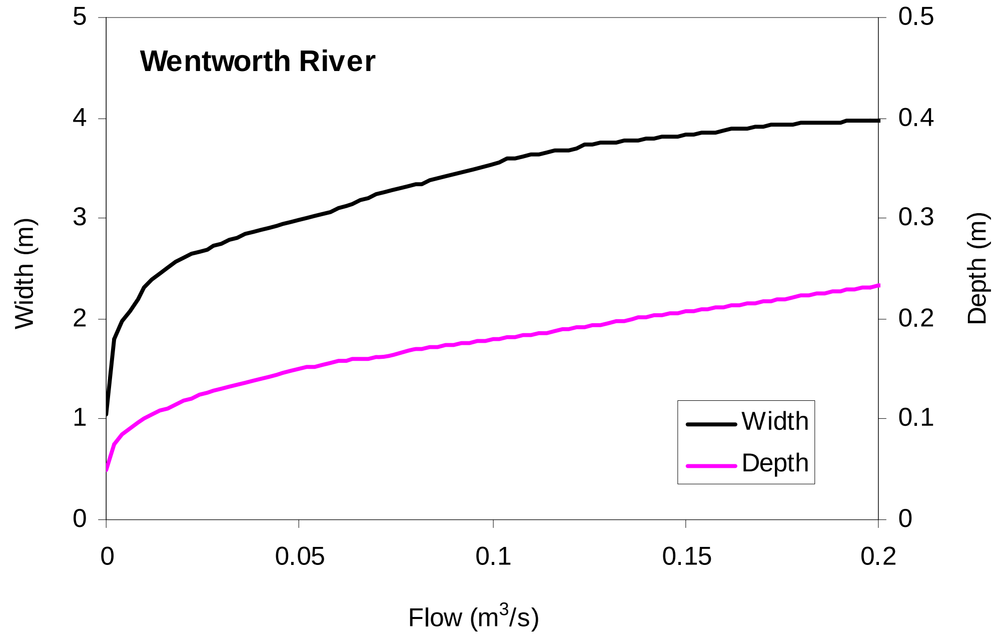

Waikanae Stream
Riffle area (m2/m)
Velocity (m/s)
Flow (m3/s)
Run area
Velocity
0.10
0.08
0.06
0.04
0.02
0.00
0.16
0.12
0.08
0.04
0
0
0.03
0.06
0.09
0.12
0.15

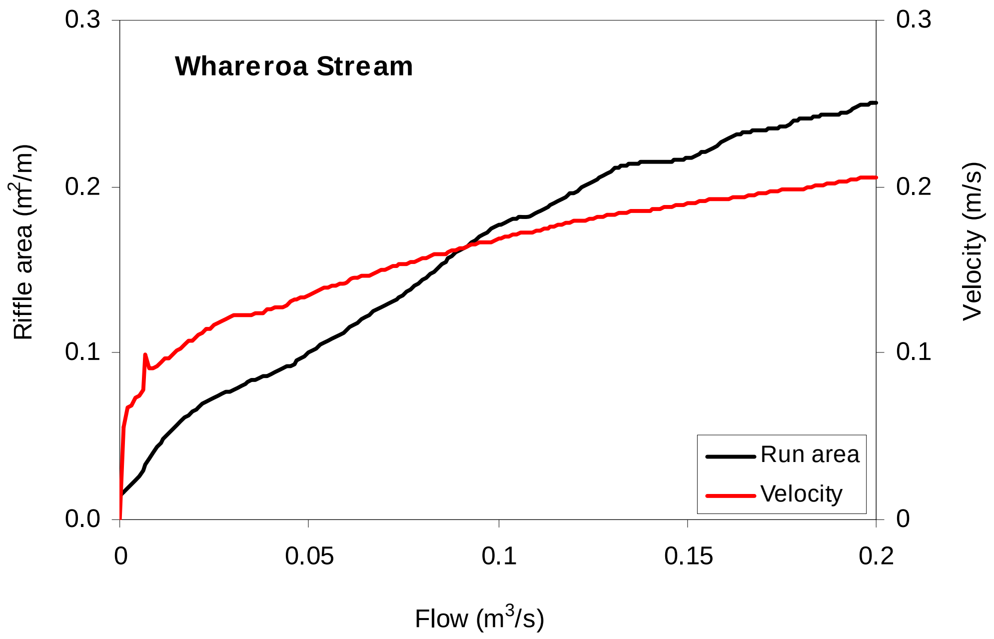

Waikanae Stream
Width (m)
Depth (m)
Flow (m3/s)
Width
Depth
4
3
2
1
0
0.5
0.4
0.3
0.2
0.1
0
0
0.03
0.06
0.09
0.12
0.15

