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Minimum Flows for Ecosystem Health in Selected Coromandel Streams:
Awaroa, Tapu, Waiomu and Wharekawa

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Minimum flows for ecosystem health in selected Coromandel streams: Awaroa, Tapu, Waiomu and Wharekawa

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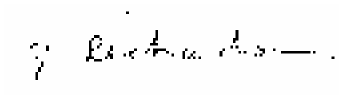

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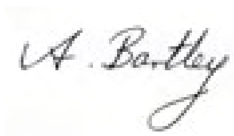

Executive Summary

Managing the water resources of the Coromandel Peninsula requires information on the flow requirements of aquatic ecosystems. Four streams were surveyed in 2006; the Wharekawa, Awaroa, Tapu and Waiomu. These streams were proposed by Environment Waikato because they are considered representative of Coromandel streams and have good flow information. This study builds on data collected by NIWA and Environment Waikato in previous years that looked at other catchments in the Coromandel.

Potential instream ecological issues relating to flow include fish and invertebrate habitat, water temperature and dissolved oxygen. Environment Waikato asked NIWA to investigate the flow requirements for these specific issues. The relative importance of each of these issues is expected to vary between catchments and between reaches within a catchment. The selected catchments were divided into hydraulically similar sections with common issues, distinguishing upland reaches from lowland reaches. The methods chosen to investigate each issue were WAIORA for oxygen modelling and RHYHABSIM for habitat and temperature 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 the Awaroa Stream, Tapu River and Waiomu Stream. Further oxygen modelling is required to confirm preliminary results that oxygen is the critical issue for the Wharekawa River. The change in water temperature with flow was modelled for the Tapu River, Waiomu Stream and the Wharekawa River. The predicted change in temperature with flow is expected to be small (fraction of a degree), especially when compared to daily temperature variation or riparian shade effects, so is not considered a critical issue.

A predictive equation was developed for estimating the minimum flow requirements of aquatic ecosystems of upland streams in the Coromandel area. This is intended for application to streams where habitat surveys have not already been carried out. For lowland and midland streams of the Coromandel, further work is recommended to develop better predictive equations for minimum flow requirements.

Table 1: Recommended minimum flows for each of the four Coromandel streams surveyed. The issue that determined the recommended minimum flow for each stream (critical issue) is also noted. In the absence of an established protection level (PL) for the Waikato Region, the Environment Bay of Plenty method was used. Should a more or less conservative protection level be adopted for the Waikato Region, this would change the minimum flows produced. Additional investigations are required for the Wharekawa River where preliminary modelling indicates oxygen is the critical issue for the lower river. Minimum flows for each issue assessed for each reach are detailed in Table 4.1. Q_5 is the 1 in 5-year 7-day low flow.

Stream	Q_5 (m^3/s)	Minimum flow (m^3/s)	Critical issue
Awaroa Stream	0.013	0.012	Habitat for redfin bully (85% PL)
Tapu River	0.17	0.152	Habitat for redfin bully (85% PL)
Waiomu Stream	0.040	0.038	Habitat for torrentfish (85% PL)
Wharekawa River	0.265	(pending)	Dissolved oxygen

1. Introduction

1.1 Study brief and background

Managing the water resources of the Coromandel Peninsula requires information on the flow requirements of aquatic ecosystems. This investigation addresses flow requirements for streams that are expected to come under abstraction pressure in the future or are representative of Coromandel streams, and their response to flow changes. This builds on work completed by NIWA and Environment Waikato in previous years that looked at other catchments in the Coromandel (Wilding 2007). It is hoped this work will ultimately identify common patterns for minimum flow requirements in Coromandel streams.

Candidate streams were proposed by Environment Waikato for investigation in 2006 (Wharekawa, Awaroa, Tapu and Waiomu), which have good flow information and are representative of Coromandel streams. Experience has taught us that lowland reaches are more likely to have water quality issues (particularly oxygen depletion), while habitat is more likely to be a critical issue in steeper upland reaches. Grouping the reaches into habitat types ensured the most efficient use of time and resources.

The purpose of this report is to assess the minimum flow requirements for aquatic ecosystems inhabiting selected Coromandel streams. Fish habitat and water quality were the focus of investigations. Emerging trends were also investigated that would support the application of results to other streams.

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 Wharekawa River are also nominated as Indigenous Fishery Class, with some small tributaries in native forest areas nominated as Natural State (upstream of the assessed reaches). The assessed reaches of the Tapu and Waiomu are also nominated as Indigenous Fishery Class, though large areas of these catchments are native forest and therefore classed as Natural State. The Awaroa Stream (and Opitonui River downstream) has Natural State classifications on some headwater tributaries, but the remainder of the system is not classed as Indigenous Fishery. None of the study streams are classified as Trout Habitat.

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 Tapu, Waiomu and Wharekawa to maintain or enhance existing water quality and aquatic habitat. For the Awaroa Stream (and Opitonui River) 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 most likely to be critical were expected to vary with stream type. Different methods were therefore chosen for each reach to best target the critical issues. 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. In the lower catchment, 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. Native fish communities are likely to have significant flow requirements for habitat and water quality. Flow requirements for the habitat of stream invertebrates are also potentially critical issues 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 and temperature 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. Such suitability curves can be derived directly by surveying habitats over a range of depths, velocities etc. and plotting the abundance of organisms against habitat measures to show where they are most abundant (i.e., where they prefer to live).

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

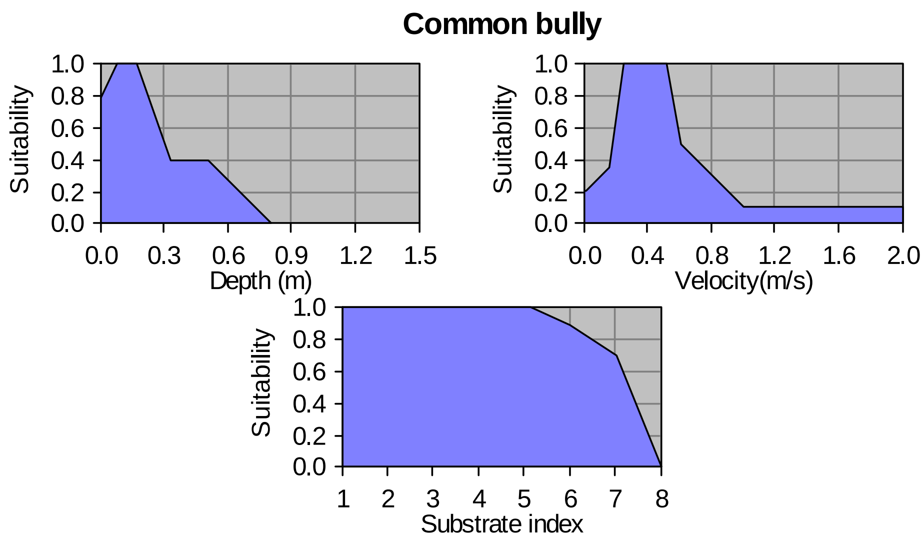

Figure 1.1: Habitat suitability curves for common bully, where suitability ranges from 0 (unsuitable) to 1 (optimal). Substrate index: 1=vegetation, 2=silt, 3=sand, 4=fine gravel, 5=gravel, 6=cobble, 7=boulder, 8=bedrock (Jowett & Richardson 1995).

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

A stratified random survey approach, called habitat mapping, was used in this study for all four streams. Habitat mapping is undertaken over the segment of river under study so that the proportions of different habitats (e.g., pool, riffle, run, etc.) can be calculated. Cross-section locations are then selected to represent each of the habitat types.

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

1.3.4 Procedure for Calculating Instream Habitat

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

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

1.3.5 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).

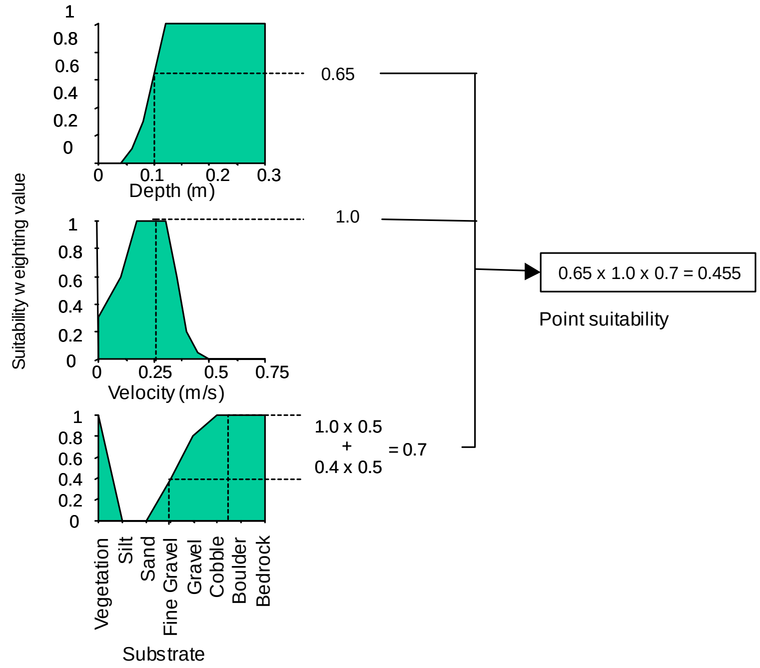

Figure 1.2: Calculation of habitat suitability for a fish species at a point with a depth of 0.1 m, velocity of 0.25 m/s, and substrate comprising 50% fine gravel and 50% cobble. The individual suitability weighting values for depth (0.65), velocity (1.0), and substrate (0.7) are multiplied together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

2. Sites and Methods

2.1 Study Sites

Four streams were surveyed in 2006: the Wharekawa, Awaroa, Tapu and Waiomu (Figure 2.1). These catchments were proposed by Environment Waikato because they are representative of Coromandel streams, have good flow information and build on the previous studies (Wilding 2007) to provide an understanding of low requirements for Coromandel streams.

The four streams were divided into sections with common issues, based on a site visit (1 February 2006). This was a visual assessment that focussed on distinguishing upland reaches from lowland reaches. From past experience, lowland reaches are more likely to have water quality issues (particularly oxygen depletion), while habitat is more likely to be a critical issue in steeper upland reaches. Grouping the reaches into simple habitat types ensured the most efficient use of time and resources.

Coromandel streams typically have a cobble bed and a moderate stream gradient. The Coromandel Range is predominantly hard volcanic rock such as adesite, dacite and rhyolite with some ignimbrite. Figure 2.2 provides a simplified map of rock types in the Coromandel. Most of the Coromandel Range is forested, either in native forest or exotic production forest (mainly *Pinus radiata*). Farming and urban settlements are typically confined to flatter, lower-elevation land such as alluvial river flats. Most of the Coromandel was logged between 1870 and 1920 (often followed by burning), and much of the native forest present today has regenerated subsequently. Gold was discovered in the Coromandel in 1852, and 100 years of gold mining impacted the vegetation, soils and rivers of the Coromandel. Mining waste, including mercury and cyanide, was discharged into nearby streams. Floods readily removed the sand down to the sea, and there is no sign of this material today except in the immediate vicinity of some batteries (Craw & Chappell 2000). Metal leachate from tailings generally discharges into the environment at low levels, though there are local hotspots such as the Tui Mine tailings (Craw & Chappell 2000).

The ranges are high enough to intercept weather systems, with both sides of the ranges receiving reliable rainfall for most of the year (annual rainfall is in the order of 2 to 4 metres). Because of the steep nature of the ranges and the frequency of high intensity rainfall, flooding of streams is frequently severe. The severity and frequency of these events directly affects the aquatic life through disturbance, and is important in shaping the habitat (including channel morphology and substrate).

Figure 2.1: Rivers and streams surveyed in 2006 as indicated by red arrows. (NZMS242 © Sourced from Land Information New Zealand data. Crown copyright reserved).

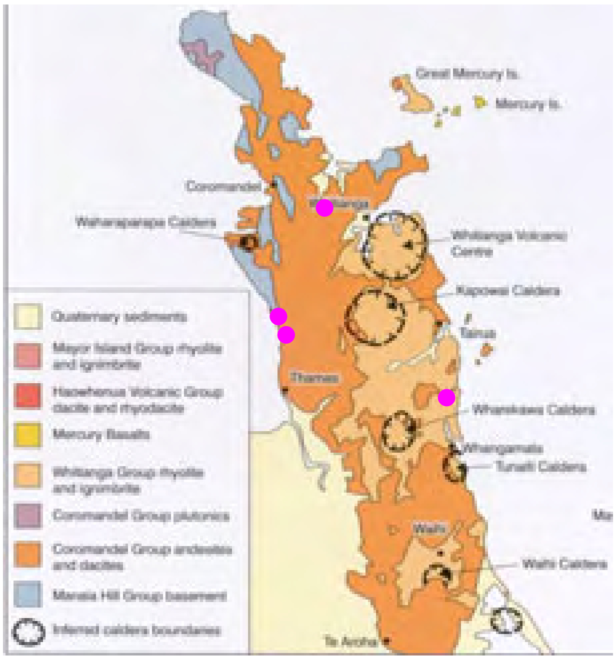

Figure 2.2: Simplified geology of the Coromandel (after Edbrooke 2001). Study sites are indicated by pink dots. Most of the sites drain 'Coromandel Group andesites and dacites', with some 'Whitianga group rhyolite and ignimbrite' in the Wharekawa River catchment. Geological map sourced from the Institute of Geological & Nuclear Sciences (Copyright Reserved).

2.1.1 Awaroa Stream

The Awaroa Stream is a tributary of the Opitonui River (Figure 2.3). Wilding & Jowett (2006) focussed on the lower reaches of this catchment (Opitonui), hence the current study focussed on habitat in the upland area, with one reach surveyed in the Whangapoua Forest. Land use upstream of the study reach is predominantly exotic forest (88.7%), with some native forest (11.3%). The stream is predominantly cobble and gravel with pools, riffles and runs (Figure 2.4). Edbrooke (2001) mapped the catchment geology as andesite and dacite (Kuaotunu subgroup of the Coromandel Group). These are relatively hard rock types, which seems inconsistent with the Rivers Ecosystem Classification database (REC) geology layer classification of the Awaroa catchment as 'soft' volcanic rock (the other three catchments surveyed are classed by the REC as 'hard' volcanic rock).

The Awaroa study reach runs upstream of Wade Road, which is 8 km from Whangapoua Harbour and approximately 60 m above sea level (REC data). The length of the migration path and altitude gain is expected to restrict access for less determined migrants (e.g., inanga) and the stream passes through at least two fords

(Figure 2.5) that potentially reduce the abundance of more capable climbers (e.g., redfin bully). The fish community in this reach is therefore not expected to be as abundant or diverse compared to reaches that are closer to the coast.

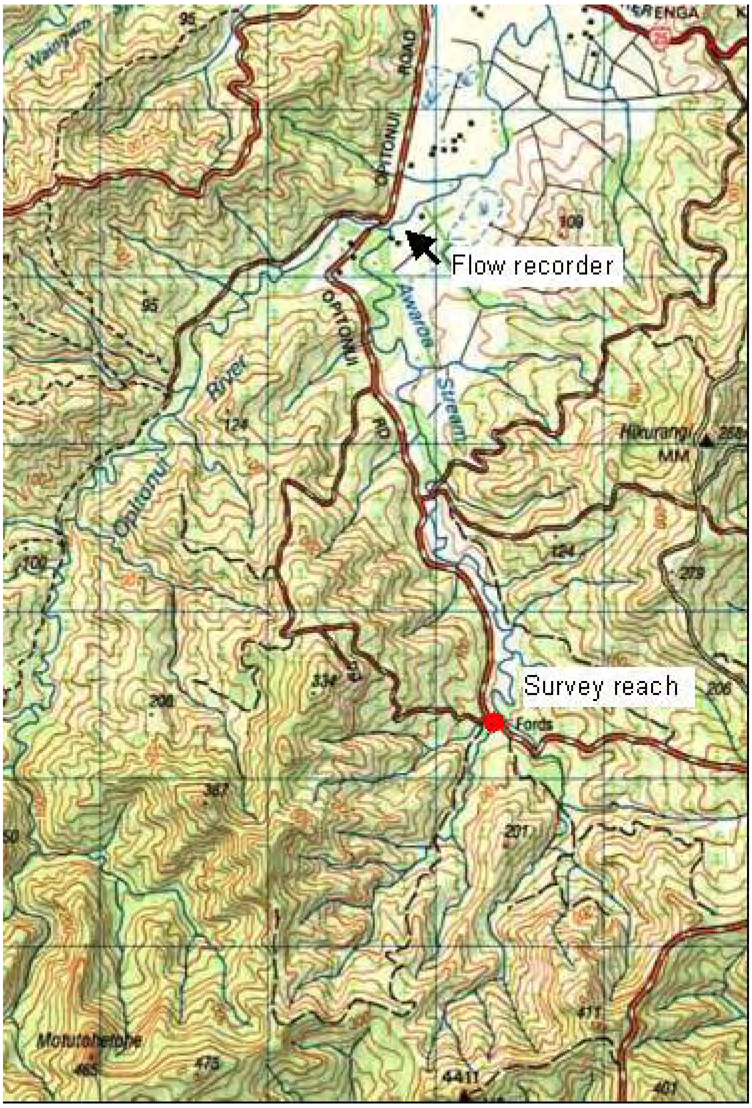

Figure 2.3: The Awaroa Stream was surveyed upstream of Wade Road (mislabelled Opitonui Road on this Topomap). The reach extends upstream of the culvert to the confluence of a second order tributary (see Appendix 2 for GPS coordinates). Environment Waikato operates a continuous flow recorder on the Opitonui River (as indicated) downstream of the study site.

Figure 2.4: The survey reach on the Awaroa Stream, located upstream of Wade Road.

Figure 2.5: Culverts for forestry roads crossing the Awaroa Stream downstream of the study reach.

2.1.2 Tapu River

The Tapu River drains a native forest catchment with only 5.1% of the catchment farmed. The geology of the catchment is andesite and dacite (Kuaotunu subgroup of the Coromandel Group, Edbrooke 2001). The Tapu-Coroglen Road follows the Tapu River for a distance, passing the Rapaura Watergardens and square kauri tree. The township of Tapu, located at the mouth of the river, has been affected by flooding, and in recent years river works were undertaken by Environment Waikato and Thames Coromandel District Council to maximise the flow capacity of the river channel. These works were confined primarily to the lower 1 km of the river where it passes through Tapu township (pers. comm. Roger Spooner, Environment Waikato).

A survey reach was selected close to the coast, immediately upstream of Tapu township and river works (Figure 2.6 & 2.7). The flow recorder, operated by Environment Waikato, is a short distance downstream of the reach with no significant inflows in between. This river was classified for this study as upland habitat all the way to the sea. A moderate gradient prevents the formation of an estuary or soft-bottomed lowland habitats. The Tapu River has a cobble bed and riffle/run/pool sequence at the State Highway 25 bridge and the river runs out across the beach into the Firth of Thames.

Figure 2.6: The survey reach on the Tapu River was a short distance upstream of Environment Waikato's flow recorder. A temperature recorder was also installed several kilometres upstream. (See Appendix 2 for GPS coordinates).

Figure 2.7: The habitat survey reach on the Tapu River.

2.1.3 Waiomu Stream

The Waiomu Stream is smaller than the Tapu River, although similar in respect to land use and geology (98.7% native forest for the greater catchment; andecite/dacite geology). The Waiomu Stream likewise retains its upland habitat character (cobble substrate, riffle/run/pool habitat) all the way to the sea, with negligible lowland or estuary transition zone. The township of Waiomu has also been affected by flooding, and Environment Waikato has responded with channel works to increase/maintain the flood capacity where it flows through the township (pers. comm. Roger Spooner, Environment Waikato). Two fords cross the stream (at 1.1 km and 1.9 km from the coast) that are potential barriers for fish migration (Figure 2.8 & cover photo). Despite the lower fish densities likely upstream of the fords, a study reach was located upstream of the fords within the DOC reserve (Figure 2.9). This provided a reach upstream of the channel works where channel morphology is natural and therefore more representative of Coromandel Streams (Figure 2.10). Fish present downstream of the fords were included in the modelling.

Figure 2.8: This ford crosses the Waiomu Stream, presenting a potential hindrance to fish migration. The second ford (further upstream) is shown on the report cover.

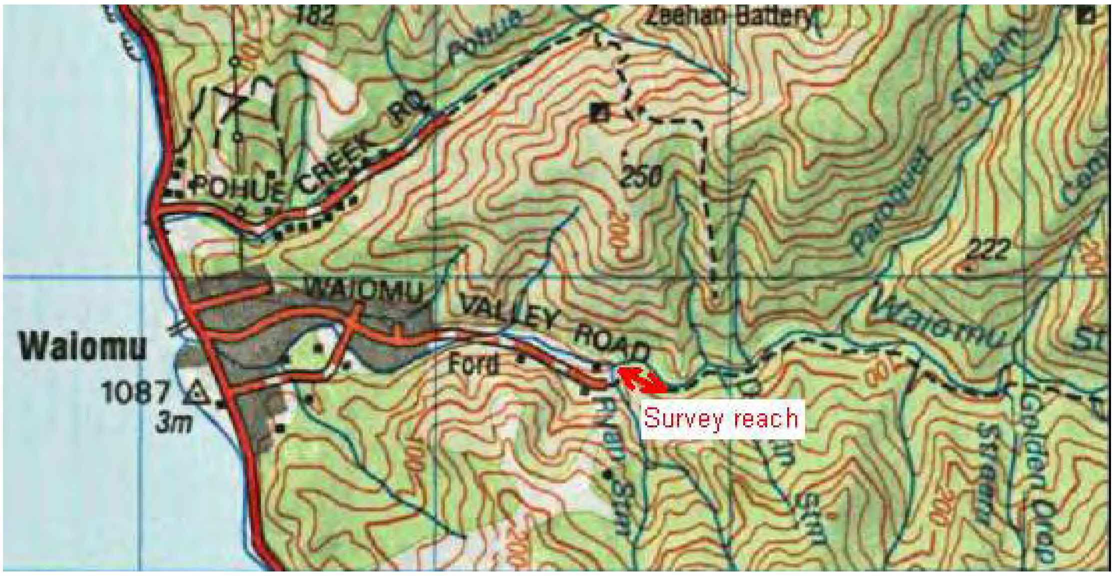

Figure 2.9: Waiomu Stream was surveyed upstream of the second ford (reach indicated by a red arrow). A temperature recorder was installed at the top of the habitat reach and a second temperature recorder at the State Highway 25 bridge. (See Appendix 2 for GPS coordinates).

Figure 2.10: The Waiomu Stream was predominantly boulder and cobble.

2.1.4 Wharekawa River

The Wharekawa River drains a catchment with large areas of both exotic and native forest. Pasture and horticulture are confined to the lower reaches (the greater catchment is 51.2% native forest and scrub, 39.6% exotic forest, 9.0% pasture and horticulture). The geology of the Wharekawa is less uniform than the other study catchments, with a mix of Coromandel and Whitianga Group volcanic rock (Edbrooke 2001). There is some older andecite/dacite rock as well as younger Minden Rhyolite, ignimbrite and pumice breccia. The agricultural plains are predominantly alluvial with some peat.

The most comprehensive study was carried out in the Wharekawa River, where there are a range of habitat types and potential minimum flow issues (Figure 2.11). Most of the catchment is upland habitat and this was represented by a reach adjacent to Mr Julian's orchard (Figure 2.12). Downstream the orchard, the gradient of the river is not as steep with more deep pools (Figure 2.13). This section still has sufficient gradient to produce occasional cobble/gravel riffles and reasonable water velocities. It falls into the upper bounds of what is considered midland habitat. A habitat survey was conducted in this reach near the Environment Waikato flow recorder. There is a similar midland reach further upstream on the flat area crossed by Taungatara Road (a Tairua-Forest road). This reach was not surveyed as it was adequately represented by the midland reach that is closer to the sea. The surveyed midland reach is well shaded with limited macrophyte growth (there are occasional beds of native charophytes). Consequently, oxygen depletion is not expected to be a critical issue here.

The upstream extent of tidal penetration was surveyed to confirm observations by local residents that the tide reaches the State Highway 25 bridge. The tidally-influenced reach, where freshwater backs up against an incoming tide, is more likely to have water quality issues, hence dissolved oxygen monitoring was carried out there. Habitat was not assessed because it is less likely to be a critical issue here and would be very difficult to model in a tidal situation.

Macrophytes were surveyed because they can be responsible for dissolved oxygen suppression during hours of darkness. The tidal reach was surveyed with macrophyte cover recorded at various cross-sections.

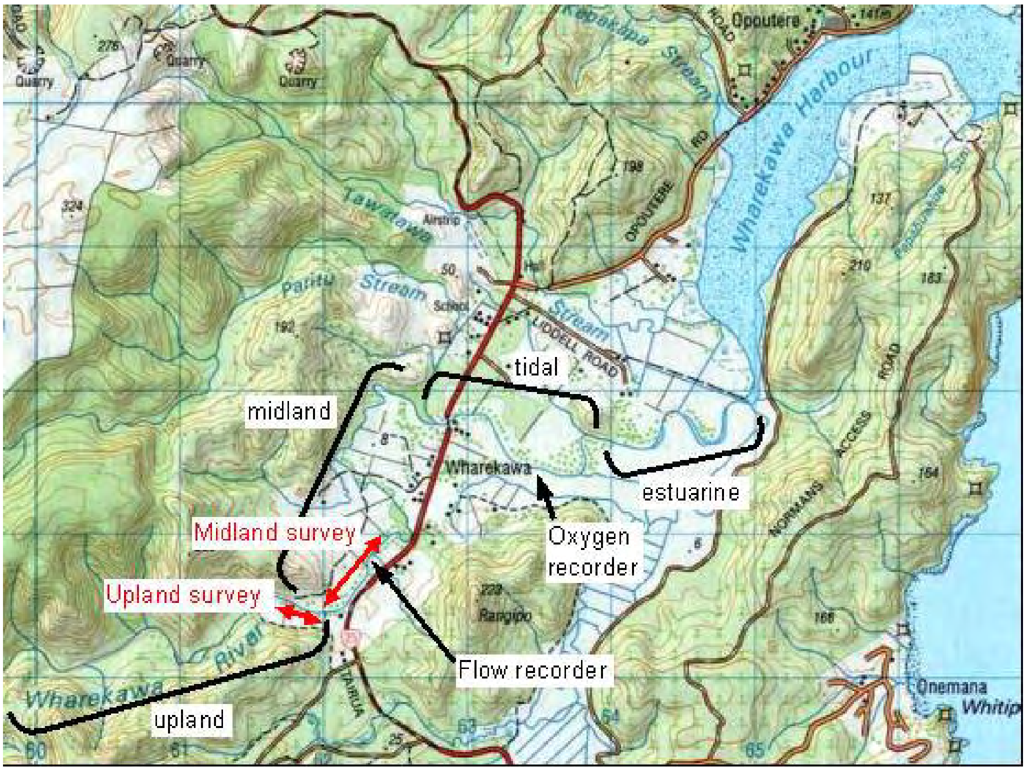

Figure 2.11: Two reaches were surveyed on the Wharekawa River for habitat modelling, one representing midland habitat and the other representing upland habitat (shown as red arrows). The main habitat types are represented indicatively on this map (upland, midland, tidal and estuarine). The locations of the oxygen recorder on the tidal reach and the flow recorder upstream are also shown (see Appendix 2 for GPS coordinates).

Figure 2.12: The Wharekawa River was surveyed beside Mr Julian's orchard to represent upland stretches of the river, which are characterised by frequent cobble riffles.

Figure 2.13: The midland reach of the Wharekawa River is characterised by more deep pools and was surveyed at cross-sections upstream and downstream of Environment Waikato's flow recorder.

2.2 Fish Community

All habitat-survey reaches were electric fished. Because there are several man-made barriers to fish migration on the Waiomu Stream, fishing was conducted downstream of the study reach. This site is intended to be representative of similar streams in the Coromandel, and fishing below the barriers provides a better depiction of the fish community likely to reside in this stream type.

An EFM 300 machine (Kainga battery powered backpack set) was used to electric fish the Tapu, Waiomu and Awaroa Streams. A generator mains set was used for the Wharekawa River. The deeper midland reach in the Wharekawa River was also fished using fyke nets which were baited and left overnight. Trout were observed from the bank in the Tapu River, but were not captured by electric fishing or seen by snorkelling the deeper pools. The New Zealand Freshwater Fish Database was searched for other fish records relevant to the surveyed reaches.

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 all reaches to measure the percentage of riffle, pool and run habitat. For the midland reach on the Wharekawa River, pools were divided into two types – shallow pools and deep pools (the shallow pools distinguished as being wadable). 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. The number of cross-sections and proportion of each habitat type for each study reach are presented in Table 2.1.

Table 2.1: Number of cross-sections surveyed and habitat mapping results for each reach. Cross-sections were divided evenly between the habitat types present (e.g., 5 riffles, 5 runs, 5 pools).

		habitat mapping			
Reach	**number of cross-sections**	**% riffle**	**% run**	**% pool**	**% shallow pool**
Awaroa	15	29.4%	28.7%	42.0%	0
Tapu	15	36.6%	32.3%	31.1%	0
Waiomu	15	48.4%	30.6%	21.1%	0
Wharekawa midland	16	16.2%	13.7%	48.5%	21.6%
Wharekawa upland	15	21.8%	44.7%	33.5%	0

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

The habitat analysis proceeded as follows:

1. Flows were computed from depth and velocity measurements for each cross-section.
2. A relationship between water level and flow (or rating curve) was developed for each cross-section (using a least-squares fit to the logarithms of the measured flows and water levels, including an estimated stage at zero flow).
3. Water depths and velocities were computed at individual measurement points for a range of simulated flows. The predicted velocity and depth for each point at each simulated flow was evaluated using habitat suitability curves for each fish species (Appendix 3).
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 excellent (Appendix 4). Several pegs were lost from the Tapu River before the last gauging, but earlier gaugings provided adequate ratings. Some pegs were also lost from the Waiomu Stream during the same flood event, but only had detrimental effects on the rating for Cross-section 1. Three cross-sections in the Awaroa Stream appeared to change between visits (or the pegs had moved), but the data otherwise provided good rating curves.

Different approaches can be used to determine minimum flow requirements from the plots of habitat (WUA) against flow, as discussed in Section 1.3.5. 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 Category 2 species (95%)).

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, with reduced flows potentially exacerbating this situation. Oxygen levels were monitored in the tidal lowland reach of the Wharekawa River (Figure 2.11). This reach was considered the most susceptible to oxygen depletion (deep, slower flowing with some macrophyte beds). The Wharekawa flow recorder (operated by Environment Waikato) provided flow information for the monitoring period.

The effect of reduced flows on dissolved oxygen levels was modelled using WAIORA (Version 2.0, Hill & Jowett 2004). The data-logger record and the midland habitat-survey data provided the necessary information to model the relationship between flow and oxygen (average flow and temperature for the monitoring period; daily average and range of dissolved oxygen; time-lag between oxygen maxima and solar-noon). The data-logger parameters were averaged to produce a typical diurnal cycle for use in the model (representing summer low flow conditions).

Selecting an appropriate guideline for dissolved oxygen in Coromandel streams should reflect the natural values of the stream. Streams in less modified catchments are more likely to support fish that are sensitive to low oxygen levels and therefore require higher protection levels to avoid adverse effects. Adopting a higher protection level for less modified catchments is consistent with the Proposed Waikato Regional Plan, which uses Water Management Classes to afford more protective policy and methods to more sensitive catchments. The Wharekawa River has a largely forested catchment with intact riparian vegetation and, as a consequence, a diverse, lowland fish community. It is a reasonable expectation that the lowland and midland reaches of such high value streams will support taxa that are sensitive to low oxygen levels.

Dean & Richardson (1999) investigated the dissolved oxygen requirements of native fish. For the fish species tested, surfacing (an indicator of hypoxic stress) was rarely observed at 5 g/m^3 of dissolved oxygen, and the authors concluded the USEPA (1986) dissolved oxygen criteria for salmonid waters provided adequate protection for New Zealand native fish (Table 2.2). The most relevant criterion to apply to the results of the oxygen modelling is the 7-day mean minimum (24-hour minima averaged over seven days), which for salmonids is 5 g/m^3 (Table 2.2). Landman et al. (2005) more recently determined acute oxygen tolerances (48-h LC_{50} value) for a range of New Zealand fish species; these ranged from 2.65 g/m^3 for inanga whitebait to 0.54 g/m^3 for elvers (juvenile shortfin eel). The authors warned against adopting 5 g/m^3 for protecting more sensitive species because of the apparent higher sensitivities of inanga whitebait compared to salmonids (and the potential for sub-lethal and synergistic effects). When denied access to the surface, inanga whitebait had an acute oxygen tolerance (48-H LC_{50}) of 2.65 g/m^3, which is about 1 g/m^3 higher than rainbow trout (1.61 g/m^3) (Landman et al. 2005). Therefore, a dissolved oxygen guideline of 6 g/m^3 (as a 7-day mean minimum) is expected to provide adequate protection for native fish species inhabiting high value lowland streams of the Coromandel area (1 g/m^3 added to the USEPA criteria of 5 g/m^3).

Table 2.2: Dissolved oxygen concentrations (g/m^3) recommended by the USEPA (1986) to avoid detrimental effects, for various measurement intervals, for streams with salmonids or without salmonids. USEPA criteria are also presented to provide five levels of protection (last 5 rows). NA - not applicable. * Salmonids bury their eggs in the gravel, hence higher oxygen requirements are set for the water column (plus 3 g/m^3) to achieve required dissolved oxygen concentrations for pore-water surrounding eggs and alevins. + Termed "some" impairment in USEPA document.

	Salmonid waters		**Non-salmonid waters**		**Invertebrates**
	Early life stages*	**Other life stages**	**Early life stages**	**Other life stages**	
30 day mean	NA	6.5	NA	5.5	
7 day mean	9.5	NA	6	NA	
7 day mean minimum	NA	5	NA	4	
1 day minimum	8	4	5	3	
No impairment	11	8	6.5	6	8
Slight impairment	9	6	5.5	5	5+
Moderate impairment	8	5	5	4	
Severe impairment	7	4	4.5	3.5	
Acute limit	6	3	4	3	4

For lowland streams in the Coromandel draining highly modified catchments, where limited riparian vegetation allows prolific growth of aquatic plants, a lower concentration of dissolved oxygen is expected to offer adequate protection. This is because the resident aquatic ecosystem has likely been exposed to low oxygen conditions, irrespective of water abstraction. As well as habitat for resident fauna, the lowland reaches are also important migratory pathways for other species heading further upstream where water quality is better. Migratory species that are less tolerant of hypoxia, such as juvenile inanga and smelt (whitebait), are expected to have reached their destination before low oxygen levels become critical in summer and autumn (Wilding 2000a). Migrants continuing to arrive in late summer, such as bullies and eels, were found to be more tolerant of low oxygen (juvenile common bully LC_{50}

0.91 g/m^3; juvenile shortfin eel LC_{50} 0.54 g/m^3; Landman et al. (2005)). The USEPA criteria for non-salmonid waters of 4 g/m^3 (7-day mean minimum, Table 2.2) is recommended to provide adequate protection for the more tolerant taxa expected to be resident in lowland and midland reaches of highly modified catchments in the Coromandel area.

2.5 Water temperature

The effect of reduced flow on water temperature was investigated for the Tapu River, Waiomu Stream and the Wharekawa River[1]. Where possible, temperature was monitored at the forest margin and close to the mouth of the river to measure how rapidly the river warms under existing shade. Temperature was monitored using ONSET dataloggers, with data also provided by Environment Waikato from their recorder sites (Wharekawa and Tapu). Temperature loggers were deployed for approximately one month from mid-March to mid-April (13 or 14 March to 11, 12 or 13 April 2006) and set to record every 15 minutes.

The effect of flow changes on temperature was modelled using RHYHABSIM. This model predicts the rate at which temperature increases as water flows downstream, and how this rate changes with flow. The model was first calibrated to reproduce the observed data-logger temperatures at the upstream site (forest margin), which was assumed to be at equilibrium. The model parameters for the study reach were then calibrated to reproduce the observed increase in temperature at the downstream data-logger site. Nearby meteorological data were obtained for the monitoring period, with riparian shade and bed temperatures varied to calibrate the model to observed stream temperatures for the monitoring period. Meteorological settings were then changed to typical February conditions and the model run to predict the effect of flow changes on water temperature during summer. Only a few meteorological parameters were available from a Coromandel monitoring site (Whitianga), the rest were sourced from Auckland airport data (providing data from a coastal site at an equivalent latitude).

2.6 Tide and aquatic plant survey

A tidal survey was undertaken on the Wharekawa River to determine the extent of tidal influence. The limit of tidal extent provides a boundary for the reaches under study. Speaking to adjacent landowners who were familiar with the river narrowed

[1] The Awaroa Stream was not modelled because temperature modelling was carried out further downstream for a separate study (Wilding & Jowett 2006).

down the likely extent of tidal influence. Water levels were recorded along this section of river at high and low tides to quantify tidal inundation.

Aquatic plants were surveyed in the tidal reach of the Wharekawa River. Excessive growth of aquatic plants can be responsible for dissolved oxygen suppression at night. Random cross-sections were surveyed for aquatic plants on 14 March 2006, with the species and percent cover recorded. Grab samples were collected (using a grapnel and rope) where the river was too deep to see the bottom.

Aquatic plants were also used as indicators of saltwater inundation. Freshwater aquatic plants do not tolerate saltwater intrusion. Saltwater is heavier than freshwater, hence the seawater extends along the bottom of the river as a salt-wedge. The salt-wedge and tidal reach rarely coincide because the river is flowing. The high tide level can act like a dam, causing river water to back-up, with only a thin wedge of saltwater penetrating inland.

3. Results

3.1 Natural flow estimates

Estimates of the natural flow statistics are required to derive minimum flows using the Environment Bay of Plenty method. All four rivers under study have continuous flow records, with all but the Waiomu Stream still monitored today. Environment Waikato provided natural flow estimates for each river based on these flow records (Table 3.1).

Two of the study reaches (Awaroa and Waiomu) were located in different reaches to the flow recorder. For these reaches, natural flow estimates were calculated by scaling the flow recorder estimates. NIWA has calculated estimates of mean flow and MALF for each section of river and stream in New Zealand as part of the REC data (Snelder et al. 2004; Henderson et al. 2005). Estimates of mean flow were calculated using a model that incorporated catchment area, rainfall and evaporation (the climate model for rainfall and evaporation was based on parameters such as location and altitude). Derivation of MALF estimates used this data in addition to hydrogeological information. Scaling the flows for the recorder sites by the proportion of the REC flow provided flow estimates for the surveyed reaches of the Awaroa Stream and Waiomu Stream (REC MALF for estimating Q_5 (one in five-year 7-day low flow), MALF and median; REC mean flow for estimating mean flow). These estimates were within 1.5% of estimates obtained for the Awaroa using conventional simultaneous gauging techniques. Flows measured over the period of the survey are presented for each site in Table 3.2.

Table 3.1: 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. Flows were calculated by Environment Waikato from flow recorder data. There are no major inflows between the midland and lowland reach on the Wharekawa River, hence the flow recorder figures are applicable to both. For the Waiomu and Awaroa, flow recorder figures were adjusted because the study reaches were upstream of the recorder.

Stream	Reach	Q_5	MALF	Median	Mean	data source
Awaroa	Wade Road ford	0.012	0.017	0.042	0.088	derived
Tapu	Tapu township	0.17	0.18	0.45	0.96	Env. Waikato
Waiomu	upstream of 2nd ford	0.040	0.048	0.131	0.266	derived
Wharekawa	Adams Farm	0.265	0.32	0.81	1.86	Env. Waikato

Table 3.2: Flow measurements (m^3/s) recorded on each occasion for the survey reaches (2006). Up to three calibration gaugings were measured for each stream. The time of day (NZST) is given for higher flows, when more rapid flow changes were likely. Flows in bold deviate from flow recorder readings and/or were outliers on the rating curves produced for that site, so may be less accurate.

	Survey	Gauge 1	Gauge 2	Gauge 3
Awaroa	0.034 m^3/s	0.023 m^3/s	0.033 m^3/s	0.062 m^3/s
	10 April	16 March	30 March	26 April (16:00)
Tapu	**0.27 m^3/s**	0.199 m^3/s	**0.282 m^3/s**	1.733 m^3/s
	11 April	13 March	29 March	26 April (13:00)
Waiomu	0.076 m^3/s	0.075 m^3/s	0.077 m^3/s	0.437 m^3/s
	12 April	13 March	30 March	26 April (11:25)
Wharekawa midland	0.442 m^3/s	**1.726** m^3/s	0.517 m^3/s	
	15 March	29 March (15:00)	13 April	
Wharekawa upland	0.452 m^3/s	1.106 m^3/s	0.487 m^3/s	
	14 March	29 March (12:00)	13 April	

3.2 Fish Community

Results are presented for electric fishing of the study sites, and from fyke netting of the Wharekawa River (Table 3.3). Other species observed during the survey or recorded in the New Zealand Freshwater Fish Database 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) were not used in determining the recommended minimum flow for each site.

The Tapu and Wharekawa reaches have good access from the sea for migrant juvenile fish. The diverse fish community encountered in the Wharekawa River (nine species of native fish) is therefore not surprising. Those preferring slower water were more common in the midland section (inanga, giant bully), while fast water species were only observed in the upland reach (torrentfish, trout). The low diversity for the Tapu River is surprising (one species caught, plus two others recorded previously). It is possible that the fishing was conducted too late in the year (14 April) by which time many species had spawned and died, or that a significant disturbance (e.g., flood) had reduced fish numbers. More extensive fishing would be needed before concluding this reach does not support redfin bully, common smelt or shortfin eel.

The Waiomu reach is close to the sea, but there are two fords on the stream that may be potential barriers to fish migration. Therefore, those species caught downstream of the fords have been included in the habitat model.

The Awaroa site is 8 km inland, further than the other sites in this study, so less fish would be expected at this site. There are at least two fords on this stream, both added deterrents to fish migration (Figure 2.5). The New Zealand Freshwater Fish Database includes records from above and below the Gentle Annie Road ford (fished on the same occasion). These records indicate smelt, inanga and torrentfish were caught immediately below the ford, but not above it. Whether these three species would migrate the extra 2.5 km upstream to the study site in the absence of artificial barriers cannot be answered conclusively, but at least one of the two fords on the Awaroa Stream could form a barrier to migration.

Table 3.3: Fish caught from the study sites. Electric fishing (EF) was used at all sites, with fyke nets also used in deeper sections of the Wharekawa River. In addition to those caught, other fauna observed during the study are marked 'obs.' and species recorded in the New Zealand Freshwater Fish Database at that site are marked 'NZFFD'. Other species expected to occur, but not caught are indicated ('E'), as well as those species that are less likely to be resident at each site ('?').

	Awaroa	**Tapu**	**Waiomu**	**Wharekawa midland**		**Wharekawa upland**
	10/04/06	14/04/06	12/04/06	16/03/06	16/03/06	16/03/06
	EF	EF	EF	EF	Fyke	EF
	60 m^2	53 m^2	50 m^2	50 m^2	5 trap-nights	100 m^2
Longfin eel	1	NZFFD	3	2	13	15
Shortfin eel	E	E	NZFFD	6	21	7
Unident. eel	4		3	14		12
Giant bully					12	
Common bully	?	?	NZFFD	?		1
Redfin bully	6	E	3	66	46	47
Torrentfish	?	1	10	?		2
Common smelt	?	E	2		37	1
Inanga	?	NZFFD	NZFFD		150	24
Banded kokopu	1		obs.			
Lamprey						2 (ammocoete)
Trout		obs. (100-300 mm)				1 brown (120 mm) (+ 250 & 450 mm trout obs.)
Koura (crayfish)	common				1	1
Kakahi (mussels)				obs.		
Shrimp	common	abundant	abundant	abundant	common	common

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 Awaroa Stream, maximum habitat occurs at greater than median flows (Figure 3.1), with only banded kokopu preferring less flow. The Environment Bay of Plenty method produced a minimum flow for this reach of 0.013 m^3/s (Table 3.4). Points of inflection were derived for those species displaying a clear breakpoint (as opposed to a gradual reduction in habitat with flow) and are summarised in Table 3.4. The point of inflection for redfin bully is higher than MALF at 0.032 m^3/s.

For the Tapu River, maximum habitat occurred at close to median flows for redfin bully, larger longfin eels and common bully (Figure 3.2, Table 3.5). Inanga preferred flows closer to MALF, with maximum habitat for the remaining species predicted to occur at much higher flows. The minimum flow produced using the Environment Bay of Plenty method for this reach was 0.152 m^3/s, based on redfin bully (Table 3.5). Points of inflection were not observed, with habitat for all species expected to reduce gradually with less flow (Figure 3.2 & 3.3).

Habitat modelling for the Waiomu Stream produced a similar response to the Awaroa Stream, with maximum habitat for all species except banded kokopu exceeding the median flow (Figure 3.4, Table 3.6). Using the Environment Bay of Plenty approach, torrentfish have the highest flow requirement and this approaches Q_5.