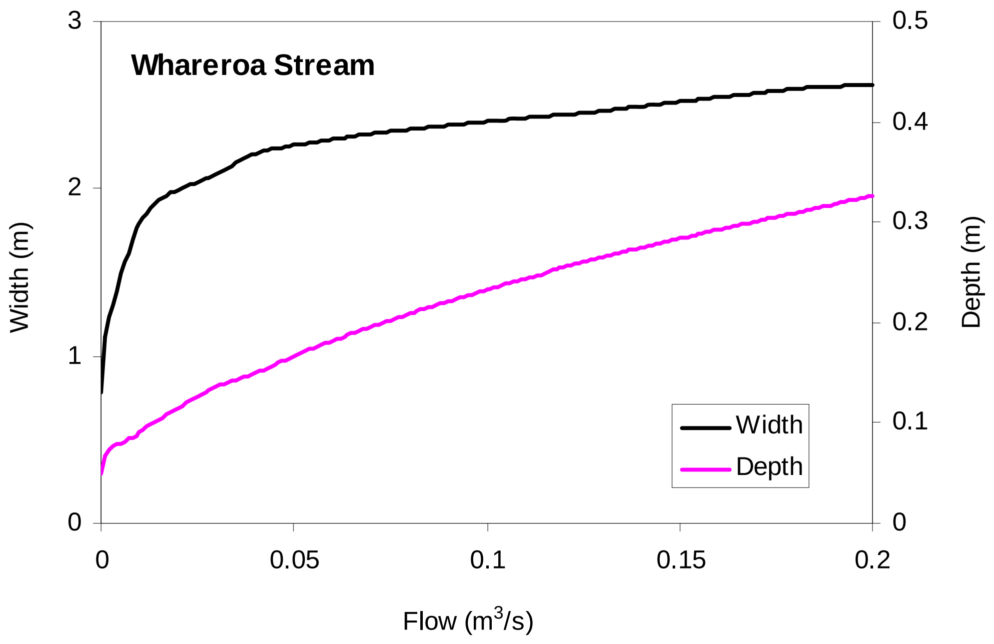

Waikawau Stream
Riffle area (m^2/m)
Velocity (m/s)
Run area
Velocity
Flow (m^3/s)
0.25
0.20
0.15
0.10
0.05
0.00
0.2
0.15
0.1
0.05
0
0
0.05
0.1
0.15
0.2


Waikawau Stream
Width (m)
Depth (m)
Width
Depth
Flow (m^3/s)
5
4
3
2
1
0
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2


Wentworth River
0.3
0.2
0.1
0.0
Riffle area (m2/m)
0.4
0.3
0.2
0.1
0
Velocity (m/s)
Run area
Velocity
0
0.05
0.1
0.15
0.2
Flow (m3/s)


Wentworth River
5
4
3
2
1
0
Width (m)
0.5
0.4
0.3
0.2
0.1
0
Depth (m)
Width
Depth
0
0.05
0.1
0.15
0.2
Flow (m3/s)


Whareroa Stream
Riffle area (m2/m)
Velocity (m/s)
Flow (m3/s)
Run area
Velocity
0.3
0.2
0.1
0.0
0
0.05
0.1
0.15
0.2


Whareroa Stream
Width (m)
Depth (m)
Flow (m3/s)
Width
Depth
3
2
1
0
0.5
0.4
0.3
0.2
0.1
0.05
0.15

13. Appendix 7 Flow requirements from previous studies

The following flow requirements for fish habitat and dissolved oxygen are reproduced from previous reports. Whenuakite from Wilding (2007a); Wharekawa from Wilding (2007b); Whangamaroro from Wilding (2005); Opitonui from Wilding and Jowett (2006).