Because of the high diversity of native fish encountered in the lower Wharekawa River (10 species in the upland and midland reaches) it is a good candidate river for the higher protection level of 90%, which is reserved for reaches supporting a high number of native fish species (Criteria 4, Appendix 1).

The midland reach of the Wharekawa River provides near maximum habitat at MALF for several inhabitants including inanga, redfin bully, longfin and shortfin eel (Figure 3.5). This is supported by the fishing results, which indicate these species are common in the midland reach. Shortfin eel have the highest flow requirement when applying the Environment Bay of Plenty approach at 0.265 m^3/s (Table 3.7). Trout were not observed in the midland reach during the survey, but habitat for trout was modelled should this reach prove to support a fishery (Figure 3.6, Table 3.7).

A habitat survey was also completed on an upland reach of the Wharekawa River. Maximum habitat was provided by flows greater than MALF for most species of fish (Figure 3.7, Table 3.8). The Environment Bay of Plenty approach indicates higher minimum flow requirements for fish habitat in the upland reach of the Wharekawa River (Figure 3.7, Table 3.8) compared to the other reaches surveyed, even if applying a lower protection level (85%), and this is further discussed in Section 3.7.

Riffle habitat was modelled as an indicator of habitat for fast-water benthic invertebrates (i.e., invertebrates most sensitive to reduced flow). Points with Froude numbers in excess of 0.41 are considered to be riffle habitat (see Jowett 1993a). This is presented instead of modelled flow responses for individual invertebrate species because of concerns expressed by Jowett (2000) and Wilding (2007) 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). The area of riffle habitat is expected to increase gradually beyond median flow, and benthic invertebrate habitat along with it. Minimum flow requirements expected to maintain riffle habitat are presented in Table 3.9, using habitat protection levels of 70% and 85% of MALF. If the minimum flow requirements for maintaining fish habitat were adopted, these would equate to protection levels for riffle habitat of between 79% and 118% (Table 3.9).

The change in velocity, depth, width and area of riffle habitat with flow are also plotted for each stream in Appendix 5. Velocity showed a similar response to the area of riffle habitat for all the reaches surveyed, and both changed more dramatically with flow compared to width or depth.

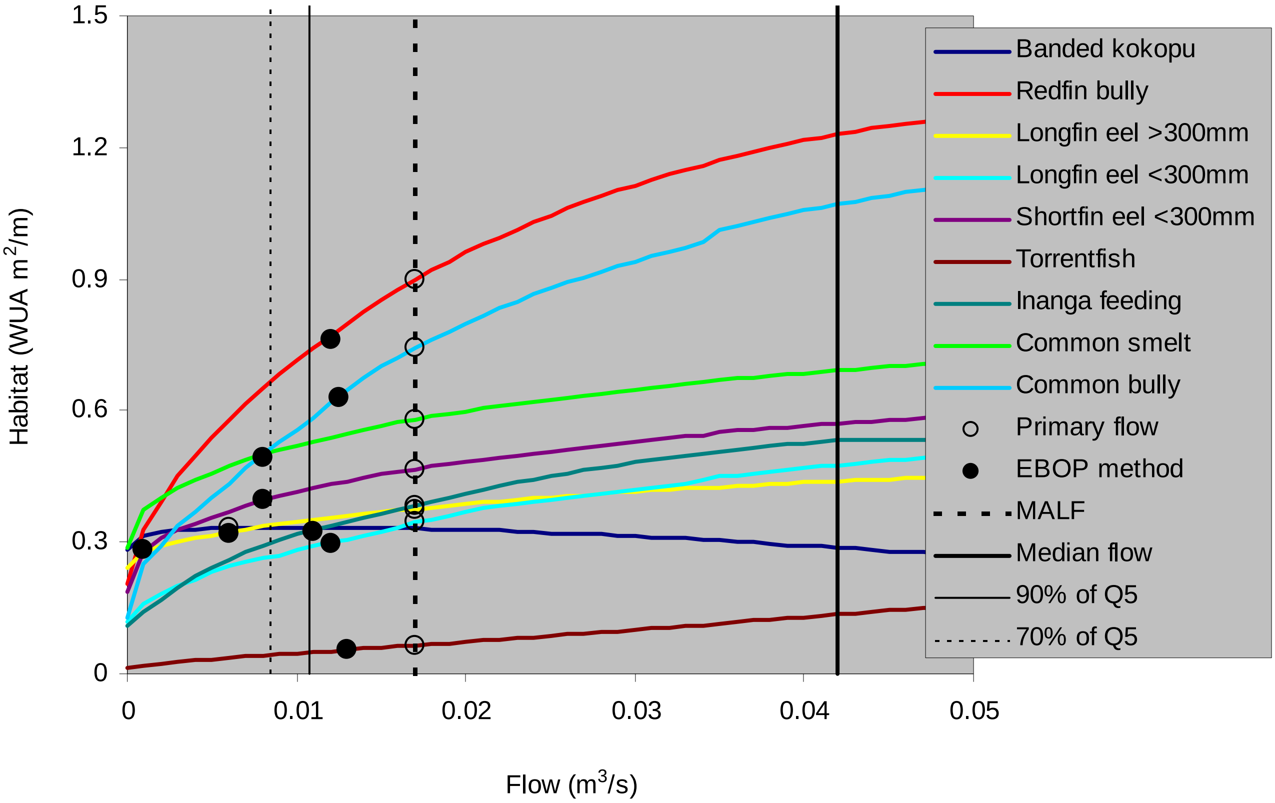

Figure 3.1: The change in habitat with flow for various species and life stages of fish in the **Awaroa Stream**. Using the Environment bay of Plenty method, the primary flow is the available-habitat value to which the habitat protection level is applied to produce the flow requirement for each species (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 3.

Table 3.4: Results derived from the habitat-flow response data for the **Awaroa Stream** (as plotted in Figure 3.1). The point of inflection is the flow at which habitat begins to decline more sharply, and is only 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%). Using this method, the recommended minimum flow (in bold) is based on the resident species with the highest flow requirement. Habitat protection levels afforded by existing and historic allocation methods (90% & 70% of Q_5 flow, respectively) are also presented. Species and life stages marked * are not expected to reside in this reach, and are included for reference only. MALF is the 7-day mean annual low flow; Q_5 is the one in 5-year low flow (see Table 3.1).

	Flow at max. habitat (m^3/s)	**EBOP method (m^3/s)**	**Point of inflection (m^3/s)**	**Protection level at 70% of Q_5**	**Protection level at 90% of Q_5**
Awaroa Stream	(MALF 0.017 m^3/s, Q_5 0.012 m^3/s)				
Banded kokopu	0.006	0.001	0.002	100%	100%
Redfin bully	0.102	0.012	0.032	72%	80%
Longfin eel >300mm	0.111	0.006		90%	92%
Longfin eel <300mm	0.28	0.012		76%	81%
Shortfin eel <300mm	0.198	0.008		85%	89%
Torrentfish	>0.5	**0.013**		65%	72%
Inanga*	0.044	0.011	0.032	76%	83%
Common smelt*	0.196	0.008		86%	90%
Common bully*	0.138	0.0125	0.030	67%	75%

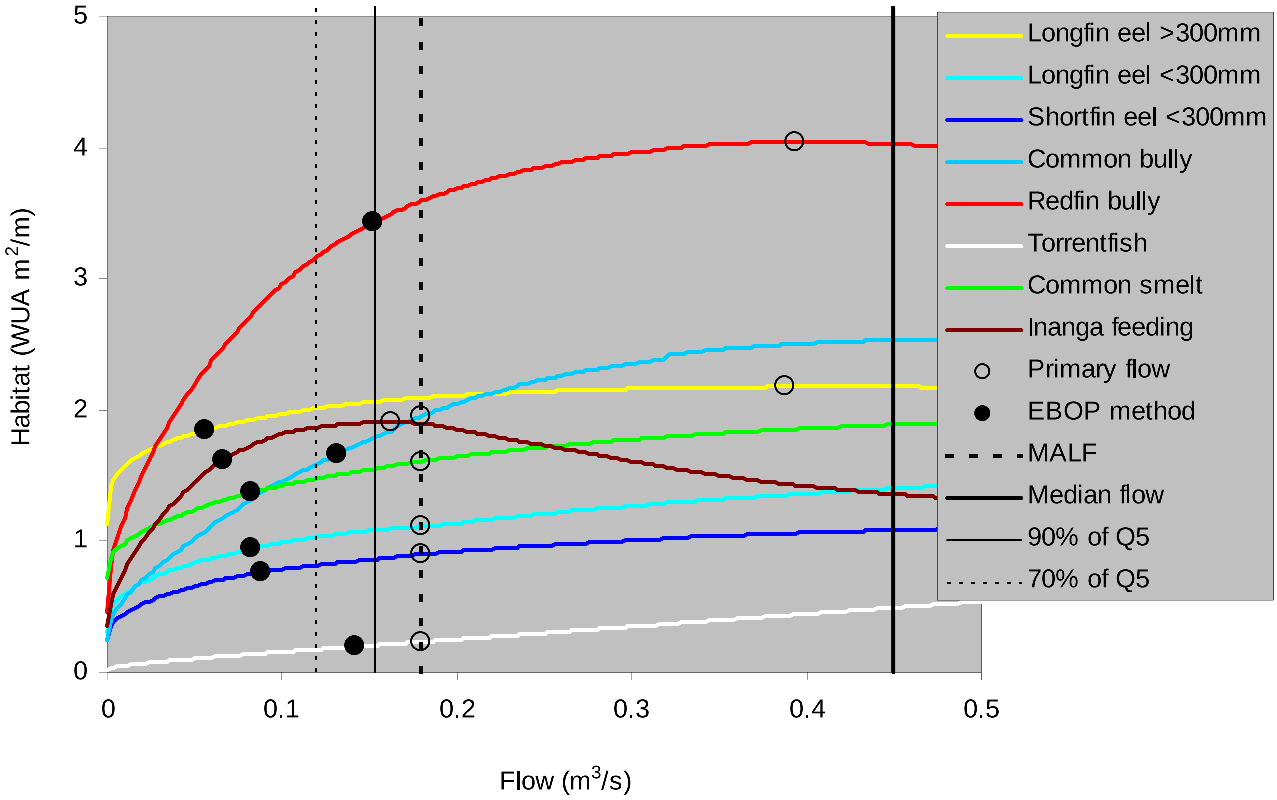

Figure 3.2: The change in habitat with flow for various species and life stages of native fish in the **Tapu River**. Otherwise as per Figure 3.1.

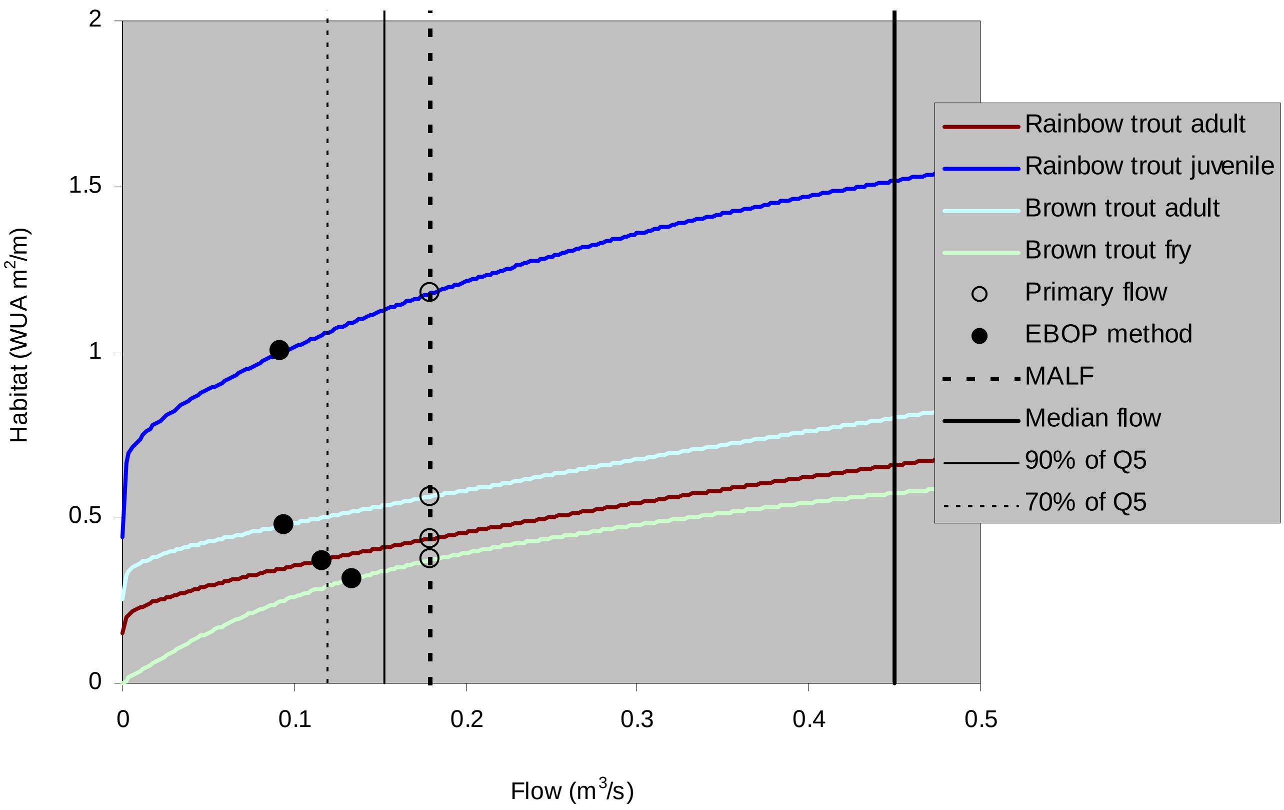

Figure 3.3: The change in habitat with flow for various life stages of rainbow and brown trout in the **Tapu River**. Otherwise as per Figure 3.1.

Table 3.5: Results derived from the habitat-flow response data for the **Tapu River** (as plotted in Figure 3.2 & 3.3). Otherwise as per Table 3.4.

	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**
Tapu River	(MALF 0.18 m^3/s, Q_5 0.17 m^3/s)				
Longfin eel >300mm	0.388	0.056	0.06	92%	95%
Longfin eel <300mm	2.8	0.082		93%	97%
Shortfin eel <300mm	1	0.088		90%	96%
Common bully*	0.464	0.132		80%	91%
Redfin bully	0.394	**0.152**		78%	85%
Torrentfish	4.9	0.142		75%	89%
Common smelt	1	0.082		91%	96%
Inanga feeding	0.162	0.066		98%	100%
Rainbow trout adult	2.1	0.116		85%	94%
Rainbow trout juvenile	1.5	0.092		90%	96%
Brown trout adult	1.9	0.094		89%	95%
Brown trout fry	1.1	0.134		78%	91%

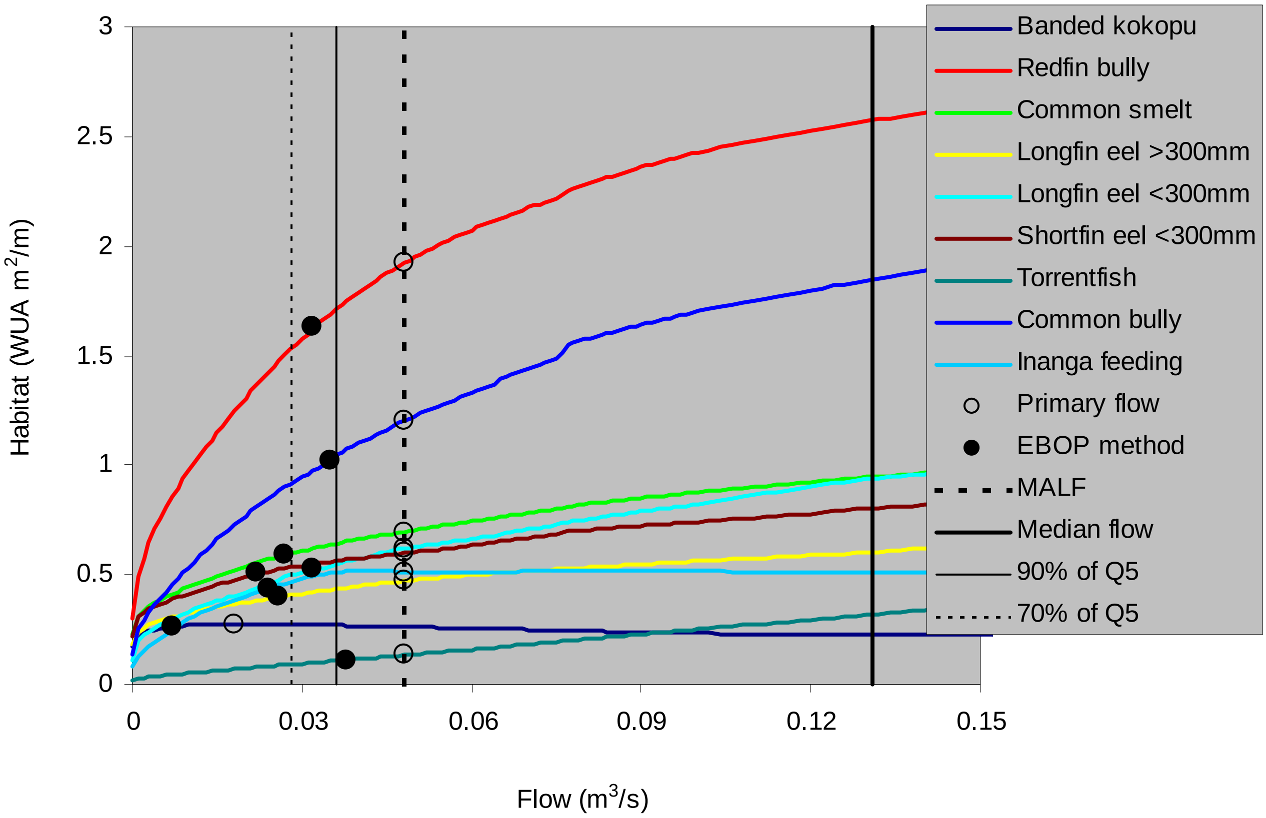

Figure 3.4: The change in habitat with flow for various species and life stages of fish in the **Waiomu Stream**. Otherwise as per Figure 3.1.

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

	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**
Waiomu Stream	(MALF 0.048 m^3/s, Q_5 0.040 m^3/s)				
Banded kokopu	0.018	0.007	0.01	100%	97%
Common smelt	0.412	0.027		85%	92%
Longfin eel >300mm	>1.0	0.026		85%	92%
Longfin eel <300mm	>1.0	0.032		79%	89%
Redfin bully	0.25	0.032		78%	89%
Shortfin eel <300mm	0.448	0.022		88%	94%
Torrentfish	>1.0	**0.038**		66%	81%
Common bully	0.246	0.035		75%	87%
Inanga	0.458	0.024	0.025	89%	100%

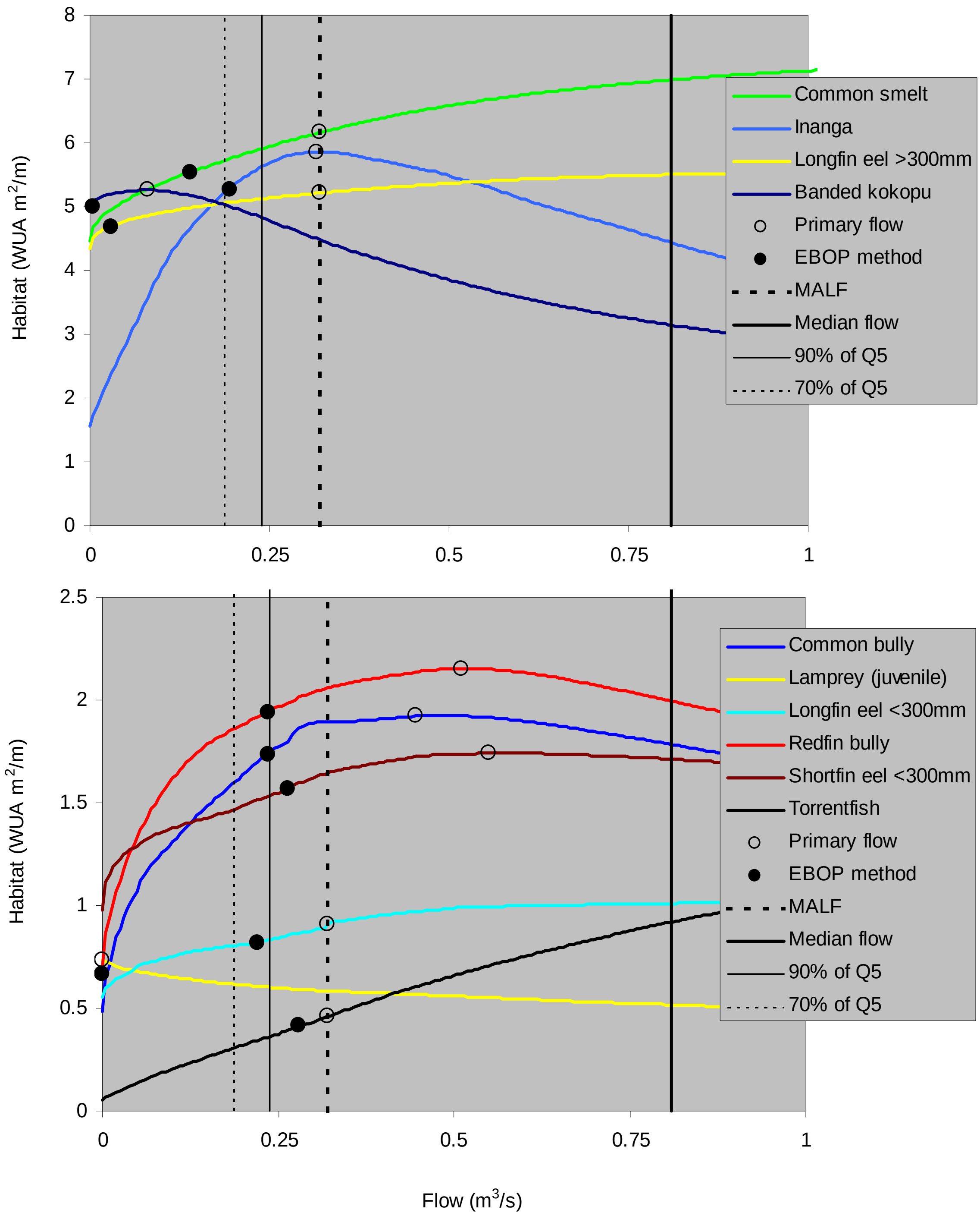

Figure 3.5: The change in habitat with flow for various species and life stages of fish in the **Wharekawa River midland reach**. Protection levels for native fish are 90% (except banded kokopu with 95%). Otherwise as per Figure 3.1. Three plots are used to display results for improved clarity, two of which are presented here and the third in Figure 3.6. Note: habitat suitability data for giant bully are not available, but may be similar to common bully.

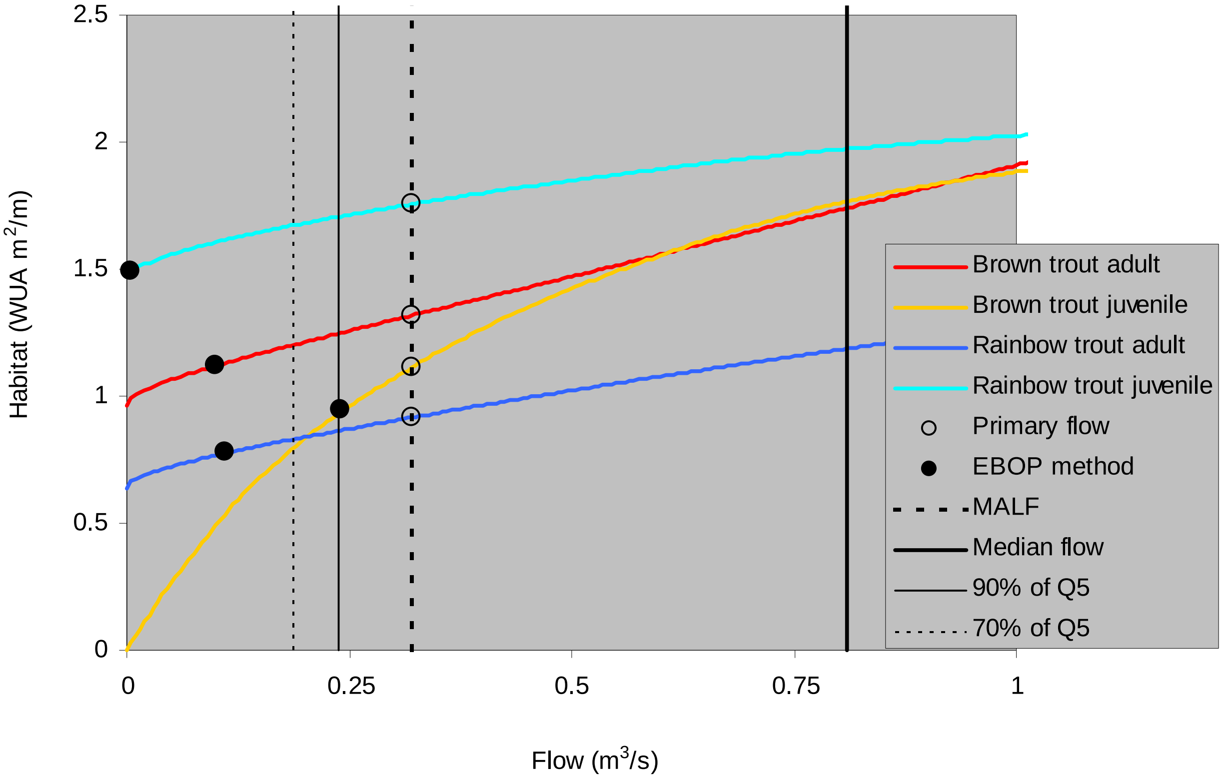

Figure 3.6: The change in habitat with flow for various species and life stages of fish in the **Wharekawa River midland reach**. Three plots are used to display results for improved clarity, the third of which is presented here. Otherwise as per Figure 3.1.

Table 3.7: Results derived from the habitat-flow response data for the **Wharekawa River midland** (as plotted in Figure 3.5 & 3.6). PL = protection level ([#] protection level for banded kokopu 95%). Otherwise as per Table 3.4.

	Flow at max. Habitat (m^3/s)	**EBOP method (m^3/s) 85% PL**	**EBOP method (m^3/s) 90% PL**	**Point of inflection (m^3/s)**	**Protection level at 70% of Q_5**	**Protection level at 90% of Q_5**
Wharekawa River midland	(MALF 0.32, Q_5 0.265)					
Common bully*	0.445	0.195	0.235	0.29	82%	90%
Common smelt	1.855	0.07	0.14		93%	96%
Inanga	0.315	0.165	0.195	0.18	89%	96%
Lamprey (juvenile)	0	0	0		84%	82%
Longfin eel >300mm	1.44	0.005	0.03		97%	98%
Longfin eel <300mm	1.98	0.125	0.22		88%	91%
Redfin bully	0.51	0.17	0.235		86%	90%
Shortfin eel <300mm	0.55	**0.195**	**0.265**	0.38	84%	88%
Torrentfish*	1.99	0.26	0.28		66%	78%
Banded kokopu*	0.08	0.005[#]			96%	92%
Brown trout adult*	>4	0.1			91%	94%
Brown trout juvenile*	1.49	0.24			71%	83%
Rainbow trout adult*	>4	0.11			91%	94%
Rainbow trout juvenile*	1.755	0.005			95%	97%

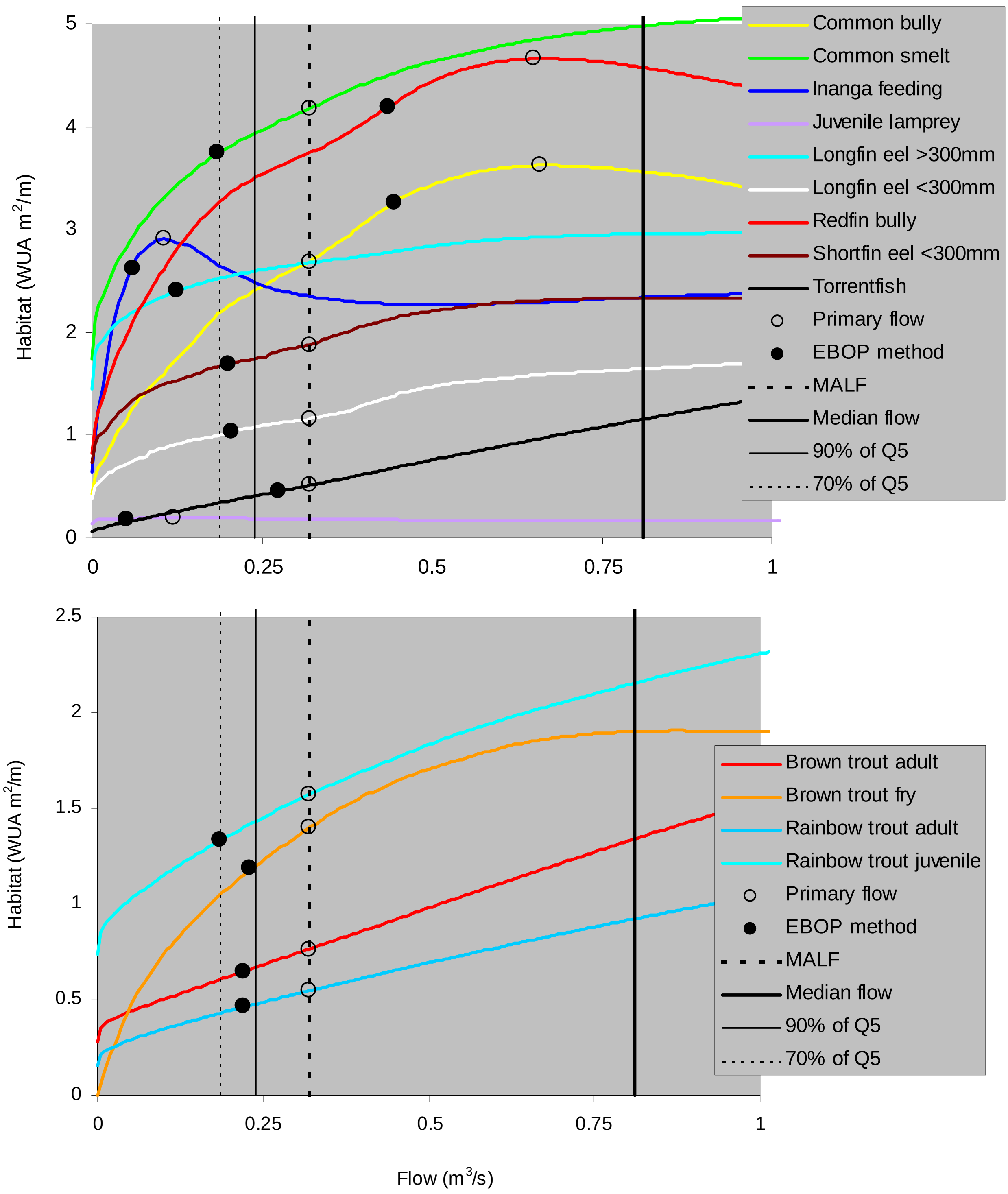

Figure 3.7: The change in habitat with flow for various species and life stages of fish in the **Wharekawa River upland reach**. Two plots are used to display results for improved clarity. Protection levels for native fish are 90%. Otherwise as per Figure 3.1.

Table 3.8: Results derived from the habitat-flow response data for the **Wharekawa River upland** (as plotted in Figure 3.7). PL = protection level. Otherwise as per Table 3.4.

	Flow at max. habitat (m^3/s)	EBOP method (m^3/s) 85% PL	EBOP method (m^3/s) 90% PL	Point of inflection (m^3/s)	Protection level at 70% of Q_5	Protection level at 90% of Q_5
Wharekawa River upland	(MALF 0.32 m^3/s, Q_5 0.265 m^3/s)					
Common bully	0.66	**0.40**	**0.445**		60%	66%
Common smelt	1.355	0.145	0.185		90%	94%
Inanga feeding	0.105	0.05	0.06	0.06	91%	86%
Juvenile lamprey	0.12	0.005	0.05		96%	94%
Longfin eel >300mm	1.2	0.08	0.125		94%	97%
Longfin eel <300mm	2.8	0.175	0.205		86%	93%
Redfin bully	0.65	0.38	0.435		70%	75%
Shortfin eel <300mm	0.82	0.15	0.2		89%	92%
Torrentfish	2.7	0.26	0.275		66%	79%
Brown trout adult	1.925	0.22			79%	87%
Brown trout fry	2.5	0.23			75%	85%
Rainbow trout adult	2.6	0.22			79%	87%
Rainbow trout juvenile	2.5	0.185			85%	91%

Table 3.9: Flows required (m^3/s) to maintain riffle habitat at 70% and 85% of that available at MALF (mean annual low flow). The protection level afforded by the flow requirement determined for fish habitat (using the Environment Bay of Plenty method) is also presented. A smoothing function was run for all reaches to remove the effect of 'bumps' in the modelling results (plotted data presented in Appendix 5).

Stream / reach	70%	85%	Prot. Level (fish habitat)
Awaroa Stream	0.010	0.013	85%
Tapu River	0.138	0.160	79%
Waiomu Stream	0.030	0.038	85%
Wharekawa River (midland)	0.005	0.080	92%
Wharekawa River (upland)	0.185	0.250	118%

3.4 Dissolved oxygen

Low oxygen concentrations are stressful to aquatic life (Dean & Richardson 1999) and reduced flows have the potential to exacerbate this by reducing the re-aeration of water (i.e., reduce how much oxygen is dissolved into the water from the atmosphere).

Dissolved oxygen was monitored in the tidal reach of the Wharekawa River — the reach where macrophytes were most common and the water was deep and slow flowing (Figure 2.11). Macrophytes stop producing oxygen when it is dark and consume oxygen instead (through respiration) causing an oxygen minima in the morning.

The first logger deployed in March failed. Although a second logger was deployed in April, the river was cooler and flows higher by this time, meaning the results needed to be extrapolated further to provide a prediction of summer low flow conditions. From the April data (logger deployed 13 to 24 April, recording every 30 minutes), average dissolved oxygen concentrations were 7.9 g/m^3 at an average temperature of 14.4 °C (78% oxygen saturation). Flows over this period averaged 0.558 m^3/s, with one small fresh of 1.046 m^3/s on 19 April (from flow recorder data). Oxygen concentrations were stable during the fresh (negligible diurnal or tidal signature), but omitting these data had a negligible effect on the results, so were retained for the modelling. Dissolved oxygen was highest in the evening (peaking 4.5 hours after solar noon) and lowest in the morning, with an average range of 0.7 g/m^3 (Figure 3.8). The 24-hour minimum oxygen concentration averaged 7.6 g/m^3 with an absolute minimum oxygen concentration of 6.8 g/m^3. Both values are adequate to support aquatic life, exceeding the recommended guideline for high value lowland streams of the Coromandel (6 g/m^3 as a 7-day average of 24-hour minima; see Section 2.4).

The computer programme WAIORA was used to model oxygen concentrations and predict how oxygen would be affected by reduced flows. The model was calibrated using oxygen and temperature data collected in April. Habitat data from the midland reach was modified (riffle cross-sections deleted) to better represent depth and velocity conditions in the tidal reach. The model was run using a mean water temperature of 20 °C to reproduce summer conditions. Aquatic plants were assumed to be the most important primary producers in the tidal reach, because there were few shallow cobble areas for periphyton growth. The model estimated a production/re-aeration ratio of 0.15 and a re-aeration coefficient of 122.2 gO_2/m^3/day. An analysis of 28 Waikato lowland streams found re-aeration coefficients between 3.5 and 55.0 gO_2/m^3/day, and production/re-aeration ratios between 0.07 and 1.87 (Wilcock et al.

1998). This indicates re-aeration in the Wharekawa River is higher than typical lowland Waikato streams.

The predicted change in oxygen concentrations (24-hour minimum) with flow is presented in Figure 3.9. This indicates oxygen concentrations (24-hour minimum) decline more rapidly at flows less than 0.7 m^3/s. To achieve the recommended dissolved oxygen guideline for high value lowland streams (6 g/m^3) the model predicts a flow of 0.61 m^3/s is required in the tidal reach of the Wharekawa River. To achieve 5 g/m^3 of dissolved oxygen requires a flow of 0.49 m^3/s, and 0.42 m^3/s achieves 4 g/m^3 of dissolved oxygen. Maintaining 8 g/m^3 of dissolved oxygen requires a flow of 1.4 m^3/s.

Because the modelling was carried out late in the season (April), the results should be considered preliminary and further oxygen monitoring conducted next summer. Results are sufficient to indicate that oxygen is potentially a critical issue in determining minimum flow requirements for the Wharekawa River.

Overlying the observed diurnal oxygen pattern in April (Figure 3.8) was a tidal pattern in dissolved oxygen that saw oxygen concentrations at high tide drop by 0.6 g/m^3 compared to low tide (Figure 3.10). High tide presumably reduced re-aeration by increasing water depth and reducing water velocity. WAIORA does not incorporate tidal influence as a factor in the oxygen model, although the observed oxygen concentration (daily average) would be slightly lower because of the tidal effect.

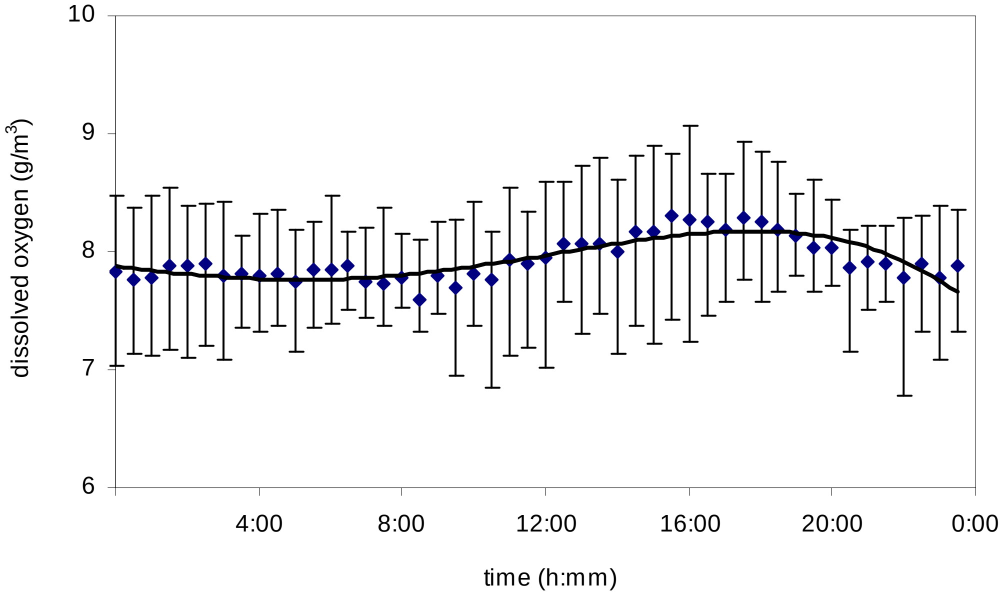

Figure 3.8: Dissolved oxygen concentrations in the tidal reach of the Wharekawa River. Oxygen concentrations were averaged for each time of day over the 12-day monitoring period (April 2006) to give the average 24-hour cycle of dissolved oxygen. Error bars show the maximum and minimum for each time of day.

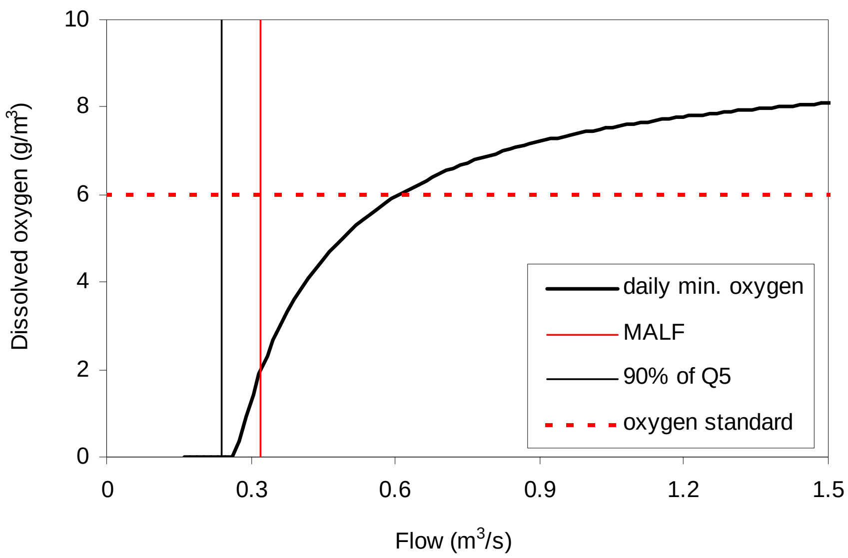

Figure 3.9: Predicted effect of reduced flows on dissolved oxygen concentration (24-hour minimum) for the tidal reach of the Wharekawa River. Existing allocation limits are also presented (90% of the 5-year low flow) as well as the recommended standard for dissolved oxygen in high-value Coromandel streams (6 g/m^3, see Section 2.4). MALF is the mean annual low flow (0.32 m^3/s).

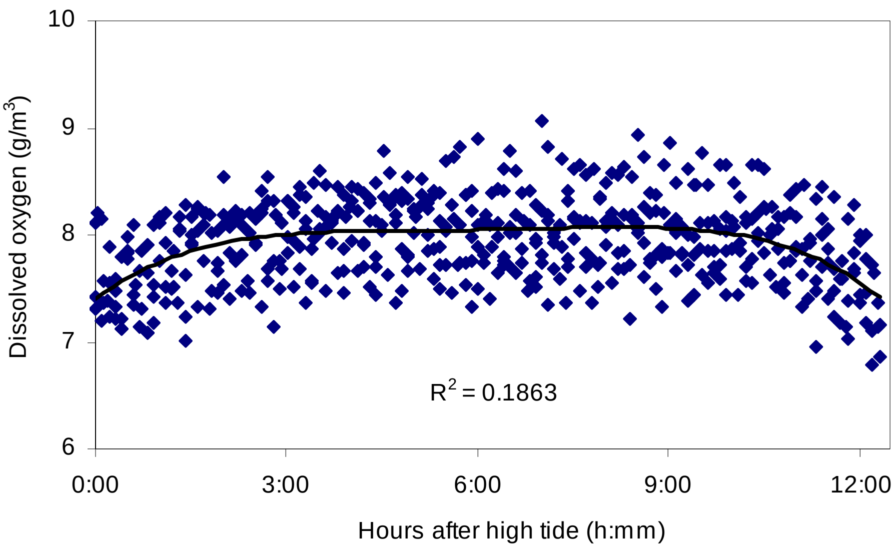

Figure 3.10: Dissolved oxygen data from the lower Wharekawa River plotted against hours after high tide (at Whitianga Harbour entrance). High tide is at 0:00 and 12:24 on this scale, with low tide at 6:12. A polynomial trendline was fitted to the data.

3.5 Water Temperature

Water temperature was monitored at two sites each for the Wharekawa River, Tapu River and Waiomu Stream. This provided the basis for the modelling of water temperature using RHYHABSIM. The model was calibrated to reproduce the observed water temperature at both the upstream and downstream sites under the climatic conditions experienced during the monitoring period, then the model was re-run using February climatic data. The method is described in more detail in Section 2.5 and the data used to calibrate the model for each site are summarised in Appendix 6.

Waiomu Stream was monitored from mid-March to mid-April at two sites (one within the forest, and the second site at the downstream end of the less sheltered urban reach). Water temperature increased over this reach by 1 °C on average, with similar increases in 24-hour maximum temperature (Figure 3.11). The model adequately reproduced the observed stream temperatures using the parameters specified in Appendix 5. The temperature model was then re-run using February climatic data. The data output was simplified to display the 24-hour maximum temperature at the river mouth, and how this was predicted to change with flow (Figure 3.12). This predicts maximum temperature will increase in the order of 0.3 °C for each 0.01 m^3/s reduction in flow.

A similar approach was taken for modelling water temperature of the Tapu River. The Environment Waikato recorder provided temperature data within a few hundred metres of the river mouth, with a second temperature logger deployed 6.5 km upstream at the forest margin (Figure 2.6). The longer un-forested reach produced a greater temperature increase compared to the Waiomu Stream, with a 2.1 °C increase in average temperature and 2.8 °C increase for the 24-hour maximum temperature (Figure 3.13). The model adequately reproduced the observed stream temperatures using the parameters specified in Appendix 5. The temperature model was then re-run using February climatic data. The maximum 24-hour temperature (at the river mouth) is expected to increase in the order of 0.05 °C for each 0.01 m^3/s reduction in flow (Figure 3.14). This increase is less than that predicted for the Waiomu Stream, principally because the longer un-shaded reach for the Tapu (6.5 km cf. 2.1 km for the Waiomu Stream) enables the river to approach equilibrium temperature even at flows approaching MALF.