m^3/s	Whenuakite (lowland)	Whenuakite (tidal)	Wharekawa (midland)	Whangamaroro	Opitonui
Dissolved oxygen		0.205 [B]			0.11 [E]
Fish habitat	0.075[A]		0.265 [C]	0.55 [D]	0.15 [F]
Q_5	0.10	0.16	0.265	0.58	0.16
MALF	0.13	0.21	0.32	0.66	0.22
Median flow	0.52	0.84	0.81	1.82	0.55

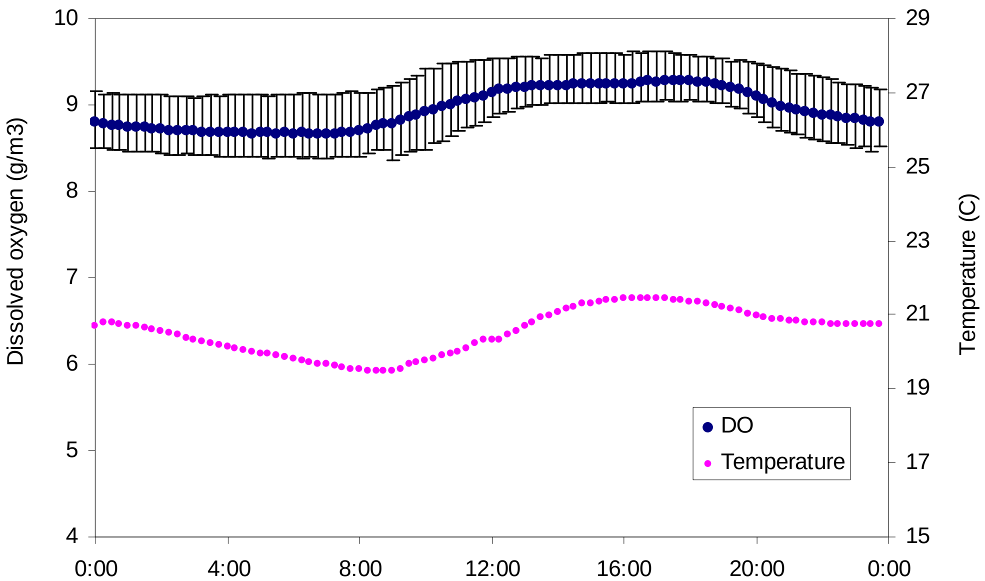
A. Flow required to maintain 85% of maximum habitat for inanga.
B. Flow required to exceed the selected dissolved oxygen guideline of 4 g/m^3.
C. Flow required to maintain 90% of maximum habitat for shortfin eel.
D. Flow required to maintain 85% of maximum habitat for common bully.
E. Flow required to exceed the selected dissolved oxygen guideline of 4 g/m^3.
F. Flow required to maintain 85% of maximum habitat for redfin bully.

14. Appendix 8 Dissolved oxygen results

Dissolved oxygen and temperature results for sites monitored by Environment Waikato using D-OPTO loggers. Some data was excluded to remove effect of floods on diurnal statistics. Maximum and minimum are given for a typical day (oxygen averaged for each time of day as per Section 3.5) as well as absolute maximum and minimum. Plots also as per Section 3.5. For March monitoring, indicator flow sites averaged 65% of MALF for Opitonui, 103% of MALF for Wharekawa and 120% of MALF for Tairua. For April monitoring, the Tairua River was flowing at 206% of MALF.