Problems were encountered modelling temperature for the Wharekawa River. The observed increase in water temperature (average temperature increased from 16.9 °C to 19.4 °C, Figure 3.15) could not be reproduced using the RHYHABSIM model over such a short reach (1.2 km), even with negligible shade (0.1 degree canopy angle) and high bed temperatures (35 °C). It seems likely, therefore, that at least one of the loggers was affected by localised temperature anomalies (e.g., backwater hot or cold spot). The model was re-run with reach settings the same as those used for the Tapu River (for shade and bed temperature), with upstream settings retained to achieve the observed forest margin temperatures for the Wharekawa River. This provided a more likely scenario for modelling water temperature in the Wharekawa River. Water temperatures (24-hour maximum) are expected to increase in the order of 0.015 °C per 0.1 m^3/s reduction in flow at a point 5 km downstream (Figure 3.16).

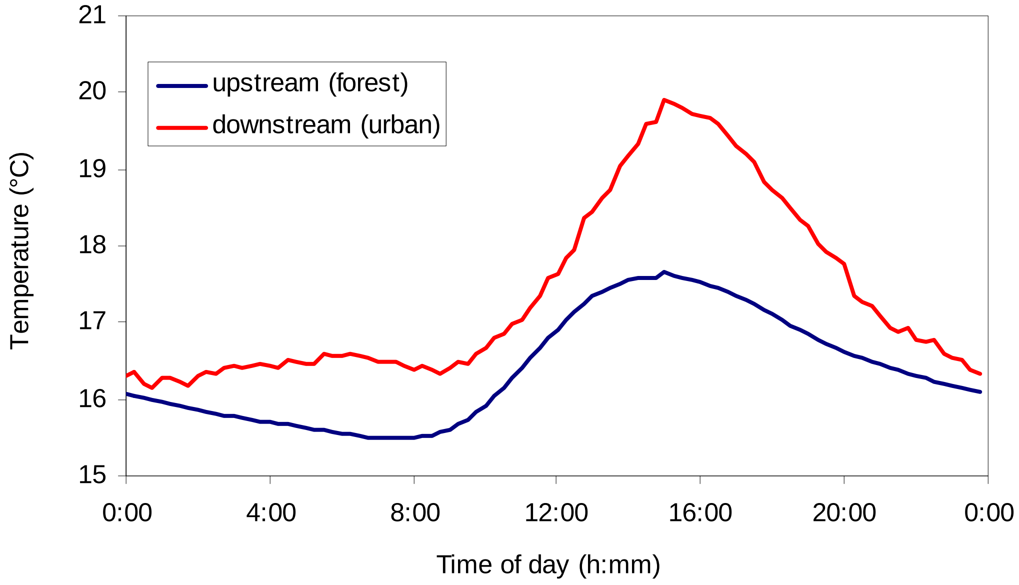

Figure 3.11: Water temperature results from two sites on the **Waiomu Stream**, the upstream site within the forest and the downstream site 2.1 km downstream after passing through Waiomu village. The temperature for each time of day was averaged over the monitoring period (13/3/06 to 12/4/06). The downstream site was tidal and seawater intrusions were removed from the dataset by deleting data collected 3 hours either side of high tide (the period when temperature spikes were observed).

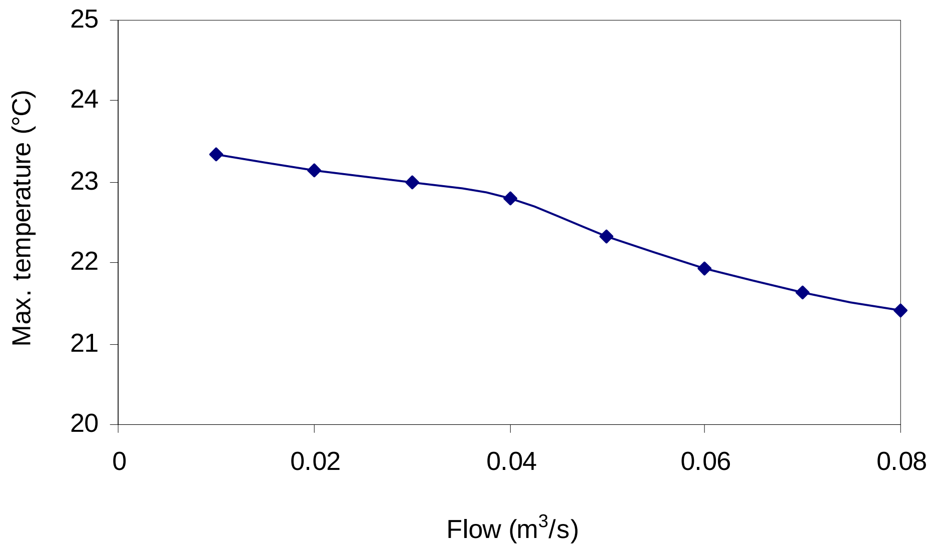

Figure 3.12: The effect of reduced flow on water temperature in the **Waiomu Stream** was modelled and results are presented here in terms of the 24-hour maximum temperature at the river mouth during summer against flow (average February climatic data used, see Appendix 5).

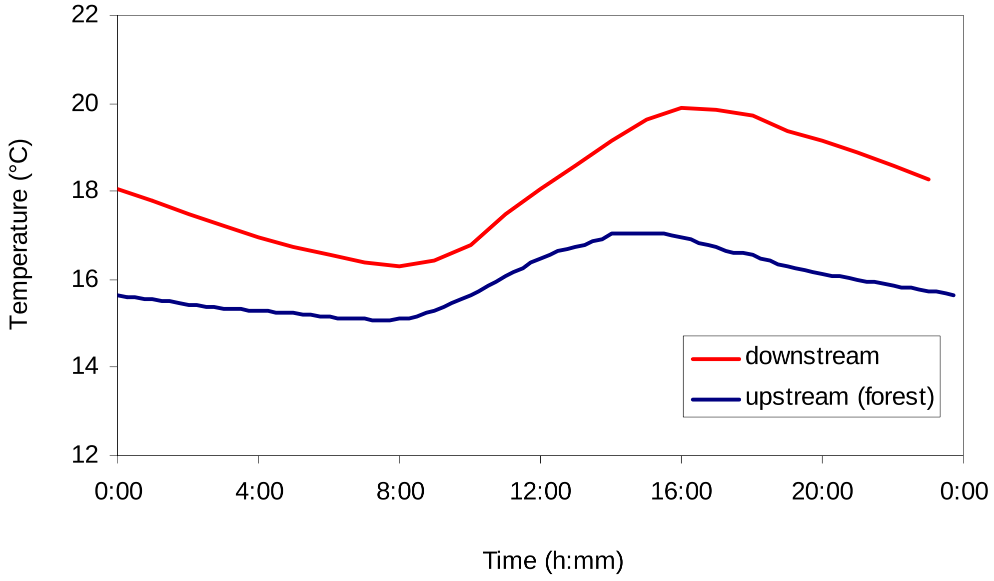

Figure 3.13: Water temperature results from two sites on the **Tapu River**, the upstream site close to the forest margin and the downstream site 6.5 km downstream (see Figure 2.6). The average temperature for each time of day was calculated for the monitoring period (13/3/06 to 11/4/06). Temperature data was omitted during two high flow events (26 March and 2 April).

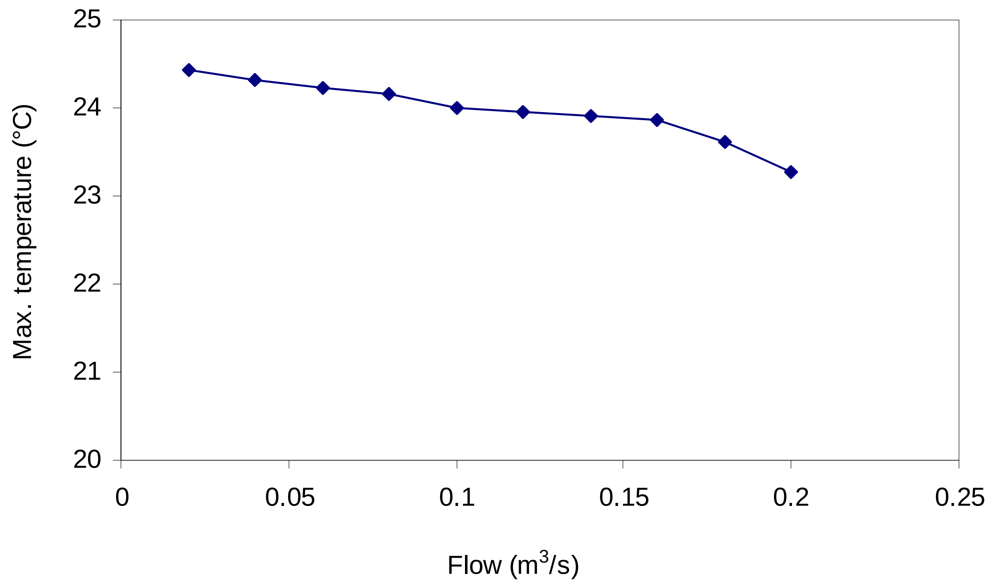

Figure 3.14: The effect of reduced flow on water temperature was modelled for the **Tapu River** and results are presented here in terms of the 24-hour maximum temperature at the river mouth during summer against flow (average February climatic data used, see Appendix 5).

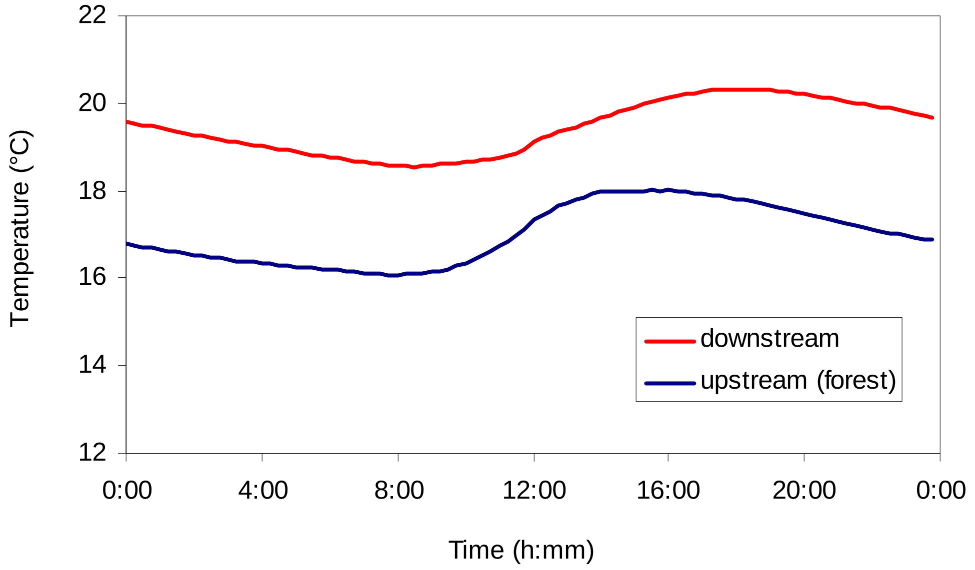

Figure 3.15: Water temperature results from sites monitored on the **Wharekawa River**. The upstream site is close to the forest margin and the downstream site is 1.2 km downstream (Environment Waikato flow recorder). The average temperature for each time of day was calculated for the monitoring period (14/3/06 to 13/4/06). Temperature data was omitted for the period of high flow events (26 March to 7 April).

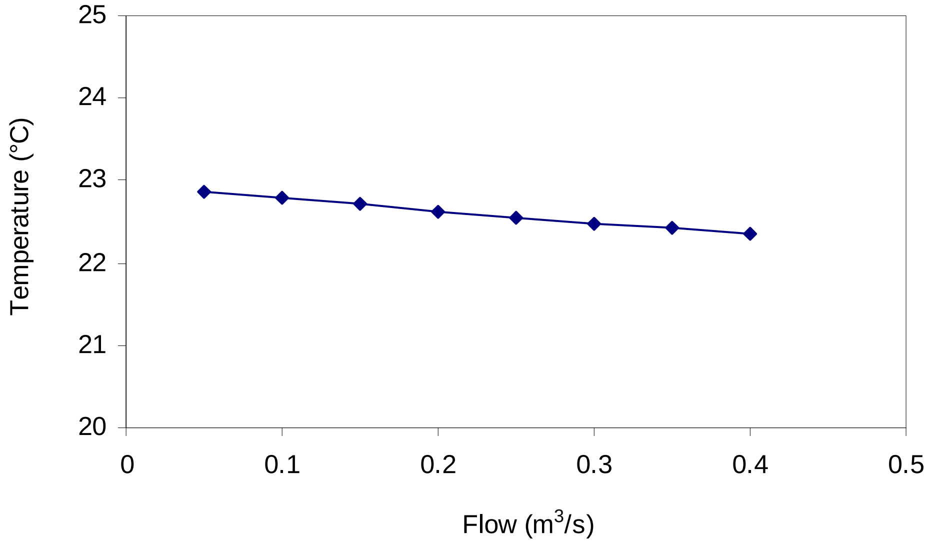

Figure 3.16: The effect of reduced flow on water temperature was modelled for the **Wharekawa River** and results are presented here in terms of the 24-hour maximum temperature during summer at a distance 5 km downstream of forest margin (at the saline estuary), against flow (average February climatic data used, see Appendix 5).

3.6 Tide and aquatic plant survey of the Wharekawa River

In order to identify the extent of the tidal lowland reach for the Wharekawa River, tidal fluctuation in water level was measured at several points. Local residents indicated the tide reached the State Highway 25 bridge. Pegs were installed at sites above and below the bridge to provide temporary staff gauges (GPS locations are specified in Appendix 2). Water levels were measured against the pegs at low tide (13:22 to 14:16 DST on 14/03/2006) and at high tide (07:57 to 08:49 DST on 15/03/2006). High tide reached as far the State Highway 25 bridge, with a 0.064 m tidal range at this point. At a distance of 0.7 km downstream of the bridge, the tidal range was 0.53 m.

There was a lag between high tide at the harbour entrance and in the Wharekawa River of 18 minutes. The high tide at Whitianga Harbour entrance reached a height of 0.7 m above mean water level at 08:12 am on 15 March. March tides ranged from 0.47 m to 1.08 m (above mean water level), indicating the survey was conducted at an average tide height. During spring tides, an extra 0.38 m of tide is expected and would presumably push further up the river (perhaps a kilometre or so).

Aquatic plants were surveyed as a potential cause of oxygen suppression in the lower river, and as an indicator of saltwater intrusion into the river (freshwater plants do not tolerate salt water immersion; Matheson et al. 2004). The coverage of aquatic plants was low in the tidal reach of the Wharekawa River when surveyed (Table 3.10). Most cross-sections were devoid of aquatic plants, and when present were generally confined to the shallow margins or mid-channel sand bars. Several native aquatic plants were found, but none of the most troublesome exotics were observed (such as *Lagarosiphon major*, *Egeria densa* or *Ceratophyllum demersum*).

The presence of crab-holes and a lack of aquatic plants indicate saltwater influence within 1 km of the river mouth (GPS locations are specified in Appendix 2). Saltwater may penetrate further upstream, but this section was not accessible for observation because of frequent logjams. The limit of saltwater influence was narrowed down to a 1.5 km reach in the vicinity of the hill at the end of Liddell Road (Figure 2.11).

Table 3.10: The percentage of channel-width occupied by each species of aquatic plant for 7 cross-sections of the lower Wharekawa River (below State Highway 25 Bridge).

Dist. to harbour (km)	**3.43**	**3.37**	**3.15**	**2.96**	**2.66**	**0.89**	**0.24**
Easting	**2762872**	**2762928**	**2763115**	**2763193**	**2763349**	**2764546**	**2764830**
Northing	**6447763**	**6447790**	**6447814**	**6447692**	**6447451**	**6447757**	**6447905**
Elodea canadensis (exotic)	2	3		15	25		
Myriophyllum cf. *triphyllum*	1	3		20			
Potamogeton suboblongus		1			1		
Polygonum sp.				15			
Callitriche sp.				2			
Charophyte (cf. *Nitella* sp.)				1	5		
Total plant cover (%)	3	7	0	53	31	0	0
Crab holes						Y	Y

3.7 Applying results to other Coromandel streams

3.7.1 Habitat

The ability to predict the minimum flow requirements for other streams using a regional method 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. To determine whether similar trends are emerging for Coromandel streams, the minimum flows for native fish habitat[2] (derived using the Environment Bay of Plenty method) were plotted against MALF (Figure 3.17). The upland Coromandel streams display a similar response to eastern Kaimai streams in the Bay of Plenty region (Figure 3.17), where geology and stream morphology are equivalent. Hence, both datasets were used to produce a more robust predictive equation for minimum flow requirements.

One outlier amongst the Coromandel streams was the upland reach of the Wharekawa River (Figure 3.17). Closer examination revealed that the elevated flow requirement for this reach was driven by two cross-sections (Cross-sections 4 and 5). A wide gravel-bar located mid-channel dries out at lower flows for these two cross-sections. The reduction from one wide wetted-channel to two narrow wetted-channels causes a significant drop in habitat for redfin and common bully (at flows less than 0.5 m^3/s).

[2] Because the intention is to apply the results to other Coromandel streams, the flow requirements were produced assuming good migratory access for native fish. This meant including torrentfish in the habitat modelling for some sites where torrentfish may not have access (due to distance inland or artificial barriers). The minimum flow for the Wharekawa River produced using an 85% protection level was used for this analysis.

Omitting these two cross-sections from the habitat model produced a minimum flow of 0.285 m^3/s, which would not be an outlier in Figure 3.17 (using the Environment Bay of Plenty method with the same protection level of 85%). This indicates that multi-channel morphology is the cause of the higher than expected minimum flow for the Wharekawa. The two cross-sections represent habitat that is present elsewhere in the upland reach of the Wharekawa River (other multi-channel sections are indicated on the topomap, Figure 2.11) and therefore cannot be discounted. However, this result is considered less significant for other streams of the Coromandel area because multi-channel streams were not encountered in the other surveys to date. Applying the predictor equation to all upland reaches that do not have extensive multi-channel habitat is expected to encompass the vast majority of the Coromandel area.

Data collected to date for midland and lowland streams indicate these reaches have lower flow requirements for fish habitat compared to upland streams. From the trendline equations, midland/lowland reaches required minimum flows of about 62% of MALF, compared to 81% of MALF for upland reaches (Figure 3.17). This is logical given the stream margins of upland reaches are typically left dry by smaller flow reductions than the deeper, slower-flowing, lowland reaches. Further, the lowland and midland reaches often lack the fast water species that prefer high flows (e.g., torrent fish).

The Environment Bay of Plenty method for deriving minimum flows for fish habitat involves applying a habitat protection level to the available habitat. The primary flow is used to describe the available habitat (maximum habitat or habitat at MALF – see Section 2.3 and Appendix I for more detail). Figure 3.18 indicates a greater flow reduction is possible in larger streams to achieve the same habitat protection level. An equation for predicting the primary flow for other streams is provided, but there is a wider scatter of points compared to the minimum flow produced after applying a habitat protection level.

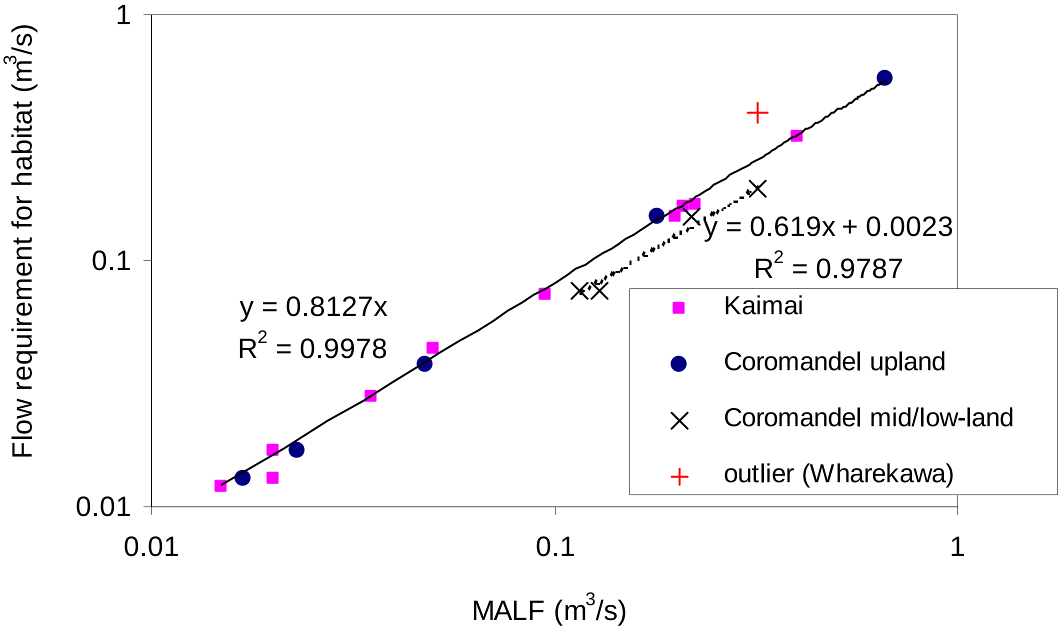

Figure 3.17: Minimum flows for fish habitat (calculated using the Environment Bay of Plenty method, with a protection level of 85%) are plotted against MALF (mean annual low flow) for surveyed reaches of the Coromandel and eastern Kaimai area (the latter sourced from Wilding 2002). Lowland and midland reaches from the Coromandel produced lower flow requirements for habitat and are plotted separately. The upland reach of the Wharekawa River emerged as an outlier and was not included in the trendline. Both axes are plotted on a log scale. Linear equations are presented for the two trendlines (solid line for combined Coromandel upland and Kaimai data with equation y=0.8127x; dashed line for mid/low-land data).