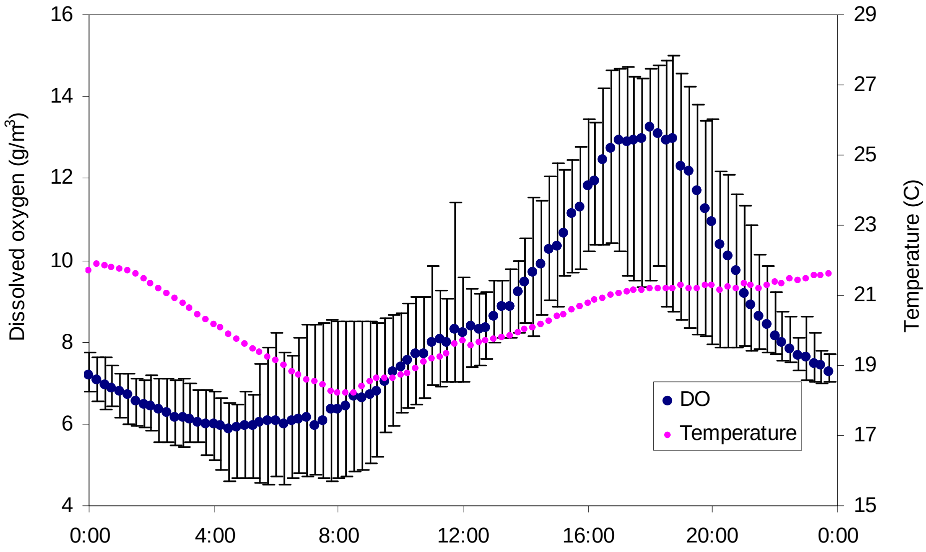
Kauaeranga - Site 2224 E2738633 N6446195

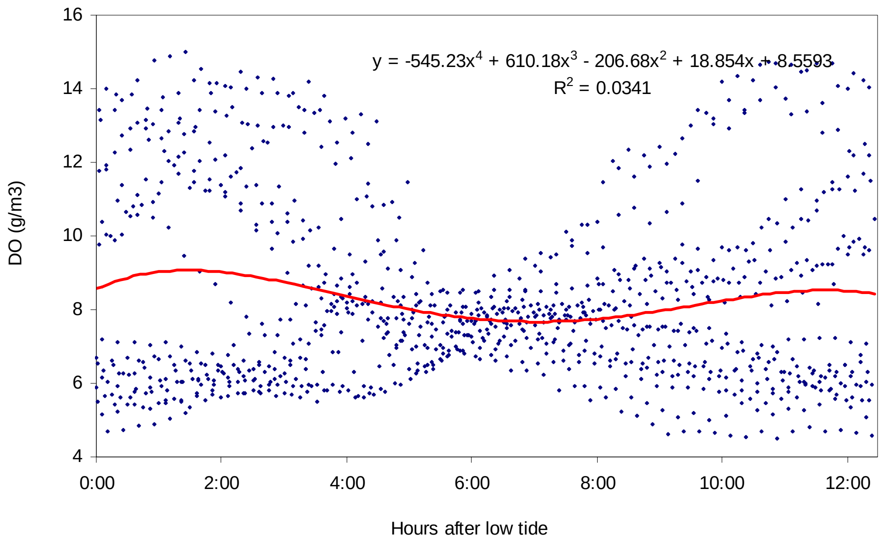
Average DO	8.94 g/m^3
Max DO	9.28 g/m^3
Min DO	8.67 g/m^3
Range DO	0.61 g/m^3
time of max (h:mm)	16:45
Absolute max DO	9.62 g/m^3
Absolute min DO	8.37 g/m^3
average temp	20.53 ºC
Average tidal DO effect	<0.1 g/m^3
Monitoring period	6/3 to 22/3/2007
Excluded data	12/3 12pm to 18/3 12pm
Distance to 20 m contour	8.5 km