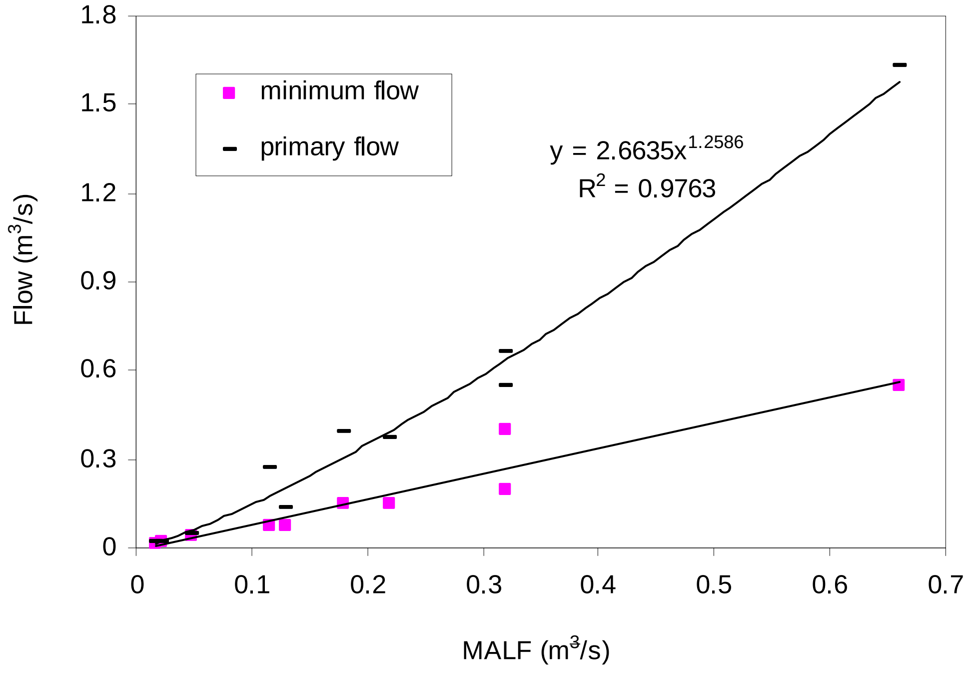

Figure 3.18: A comparison of the minimum flow calculated using the Environment Bay of Plenty method with the primary flow, both plotted against the MALF for each reach. The plot uses data from Coromandel streams. The equation for the primary flow trendline is also presented. Section 2.3 describes the primary flow in detail. Put simply, the primary flow is the value for available habitat to which the protection level is applied to derive the minimum flow (protection level 85% in this case).

3.7.2 Oxygen

Dissolved oxygen is emerging as a critical issue for the minimum flow requirements of lowland streams in the Coromandel area and it would therefore be useful to be able predict where else in the Coromandel oxygen may be a critical issue.

A gentle gradient is an obvious predictor for streams with oxygen issues. Of the three tidally influenced reaches assessed by NIWA, two had minimum flow requirements for oxygen that exceeded the requirement for fish habitat (Wharekawa River, Whenuakite River). Oxygen was also found to be a critical issue for one non-tidal lowland reach (Huruhurutakimo Stream, which is a tributary of the Whenuakite River; Wilding 2007). The three reaches with critical oxygen issues had gradients less than 0.003 m/m (estimated from measured tidal range and distance between pegs, or distance to topographic contours). The surveyed upland reaches of Coromandel Streams (reaches that are unlikely to experience severe oxygen depletion) typically have gradients greater than 0.01 m/m (calculated from the distance between 20 m contour lines on a NZMS260 Topomap).

Identifying tidal reaches in the Coromandel area using REC data was explored, but proved unsuccessful because the elevation and slope estimates were inaccurate for stream segments below 20 metres elevation (reflecting the 20 m contour data used to derive these statistics). Elevation data for lowland areas would need to be refined to enable this analysis. Simple mapping features could be used as an alternative. The tidal reaches surveyed to date were all less than half the distance from the river mouth to the first 20 m contour line. This distance also includes some of the Huruhurutakimo Stream, a non-tidal lowland stream where low oxygen was problematic.

Streams with a longer lowland reach (below the first 20 m contour) would intuitively be at greater risk of oxygen depletion, with a longer section of tidal river, more aquatic plant habitat and generally deeper and slower water with fine substrates. The Huruhurutakimo Stream, Whenuakite and Wharekawa Rivers (waterways with oxygen issues) all have more than 5 km of river downstream of the first 20 m contour.

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 criteria (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). This key is intended as a site selection method to assist further minimum flow investigations, but with further testing could have further application (e.g., to support flow management decisions).

4. Discussion

4.1 Minimum flow recommendations

Habitat, dissolved oxygen and temperature were assessed to determine the recommended minimum flow for ecosystem health of four Coromandel streams. Deciding how much flow is required to maintain aquatic habitat will be determined primarily 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 presented for fish habitat 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 is described in Section 2.4).

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, as summarised in Table 4.1.

Awaroa Stream

Fish habitat is considered the critical issue in setting a minimum flow for the Awaroa Stream and hence determines the recommended minimum flow of 0.013 m^3/s (13 L/s). Providing for the species that has the highest flow requirement is important because this is the species most likely to be affected by reduced flows. Torrentfish had the highest flow requirement (using a habitat protection level of 85% and MALF as the primary flow). Torrentfish were not caught at this site, but are expected to migrate here in the absence of culverts that are located downstream (NZFFD records from upstream and downstream of the lower culvert indicate it is an impediment to migration of torrentfish; see Section 3.2). There is merit in providing for fish reasonably expected to occur in the absence of channel structures that may be removed, replaced or retrofitted in the foreseeable future (e.g., culverts that have scoured the outlet). Otherwise, redfin bully have the next highest flow requirement (0.012 m^3/s).

Riffle habitat was used as a correlate for invertebrate habitat, hence, the minimum flow requirements for invertebrate habitat are based on the change in area of riffle habitat (as discussed in Section 3.3). Results for the Awaroa and other streams studied demonstrate that the minimum flow requirements for fish habitat provide adequately for invertebrates, with little or no compromise of habitat area (maintaining 79% to 118% of riffle habitat available at MALF (mean annual low flow)).

Dissolved oxygen and water temperature were not modelled for this reach. The steep gradient and shade afforded by pine forest and native vegetation reduce the likelihood of oxygen and temperature being critical issues for determining the minimum flow requirement. Wilding & Jowett (2006) assessed temperature, oxygen and fish habitat for the lower reaches of the Opitonui River, of which the Awaroa is a tributary. Results for the lower Opitonui River are presented in Table 4.1 for reference, but determining minimum flows for this reach is left to the source report (Wilding & Jowett 2006).

Tapu River

The recommended minimum flow for the Tapu River is 0.152 m^3/s. Habitat is again the critical issue, with redfin bully requiring a flow of 0.152 m^3/s (based on an 85% protection level and using the point of maximum habitat as the primary flow). Temperature modelling predicted that river temperatures would approach 24 °C during the warmest months of the year (at the recommended minimum flow). However, the high flow requirement for fish habitat would restrict abstraction to the point where temperature increases from reduced flow would be minor (full abstraction under a Q_5 or MALF allocation limit would produce temperature increases less than 0.2 °C). The Tapu River flows swiftly and steeply all the way to the coast. There is little slow-flowing, weedy habitat, so dissolved oxygen is not expected to be a critical issue for setting the minimum flow requirements.

Waiomu Stream

The upland reaches all displayed a common pattern in terms of minimum flow requirements, and the Waiomu Stream is no exception. Fish habitat is the critical issue again, with torrentfish determining the recommended minimum flow of 0.038 m^3/s (based on an 85% protection level and using MALF as the primary flow). Flow requirements need to be met for torrentfish resident downstream of the culverts (a few hundred metres downstream of the study reach). Culverts present a potential barrier to fish (including torrentfish) migrating to the upper reaches of the Waiomu Stream.

February water temperatures are predicted to remain a little cooler compared to the Tapu River, owing to the shorter un-shaded reach. Flow is expected to have a minor effect on water temperatures. For example, abstracting half the flow from the Waiomu Stream at MALF is expected to increase the water temperature by 0.7 °C (24-hour maximum at stream mouth) while the flow requirement for habitat is 79% of MALF. The Waiomu retains its relatively swift and shallow upland character all the way to the sea, hence, dissolved oxygen is not expected to be a critical issue.

Wharekawa River

The lower Wharekawa River supports a diverse range of fish (10 native species plus brown trout), megainvertebrates (freshwater crayfish, shrimp and mussels) and aquatic plants (6 taxa). Higher protection levels for habitat and dissolved oxygen were applied to the Wharekawa River for this reason. The Wharekawa River emerges from the hills to flow across a flat area of land. This low gradient section of the river extends the range of habitat types available to aquatic species, which is complemented by a predominantly forested catchment and relatively intact riparian vegetation through the pastoral reaches. The wide range of habitat types also produces a wider range of issues to consider when determining minimum flow requirements.

Preliminary data indicated that dissolved oxygen is the critical issue for determining minimum flow requirements. The susceptibility of the Wharekawa River to de-oxygenation at low flows, despite relatively low densities of aquatic plants, may reflect the low re-aeration rates of deep, slow-flowing tidal reaches. Problems were encountered during the initial deployment of oxygen dataloggers (during March) and a second deployment was necessary in April. The data from the second deployment indicated relatively high flows are required to maintain adequate oxygen levels (see Section 3.4). The Wharekawa River was cooler and flows higher when monitored in April, compared to what would be expected mid-summer, meaning the model had to be extrapolated further. Although it seems likely oxygen is the critical issue for the Wharekawa River, the oxygen modelling will need to be repeated earlier in the year (January to March) to obtain a more defensible minimum flow for this river.

The upland reach of the Wharekawa River requires less flow than the midland reach, based on data collected to date. This is despite the relatively high minimum flow for fish habitat in the upland reach, compared to other upland reaches (Section 3.7.1).

4.2 Applying results elsewhere

Upland reaches

The potential for applying the results from the minimum flow investigations completed so far to other streams in the Coromandel area was investigated (Section 3.7.1). Minimum flows for fish habitat derived using the Environment Bay of Plenty method provided a good relationship with MALF. The results for upland reaches of the Coromandel provided an equivalent response to streams of the eastern Kaimai Ranges (Bay of Plenty region). With the exception of one upland site, the MALF provides a satisfactory predictor for minimum flow requirements for fish habitat derived using the Environment Bay of Plenty method.

The exception to the rule was the upland reach of the Wharekawa River, which had higher flow requirements than expected (Wharekawa upland). This reach was unusual in that the channel divided around islands in several places. The geology of the Wharekawa catchment is dominated by Whitianga Group rock (ignimbrite and rhyolite), a subclass of the Coromandel rock group represented by relatively few sites to date. It is possible the higher flow requirement for the Wharekawa is a consequence of geology. It is also possible this reach is not representative of this rock type or the cross-sections are not representative of the reach. An additional survey of five cross-sections (to better represent the multi-channel sections of this river) would clarify whether cross-section selection was the cause of this outlier result and, consequently, the significance of this result for other multi-channel reaches in the Coromandel.

The predictor equation can be implemented for upland reaches of the Coromandel (minimum flow for habitat in m^3/s = 0.81 x MALF), but should not be applied to reaches with multi-channel morphology without further study (see Section 3.7.1). The equation is intended for application to streams where habitat surveys have not been carried out. Fish habitat was considered the critical issue for all of the upland reaches assessed to date. Therefore, the predictive equation based on fish habitat can be used in most cases as a stand-alone tool for determining the recommended minimum flow for aquatic ecosystems. The Coromandel area includes streams draining Coromandel Group geology, which is predominantly andecite and dacite volcanics (see Edbrooke 2001), and extends as far south as the Kaimai rail tunnel. Upland reaches are distinguished from midland and lowland reaches by frequent riffle and run habitat with cobble substrates. Forested reaches above 20 m elevation are typically upland habitats, but desktop methods for distinguishing upland habitats in pastoral areas will be less straightforward. Refinement of the REC data (particularly gradient) could provide reliable desktop methods for distinguishing upland and lowland reaches, as well as complimenting methods for tracking existing water allocation.

The temperature modelling carried out this year was comprehensive, incorporating monitoring data from several locations on each stream and further calibration with climate station data. Coromandel streams are expected to reach high and potentially stressful temperatures for aquatic life, but modelling to date indicates that flow is not a major contributing factor to elevated temperatures, especially given the constraints on flow change in providing for other issues (habitat and dissolved oxygen). High water temperature in Coromandel streams may be an issue best addressed by riparian management rather than flow management. Further temperature monitoring will be useful in confirming these observations.

Midland and lowland reaches

For midland and lowland reaches, both habitat and dissolved oxygen have emerged as likely critical issues for setting minimum flows. Therefore, applying results to as yet unstudied reaches will require consideration of both issues. Midland and lowland streams appear to have lower minimum flow requirements for fish habitat compared to upland reaches. More reaches would need to be surveyed to produce a defensible equation for predicting the flow requirements for habitat in midland/lowland streams (see Section 3.7.1).

Further investigation of lowland and midland reaches is also required to determine minimum flow required to maintain adequate dissolved oxygen, which is often a critical issue for this stream type. A decision key is presented to guide where these investigations are best focussed (Section 3.7.2). With further testing, this key might be useful in supporting flow decisions for reaches not directly surveyed (e.g., by identifying catchments where dissolved oxygen is unlikely to be an issue).

The modelling of oxygen in tidal lowland reaches presents some challenges. The WAIORA model has been used to predict changes in dissolved oxygen with flow, but does not incorporate tidal water level fluctuations. The model was run for tidal lowland reaches (freshwater) using habitat data at low tide (depth, velocity and flow) and oxygen data that represents an average tide (oxygen data for each time of day averaged over a range of tide heights). The model output is therefore a typical 24-hour minimum oxygen concentration (for a given flow) rather than a worst-case scenario (which would occur on a morning that coincided with high tide). This is considered appropriate for comparison with the selected dissolved oxygen guideline which apply to 7-day averages of the 24-hour minimum (see Section 2.4). Modelling the combined effect of tide and diurnal fluctuations would require a new or revised oxygen model. Sourcing an alternative model to WAIORA, or developing a new model, may provide a better depiction of oxygen in tidal reaches[3]. However, we have a limited knowledge of the aquatic ecosystems that inhabit tidal freshwater reaches or their tolerance of short periods of de-oxygenation at high tide (that periodically coincide with diurnal oxygen minima). Biological monitoring would be more appropriate at this stage to help establish the significance of de-oxygenation in tidal reaches before investing in more refined oxygen models.

[3] At least one oxygen-model has been developed that incorporates tidal fluctuations (Liu et al. 2005, see also Anon. 2006). However, this model was designed for rivers where contaminants are the main drivers of oxygen depletion (e.g., contaminants from sewage ponds or pulp and paper mills), rather than aquatic plants (as is most likely the case in Coromandel streams).

Table 4.1: Recommended minimum flows (m^3/s) are presented for each of the four Coromandel streams surveyed, in addition to issue-specific minimum flows that the recommendations are based on. Only the issues considered likely to be critical issues were investigated for each reach (a dash indicates issues not investigated for this reason). Some of the issues not found to have higher flow requirements are simply indicated as "Not critical". 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	Opitonui River		Tapu River[L]	Waiomu Stream[L]	Wharekawa River		
	Awaroa Stream (upland)	lowland reach			lowland/tidal reach	midland reach	upland reach
Dissolved oxygen	-	0.11[H]	-	-	0.61[A]	-	-
Temperature	-	Not critical[I]	Not critical	Not critical	Not critical	Not critical	-
Fish habitat	0.013[B]	0.15[J]	0.152[C]	0.038[D]	-	0.265[E]	0.445[F]
Invertebrate habitat	0.013[G]	-	0.16[G]	0.038[G]	-	0.080[G]	0.250[G]
Recommended minimum flow	0.013	See Wilding & Jowett (2006)	0.152	0.038	Pending revised oxygen modelling		
Q_5	0.012	0.16	0.17	0.040	0.265[K]		
MALF	0.017	0.22	0.18	0.048	0.32[K]		
Median Flow	0.042	0.55	0.45	0.131	0.81[K]		

A. Preliminary results indicate a flow of 0.61 m^3/s is required to exceed the selected dissolved oxygen guideline of 6 g/m^3. Due to data problems, more work is needed.
B. Flow required to maintain 85% of habitat available at MALF for torrentfish.
C. Flow required to maintain 85% of maximum habitat for redfin bully.
D. Flow required to maintain 85% of habitat available at MALF for torrentfish.
E. Flow required to maintain 90% of maximum habitat for shortfin eel.
F. Flow required to maintain 90% of maximum habitat for common bully.
G. Flow required to maintain 85% of riffle habitat available at MALF.
H. From Wilding & Jowett (2006), a flow of 0.11 m^3/s is required to exceed 5 g/m^3 of dissolved oxygen; 0.135 m^3/s is required to exceed 6 g/m^3.
I. From Wilding & Jowett (2006).
J. From Wilding & Jowett (2006). Flow required to maintain 85% of maximum habitat for common bully.
K. Natural flow equivalent across all 3 reaches of Wharekawa (no major inflows).
L. Upland habitat all the way to the sea.

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6. References

Annear, T.C.; Conder, A.L. (1984). Relative bias of several fisheries instream flow methods. *North American Journal of Fisheries Management 4*: 531-539.

Anon. (2006). Total maximum daily load evaluation for the St. Marys River in the St. Marys River Basin for dissolved oxygen. The Georgia Department of Natural Resources Environmental Protection Division, Atlanta, Georgia.

Biggs, B.J.F. (1996). Hydraulic habitat of plants in streams. *Regulated Rivers: Research and Management 12*: 131-144.

Biggs, B.J.F.; Close, M.E. (1989). Periphyton biomass dynamics in gravel bed rivers: the relative effects of flows and nutrients. *Freshwater Biology 22*: 209-231.

Craw, D.; Chappell, D.A. (2000). Metal redistribution in historic mine wastes, Coromandel Peninsula, New Zealand. *New Zealand Journal of Geology & Geophysics 43*: 187-198.

Dean, T.L.; Richardson, J. (1999). Responses of seven species of native freshwater fish and a shrimp to low levels of dissolved oxygen. *New Zealand Journal of Marine and Freshwater Research 33*: 99-106.

Edbrooke, S.W. (compiler) (2001). Geology of the Auckland area. 1:250 000 geological map 3 (1 sheet and 74 pages). Institute of Geological & Nuclear Sciences.

Estes, C.C.; Orsborn J.F. (1986). Review and analysis of methods for quantifying instream flow requirements. *Water Resources Bulletin 22*: 389-397.

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

Henderson, R.; Woods, R.A.; Schmidt, J. (2005). "Mapping low flow in ungauged New Zealand streams." Presented at the New Zealand Freshwater Sciences Society: ecology at the waters edge, Nelson, August 2005.

Hill, J.; Jowett, I.G. (2004). WAIORA – Water allocation impacts on river attributes. Version 2.0. Can be downloaded from www.niwa.co.nz/ncwr/tools/waiora.

Hudson, H.R.; Byrom, A.E.; Chadderton, W.L. (2003). A critique of IFIM - instream habitat simulation in the New Zealand context. Science for Conservation 231. Department of Conservation, Wellington.

Jellyman, D.J.; Bonnett, M.L.; Sykes, J.R.E.; Johnstone, P. (2003). "Contrasting use of daytime habitat by two species of freshwater eel (Anguilla spp.) in New Zealand rivers." In: Dixon, D.A. (ed) Presented at the Biology, Management, and Protection of Catadromous Eels. Bethesda, MD. American Fisheries Society Symposium.

Jellyman, D.J.; Glova, G.J. (2002). Habitat use by juvenile lampreys (Geotria australis) in a large New Zealand river. *New Zealand Journal of Marine and Freshwater Research 36*: 503-510.

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

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

Jowett, I.G. (1993b). Minimum flow assessment for instream habitat in Taranaki rivers. Freshwater Miscellaneous Report 75. NIWA, Christchurch.

Jowett, I.G. (1993c). Minimum flow assessment for instream habitat in Wellington rivers. Freshwater Miscellaneous Report 63. NIWA, Christchurch.

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

Jowett, I.G. (2000). Flow Management. In: Collier, K.J.; Winterbourn, M.J. (eds). New Zealand stream invertebrates: ecology and implications for management, pp. 289-312. New Zealand Limnological Society, Christchurch.

Jowett, I.G. (2002). In-stream habitat suitability criteria for feeding inanga (Galaxias maculatus). *New Zealand Journal of Marine and Freshwater Research 36*: 399–407.

Jowett, I.G.; Biggs, B.J.F. (1997). Flood and velocity effects on periphyton and silt accumulation in two New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research 31*: 287-300.

Jowett, I.G.; Duncan, M.J. (1990). Flow variability in New Zealand rivers and its relationship to in-stream habitat and biota. *New Zealand Journal of Marine and Freshwater Research 24(3):* 305-317.

Jowett, I.G.; Richardson J. (1995). Habitat preferences of common, riverine New Zealand native fishes and implications for minimum flow assessments. *New Zealand Journal of Marine and Freshwater Research 29*: 13-24.

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

Karim, K.; Gubbels, M.E.; Goulter, I.C. (1995). Review of determination of instream flow requirements with special application to Australia. *Water Resources Bulletin 31*: 1063-1077.

Landman, M.J.; Van den Heuvel, M.R.; Ling, N. (2005). Relative sensitivities of common freshwater fish and invertebrates to acute hypoxia. *New Zealand Journal of Marine and Freshwater Research 39*: 1061-1067.

Liu, W.C.; Liu, S.Y.; Hsu, M.H.; Kuo, A.Y. (2005). "Water quality simulation to determine minimum instream flow for fish survival." Presented at the Joint conference of 2nd Asia Pacific Association for Hydrology and Water Resources and 1st AOGS, Suntec Centre, Singapore.

Matheson, F.; Dugdale, T.; Wells, R.D.S.; Taumoepeau, A.; Smith, J. (2004). A new method to sterilise freshwater fishing nets. *Water & Atmosphere 12(3)*: 17.

McCullough, C.D. (1998). Abundance, behaviour, and habitat requirements of the banded kokopu - *Galaxias fasciatus* Gray (Pisces: Galaxiidae). Master of Science. University of Waikato, Hamilton. 135 p.

McDowall, R.M. (1990). New Zealand freshwater fishes; a natural history and guide. Heinemann Reed, Auckland. 553 p.

MfE (1998). Flow guidelines for instream values. Ministry for the Environment, Wellington.

Milhous, R.T.; Updike, M.A.; Schneider, D.M. (1989). Physical habitat simulation system reference manual - version II. Instream flow information paper no. 26. United States Fish and Wildlife Service, Fort Collins, Colorado.

Morhardt, J.E.; Altouney, E.G. (1986). Instream flow methodologies. Research Project 2194-2. The Electric Power Research Institute, Palo Alto.

Moyle, P.B.; Light, T. (1996). Fish invasions in California: do abiotic factors determine success. *Ecology 77(6)*: 1666-1670.

Olden, J.D.; Poff, L.; Bestgen, K.R. (2006). Life-history strategies predict fish invasions and extirpations in the Colorado River basin. *Ecological Monographs 76(1)*: 25-40.

Orth, D.J. (1987). Ecological considerations in the development and application of instream flow-habitat models. *Regulated Rivers: Research and Management 1*: 171-181.

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

Richardson, B.A. (1986). Evaluation of instream flow methodologies for fresh water fish in New South Wales. *In*: Campbell, I.C. (ed.). Stream protection, the management of rivers for instream use, pp. 143-167. Water Studies Centre, Chisholm Institute of Technology, East Caulfield.