Waiau - Site 2225 E2734603 N6487287

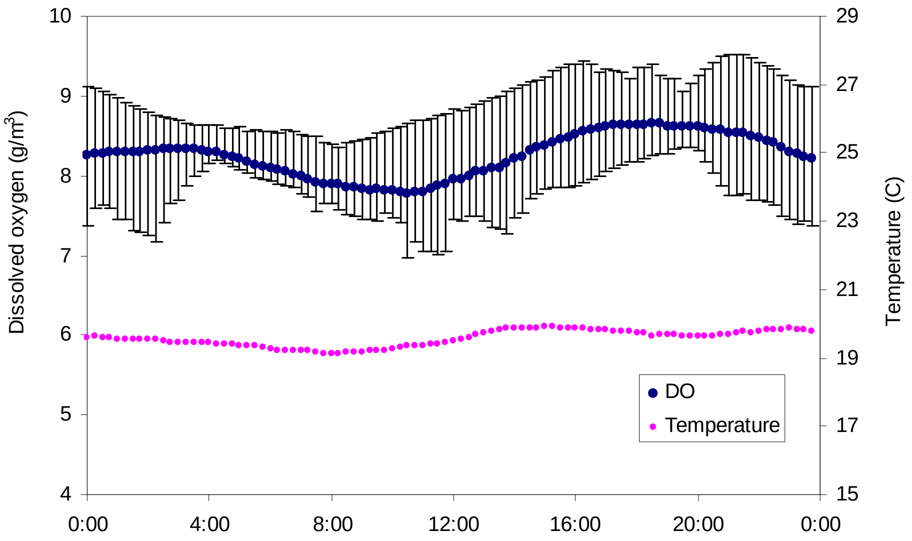
Average DO	8.41 g/m^3
Max DO	13.26 g/m^3
Min DO	5.88 g/m^3
Range DO	7.38 g/m^3
time of max (h:mm)	18:00
Absolute max DO	15.01 g/m^3
Absolute min DO	4.5 g/m^3
average temp	20.29 ºC
Average tidal DO effect	1.36 g/m^3
Monitoring period	6/3 to 22/3/2007
Excluded data	12/3 12pm to 18/3 12pm
Distance to 20 m contour	3.3 km

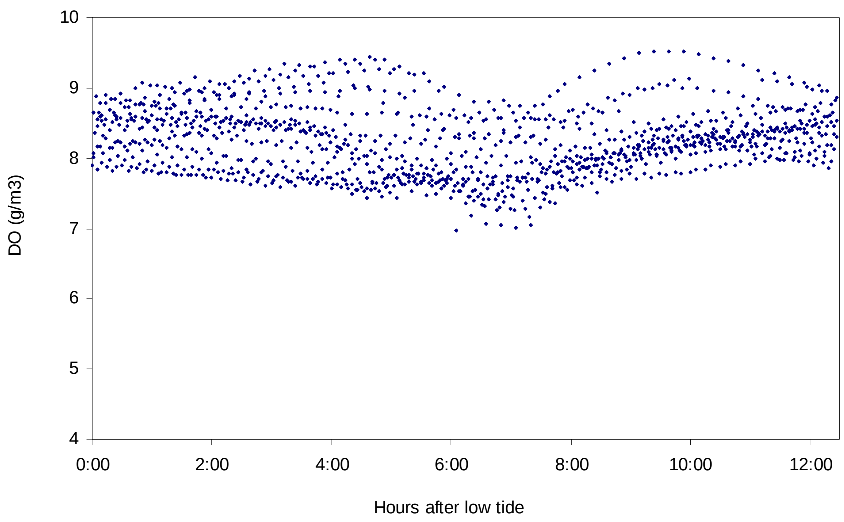




Whangamaroro - Site 2226 E2747591 N6480111

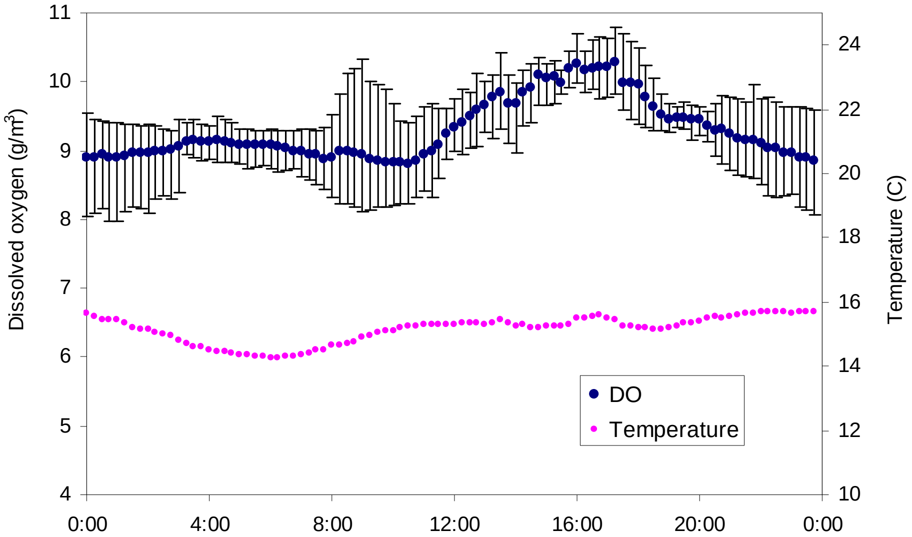
Average DO	8.25 g/m^3
Max DO	8.65 g/m^3
Min DO	7.76 g/m^3
Range DO	0.89 g/m^3
time of max (h:mm)	18:30
Absolute max DO	9.52 g/m^3
Absolute min DO	6.97 g/m^3
average temp	19.56 ºC
average flow	0.72 m^3/s
Average tidal DO effect	0.39 g/m^3
Monitoring period	6/3 to 22/3/2007
Excluded data	13/3 to 16/3
Distance to 20 m contour	8.5 km

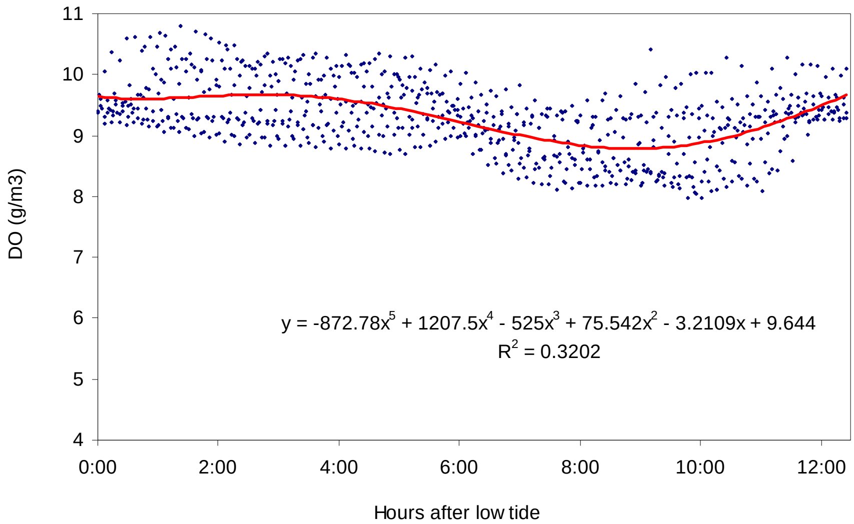




Waiwawa - Site 2227 E2750955 N6472232

Average DO	9.29 g/m^3
Max DO	10.29 g/m^3
Min DO	8.81 g/m^3
Range DO	1.47 g/m^3
time of max (h:mm)	17:19
Absolute max DO	10.79 g/m^3
Absolute min DO	7.97 g/m^3
average temp	15.13 ºC
Average tidal DO effect	0.88 g/m^3
Monitoring period	15/4 to 22/4/2007
Excluded data	Data prior and subsequent
Distance to 20 m contour	9.4 km