Schuytema, G.S. (1982). A review of aquatic habitat assessment methods. *Report EPA-600/3-82-002*. Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, Oregon.

Snelder, T.; Biggs, B.J.F.; Weatherhead, M. (2004). New Zealand river environment classification user guide. ME Number 499. Ministry for the Environment, Wellington.

Stalnaker, C.B.; Arnette, J.L. (1976). Methodologies for the determination of stream resource flow requirements: an assessment. *Utah State University and U.S. Fish and Wildlife Service NTIS report PB-253-152*. Utah State University, Logan, Utah.

Thomas, J.A.; Bovee, K.D. (1993). Application and testing of a procedure to evaluate transferability of habitat suitability criteria. *Regulated Rivers: Research and Management 8*: 285-294.

Trihey, E.W.; Stalnaker, C.B. (1985). Evolution and application of instream flow methodologies to small hydropower developments: an overview of the issues. *In*: Olsen, F.W. et al. (eds.). Proceedings of the symposium on small hydropower and fisheries, Aurora, Colorado, pp. 176-183. American Fisheries Society, Bethesda, Maryland.

USEPA (1986). Quality criteria for water 1986. EPA 440/5-86-001. United States Environmental Protection Agency, Washington.

Wesche, T.A.; Rechard, P.A. (1980). A summary of instream flow methods for fisheries and related research needs. *Water Resources Research Institute Eisenhower Consortium Bulletin 9*. University of Wyoming, Laramie.

White, R.G. (1976). A methodology for recommending stream resource maintenance flows for large rivers. *In*: Orsborn, J.F.; Allman, C.H. (eds.). Proceedings of the symposium and speciality conference on instream flow needs II, pp. 376-386. American Fisheries Society, Bethesda, Maryland.

Wilcock, R.J.; Nagels, J.W.; McBride, G.B.; Collier, K.J.; Wilson, B.T.; Huser, B.A. (1998). Characterisation of lowland streams using a single-station diurnal curve analysis model with continuous monitoring data for dissolved oxygen and temperature. *New Zealand Journal of Marine and Freshwater Research 32*: 67-79.

Wilding, T.K. (2000a). Bay of Plenty freshwater fish calendar. Environmental Report 2000/26. Environment Bay of Plenty, Whakatane.

Wilding, T.K. (2000b). Minimum flow report for the Waitahanui Stream. Environmental Report 2000/25. Environment B·O·P, Whakatane.

Wilding, T.K. (2002). Minimum flow report for streams of the Kaimai Area. Environmental Report 2002/05. Environment B·O·P, Whakatane.

Wilding, T.K. (2003). Minimum flow report for the Tauranga area. NIWA Client Report HAM2003-043. NIWA, Hamilton.

Wilding, T.K.; Jowett, I.G. (2006). Flow requirements for fish habitat in the Opitonui River (Coromandel). NIWA Client Report HAM2004-119. NIWA, Hamilton.

Wilding, T.K. (2007). Flow requirements for ecosystem health in the Whenuakite River (Coromandel). Environment Waikato technical report 2007/30. Prepared by NIWA, Client Report HAM2005-075. NIWA, Hamilton.

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

Features of a good instream management objective include:

- Retain adequate flow for ecosystem protection based on ecosystem significance.
- Provide an objective approach so 2 people can get the same answer.

Options for instream management objectives include:

1. Habitat remains unchanged.
2. Allow a percent reduction in habitat.
3. Allow change based on individual reach assessment, i.e., leaving it open to interpretation.
4. Allow change down to a region wide standard. For example, a NIWA study for Wellington and Taranaki Regional Councils suggested setting a minimum flow based on the 85%ile of percent brown trout habitat from the national "100 Rivers" study, (Jowett 1993b, 1993c).

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[4]	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).

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

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

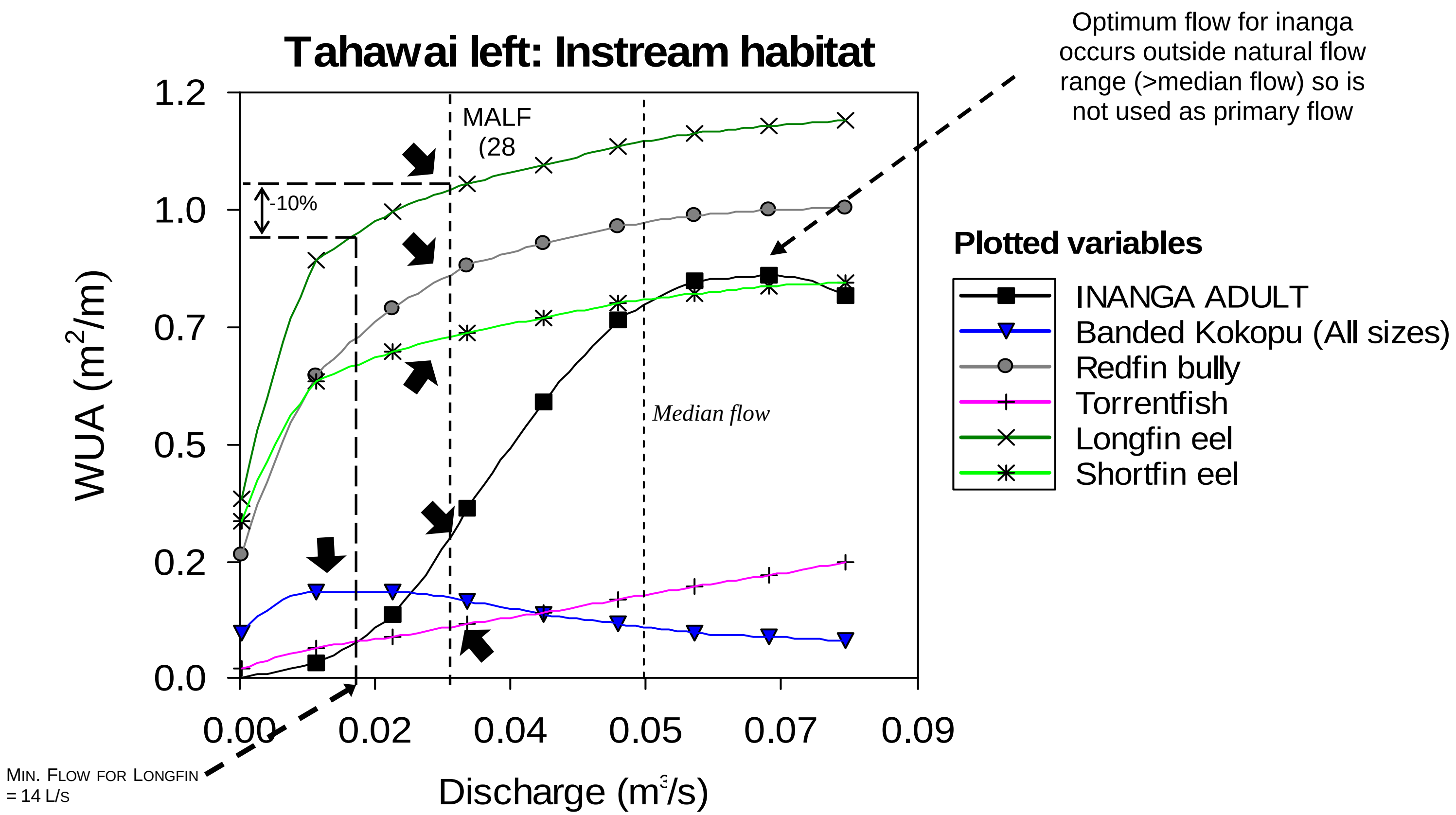


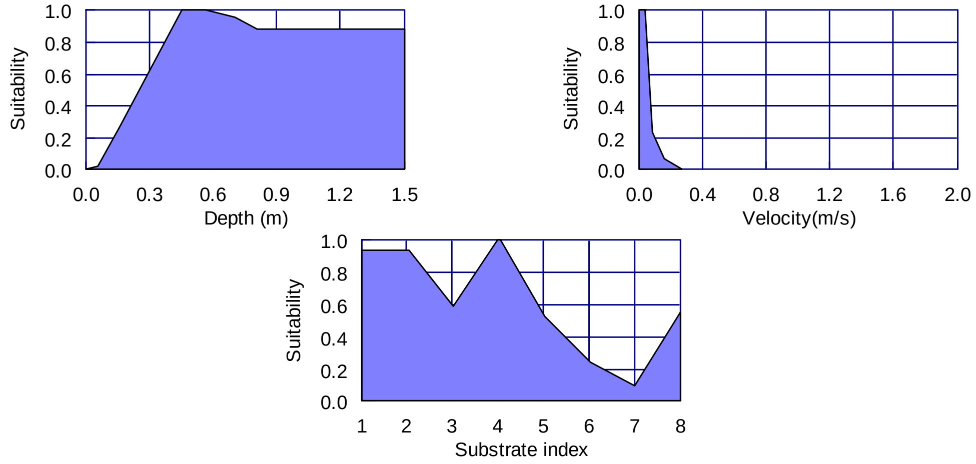
Figure 1: Modelled habitat for the Tahawai Stream (western BOP) expressed as habitat (WUA m^2/m) versus flow. Primary flows determined using established criteria are arrowed for each species. Minimum flow calculation for longfin eel illustrated. Note, this is presented as an example only, as taxa and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

8. Appendix 2: GPS locations for survey sites.

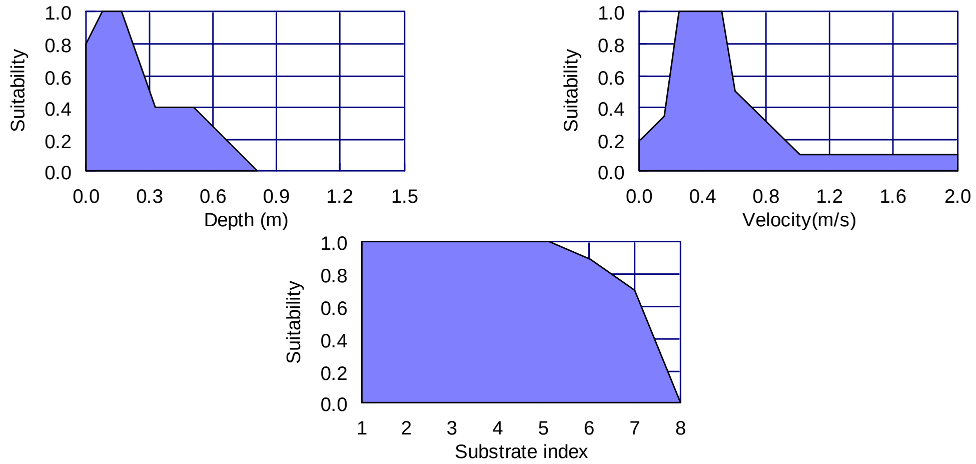
River	Reach	Survey	Site #	Easting	Northing
Wharekawa	Upland	Habitat	1	2761984	6446421
			15	2761698	6446563
	Midland	Habitat	1	2762511	6446983
			2	2762501	6446976
			3	2762484	6446959
			4	2762473	6446950
			5	2762463	6446939
			6	2762452	6446921
			7	2762408	6446875
			8	2762362	6446848
			9	2762346	6446844
			10	2762334	6446824
			12	2762254	6446633
			14	2762219	6446521
			16	2761984	6446421
		Tide	1	2763004	6447819
			2	2763186	6447821
			3	2763189	6447674
			4	2763285	6447490
			5	2762449	6447888
		Aquatic plant	1	2762872	6447763
			2	2762928	6447790
			3	2763115	6447814
			4	2763193	6447692
			5	2763349	6447451
			6	2764830	6447905
			7	2764546	6447757
		Oxygen		2763385	6447449
Awaroa	Wade Road	Habitat	1	2743347	6485373
			10	2743383	6485360
			12	2743384	6485336
			15	2743339	6485348
Tapu		Habitat	1	2733701	6465723
			15	2734053	6465641
		Temperature	upstream	2737558	6464558
Waiomu		Habitat	1	2735609	6460739
			15	2735742	6460638

9. Appendix 3: Habitat suitability curves.

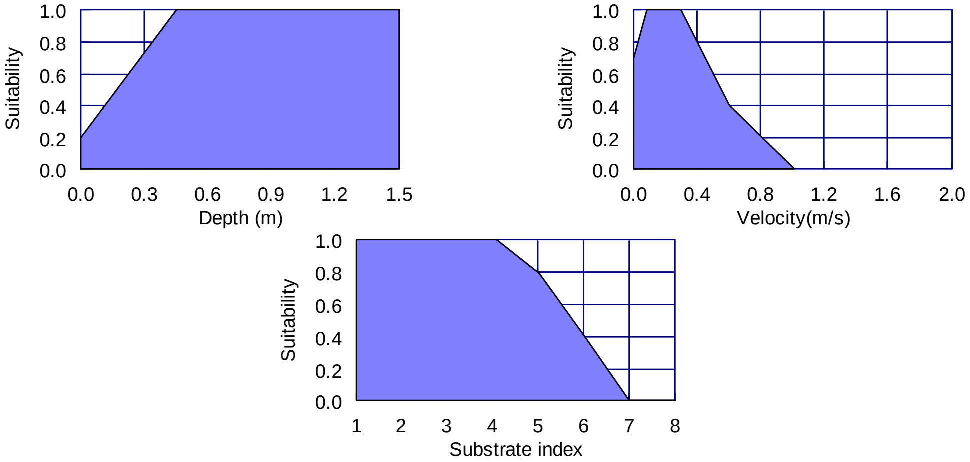
Banded Kokopu 1+ (McCullough 1998)



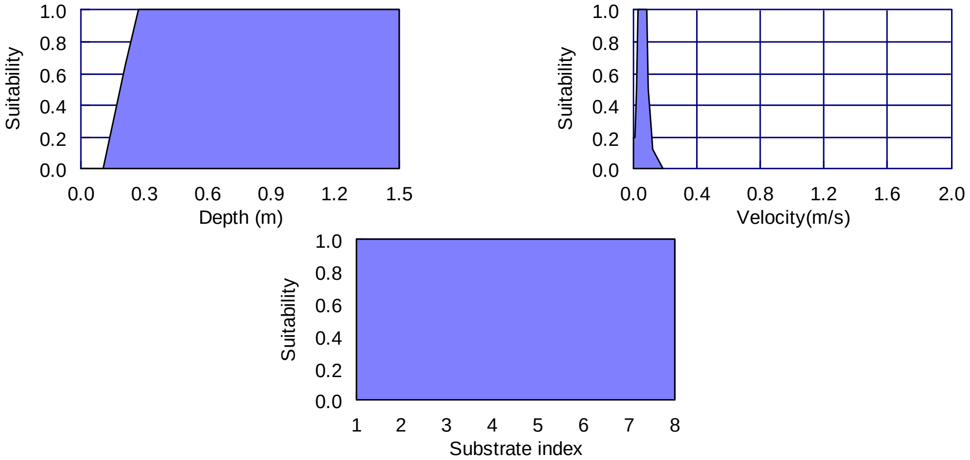
Common bully (Jowett & Richardson 1995)

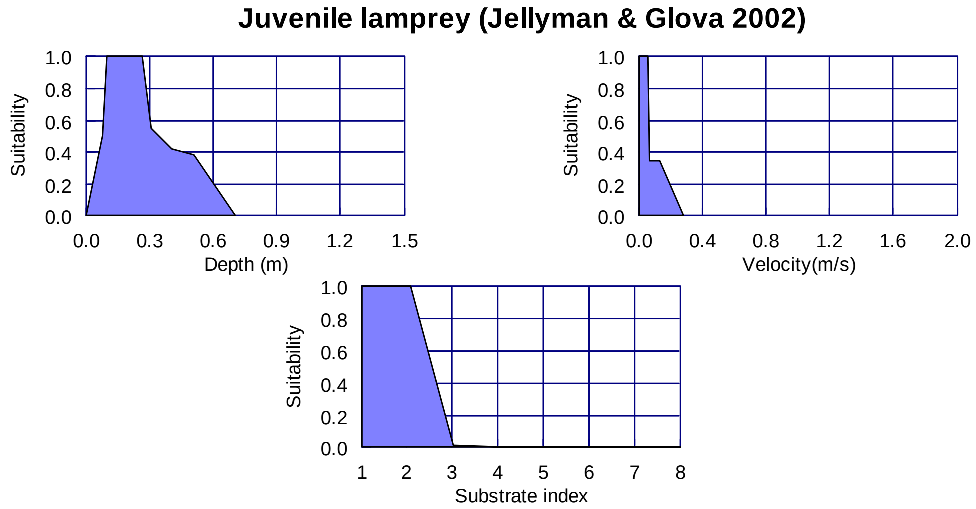


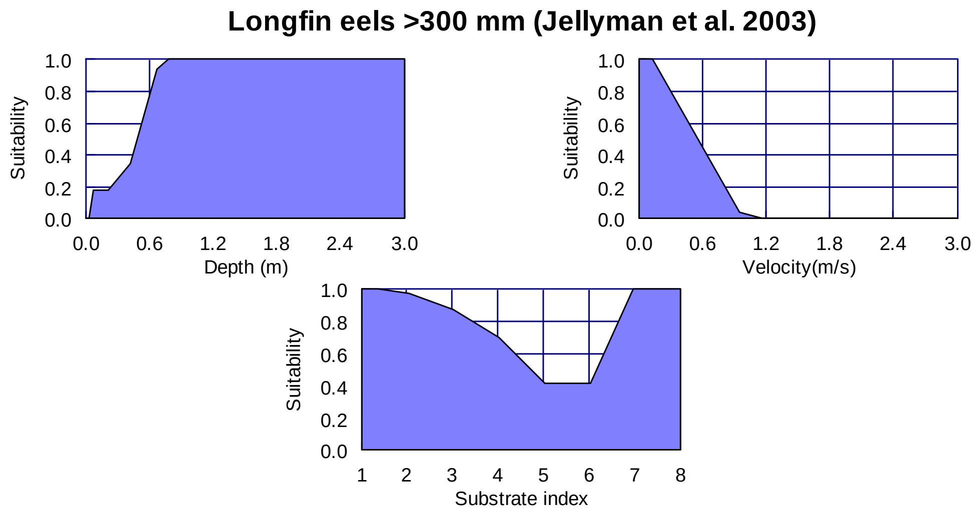
Common smelt



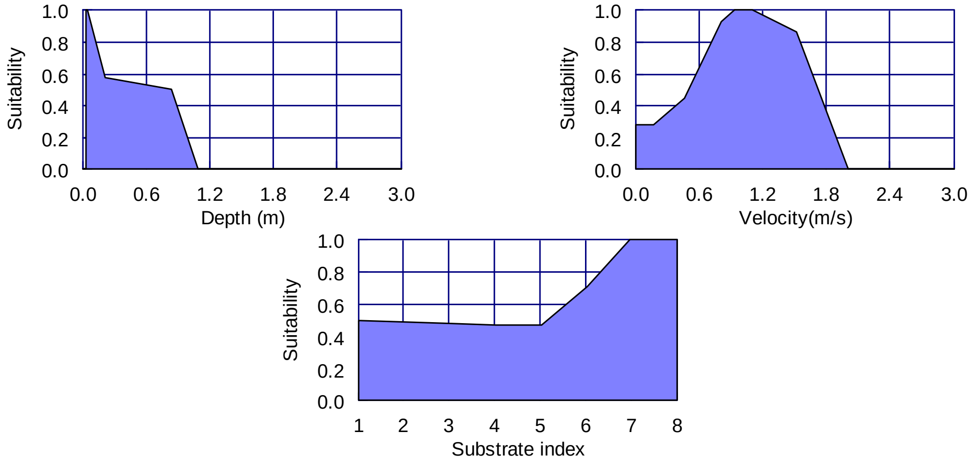
Inanga feeding (Jowett 2002)



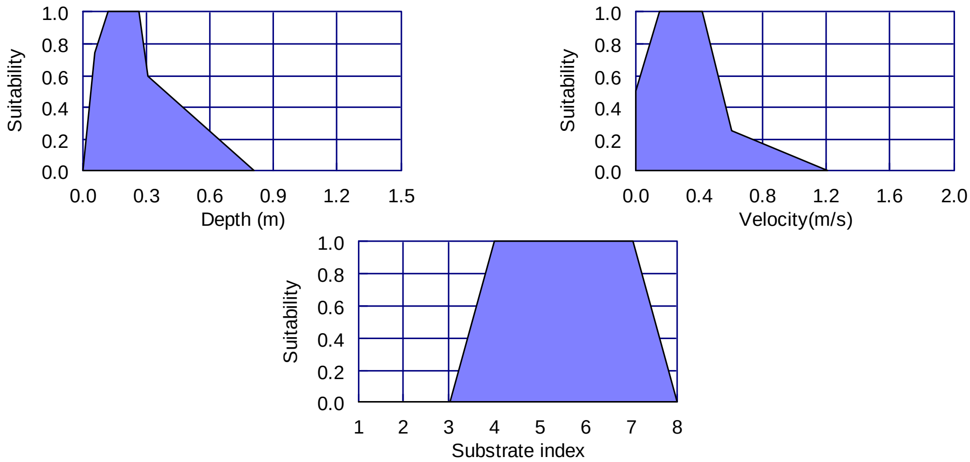

Juvenile lamprey (Jellyman & Glova 2002)
Suitability
Depth (m)
Velocity(m/s)
Substrate index


Longfin eels >300 mm (Jellyman et al. 2003)
Suitability
Depth (m)
Velocity(m/s)
Substrate index

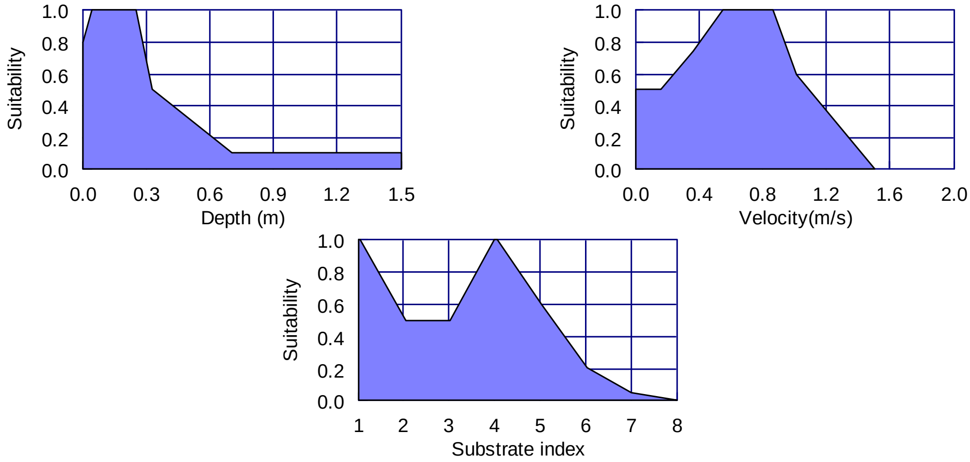
Longfin eels <300 mm (Jellyman et al. 2003)