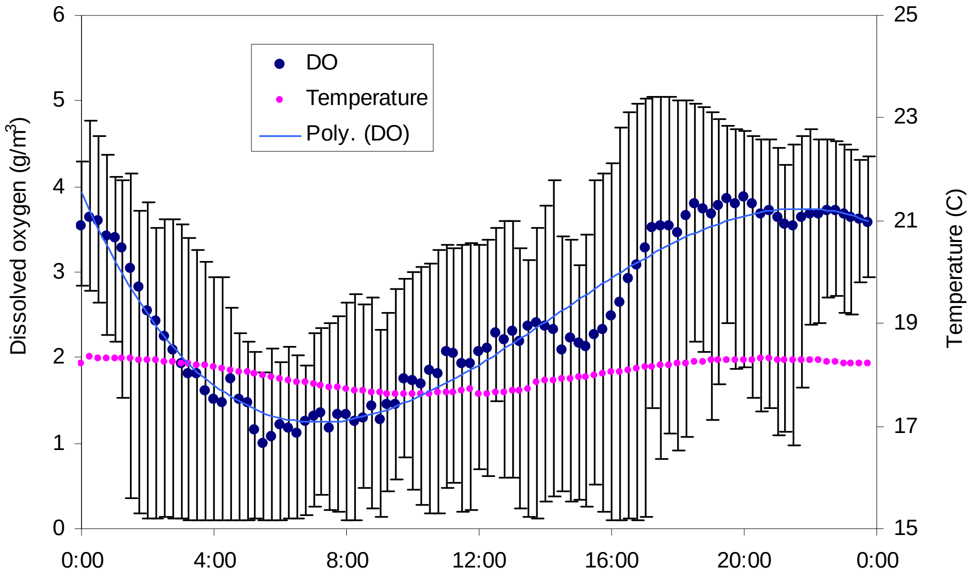


Whenuakite – Site 2229 E2756418 N6473245

Whenuakite was monitored as an 'impact' reference, with two monitoring periods, hence two sets of parameters are presented.

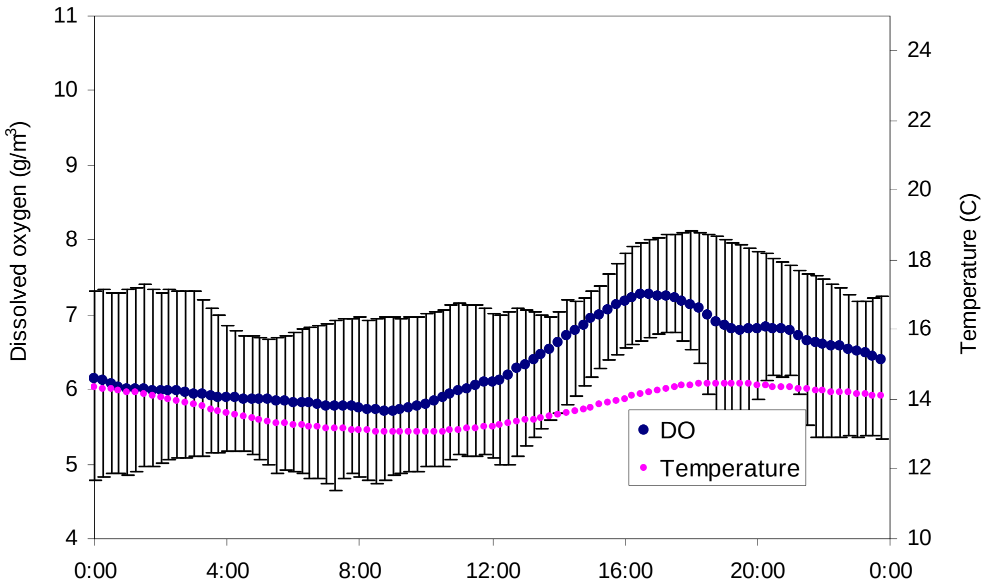
Whenuakite - March

Average DO	2.5 g/m^3
Max DO	3.88 g/m^3
Min DO	1.0 g/m^3
Range DO	2.88 g/m^3
time of max (h:mm)	20:00
Absolute max DO	5.06 g/m^3
Absolute min DO	0.1 g/m^3
average temp	18.02 ºC
Monitoring period	6/3 to 22/3/2007
Excluded data	12/3 12pm to 18/3 12pm
Distance to 20 m contour	14.4 km



Whenuakite - April

Average DO	6.33 g/m^3
Max DO	7.27 g/m^3
Min DO	5.71 g/m^3
Range DO	1.76 g/m^3
time of max (h:mm)	16:45
Absolute max DO	8.12 g/m^3
Absolute min DO	4.64 g/m^3
average temp	13.76 ºC
Average tidal DO effect	Not assessed
Monitoring period	15/4 to 22/4/2007
Excluded data	



15. Appendix 9 Upland flow requirement for habitat

Minimum flows for fish habitat (calculated using the Environment Bay of Plenty method, with a protection level of 85%) are plotted against Q_5 (five-year low flow) for lowland reaches of the Coromandel area, compared to upland reaches of the Coromandel/Kaimai area. Upland reach data is as per Wilding (2007b), but plotted against Q_5 instead of MALF.