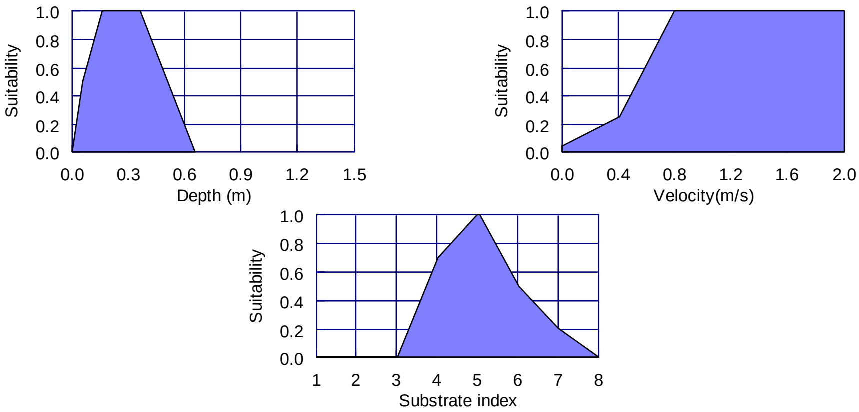
Redfin bully (Jowett & Richardson 1995)



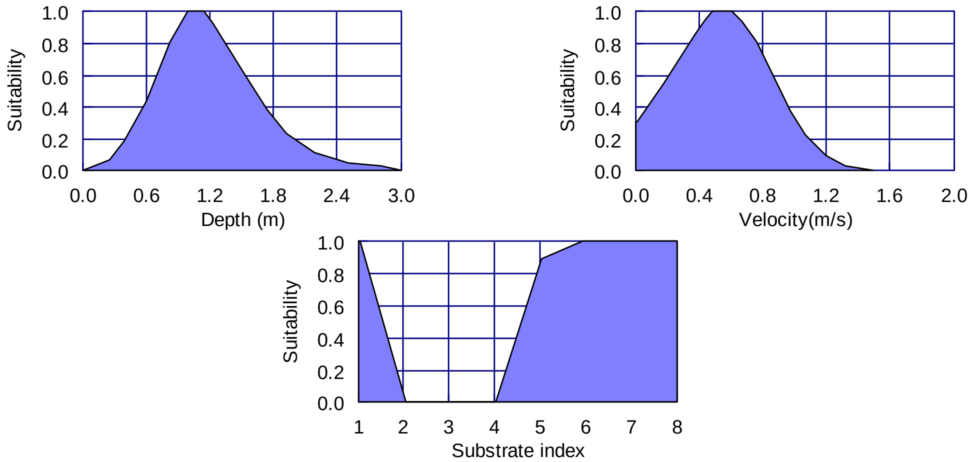
Shortfin eel <300mm (Jowett & Richardson 1995)



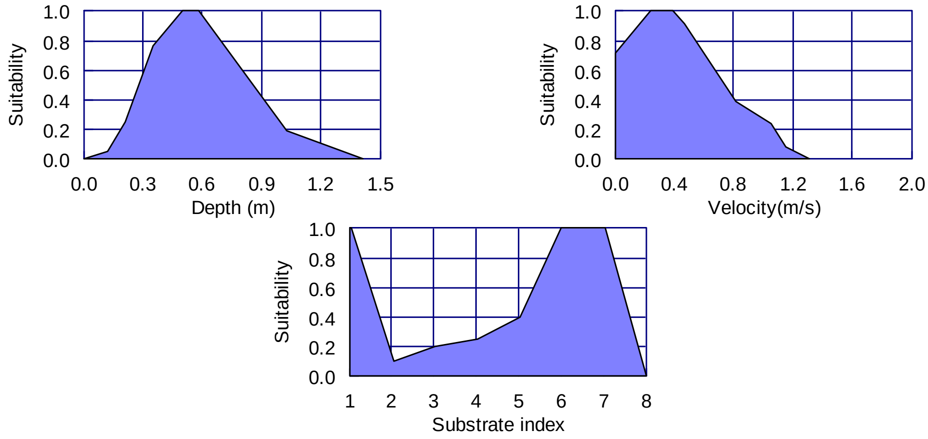
Torrentfish (Jowett & Richardson 1995)



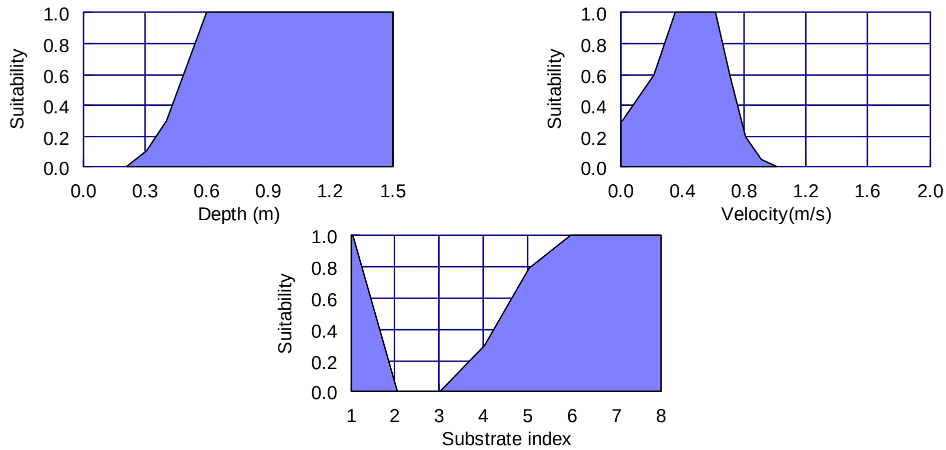
Rainbow trout adult feeding (Thomas & Bovee 1993)



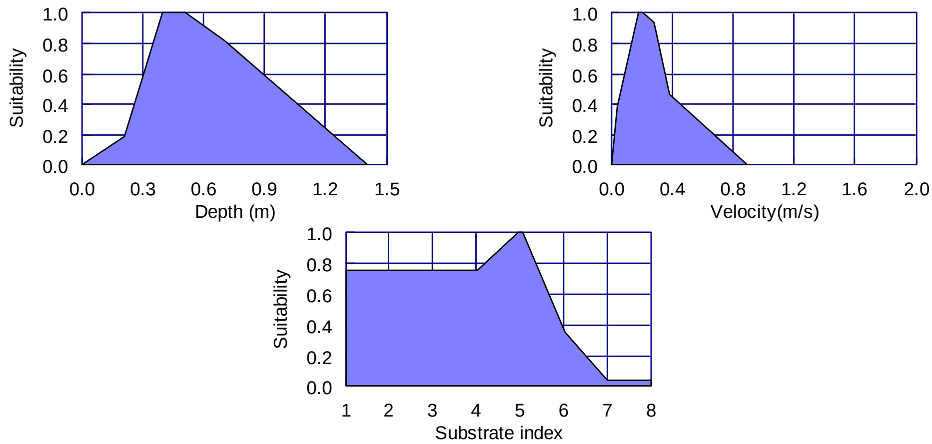
Rainbow trout juvenile feeding (Thomas & Bovee 1993)



Brown trout adult (Hayes & Jowett 1994)



Brown trout fry to 15cm (Raleigh et al. 1986)

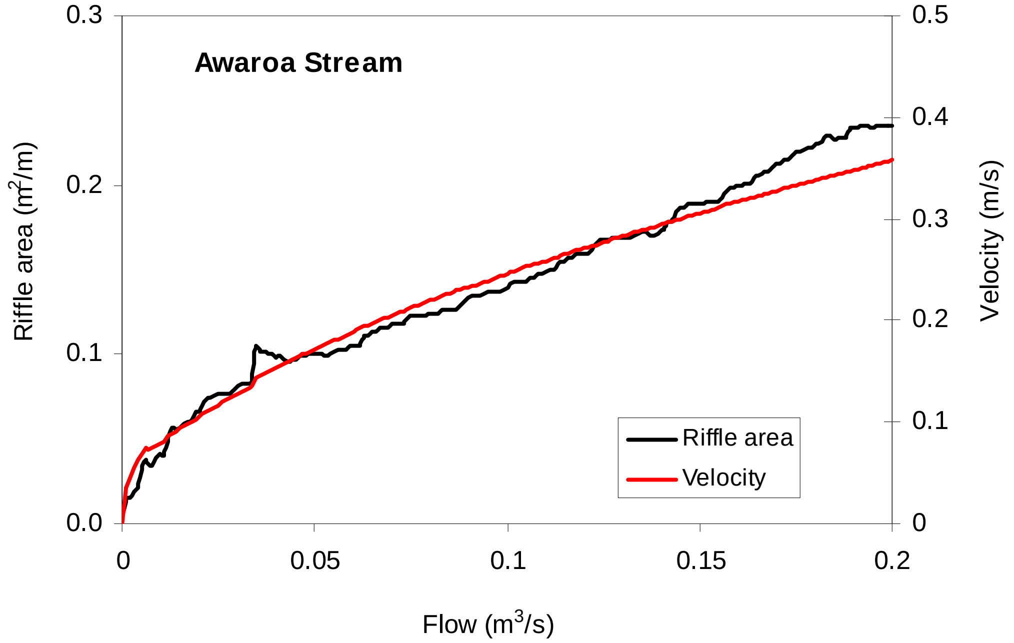


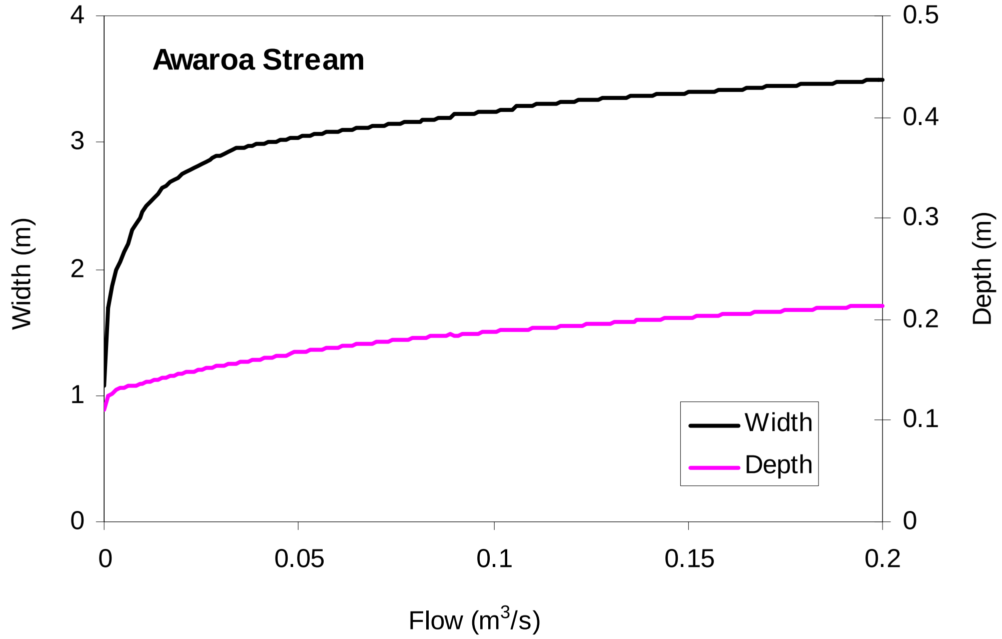
10. Appendix 4: Rating curve changes.

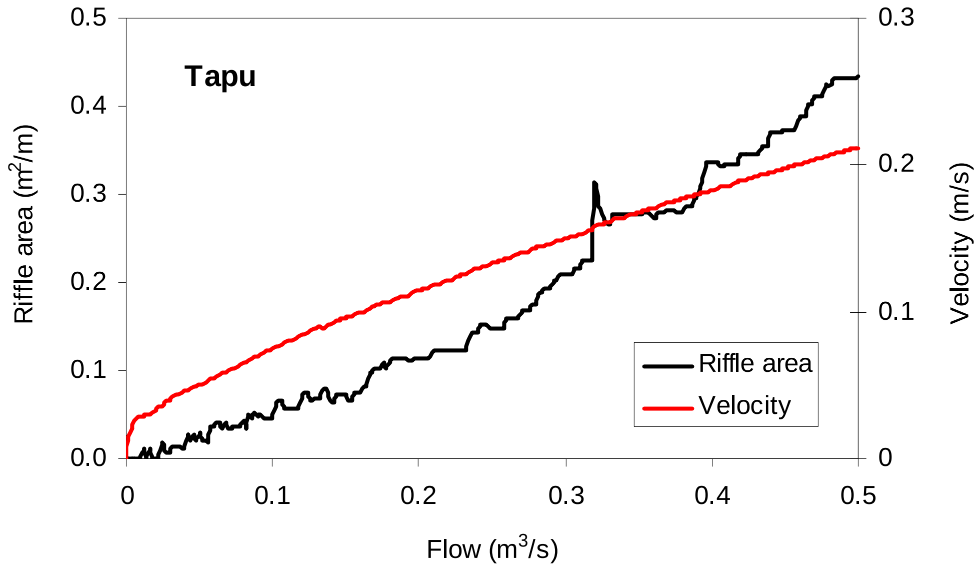
Changes to the default rating curves (as produced from the raw data) are detailed for each reach (entries were only included in this table where changes to the default were necessary). The default rating is the least squares fit to the logarithms of the measured flows and water levels, including an estimated 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.

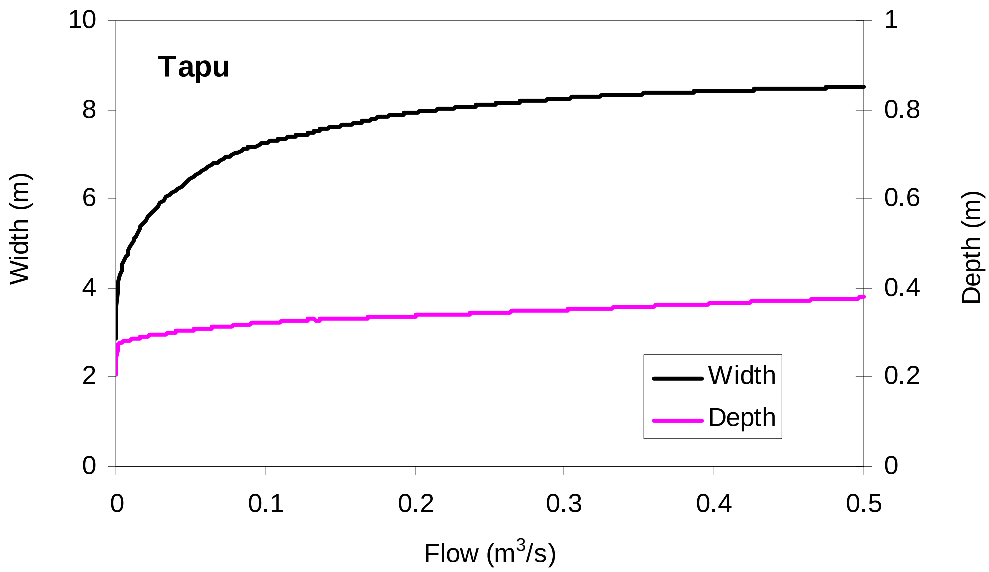
Cross-section	Calculated exponent	Nominated exponent	Other changes
Awaroa Stream			
3			First 2 gaugings deleted (peg or channel changed).
5			First 2 gaugings deleted (peg or channel changed).
8			Outlier gauging deleted.
9			Outlier gauging deleted.
11			First 2 gaugings deleted (peg or channel changed).
Tapu River			No changes necessary.
Waiomu Stream			
1	0.81	2.5	
10			Outlier gauging deleted.
Wharekawa River midland reach			EW recorder flow used for 29 March gauging.
Wharekawa River upland reach			No changes necessary.

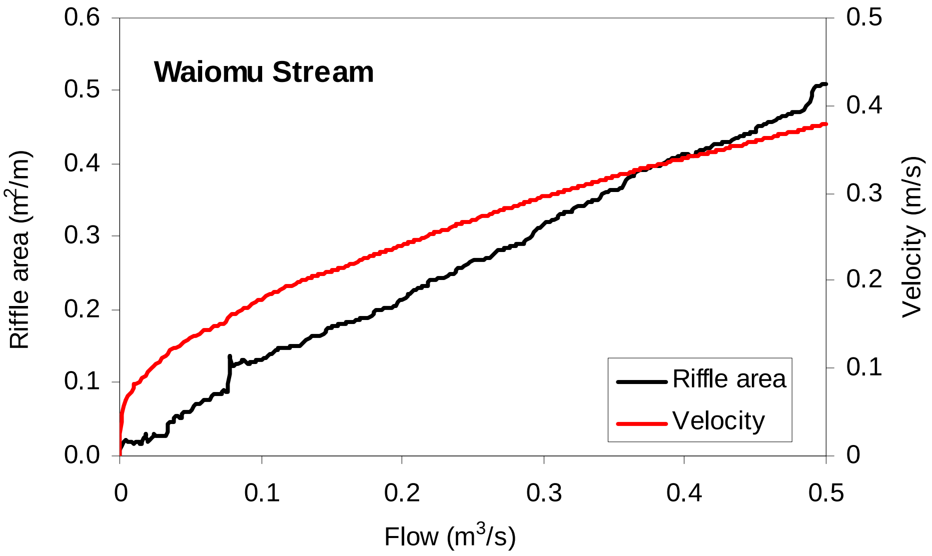
11. Appendix 5: Physical habitat data.

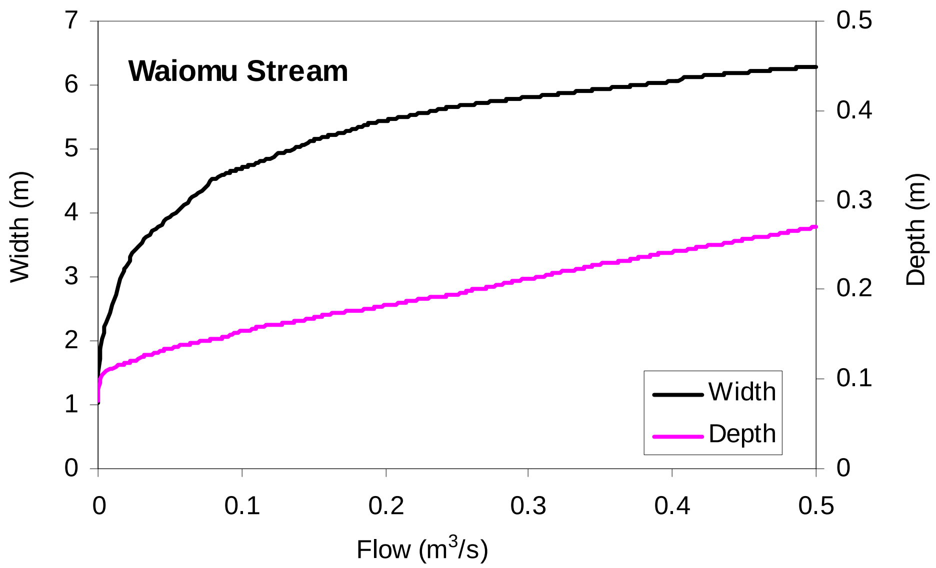


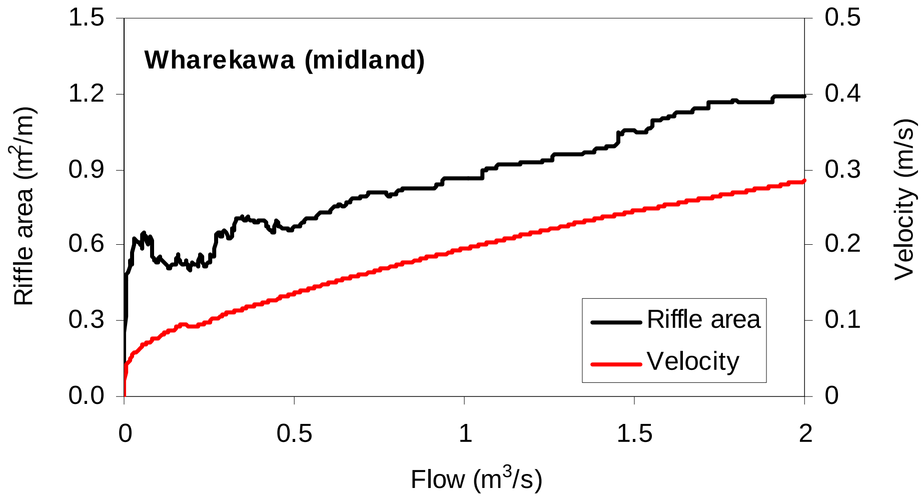


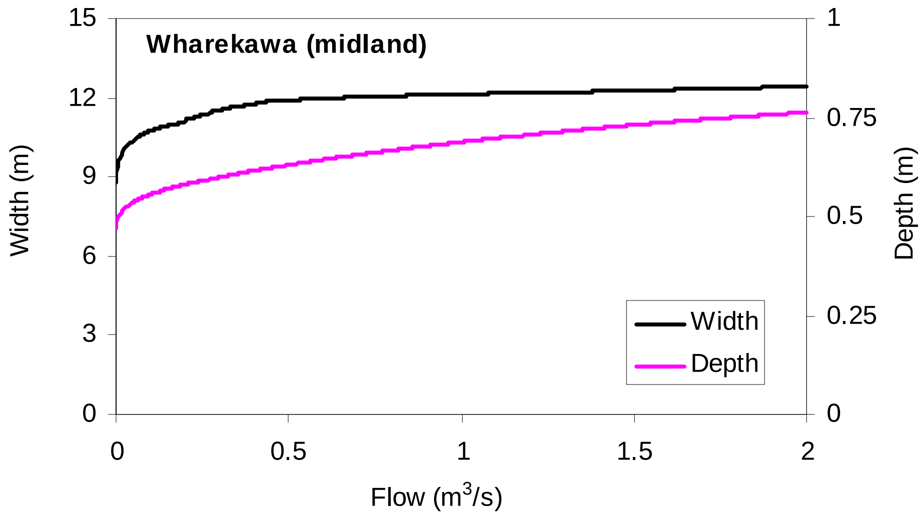

Tapu
Riffle area (m2/m)
Velocity (m/s)
Flow (m3/s)
Riffle area
Velocity
0.0
0.1
0.2
0.3
0.4
0.5
0
0.1
0.2
0.3
0.4
0.5
0
0.1
0.2
0.3

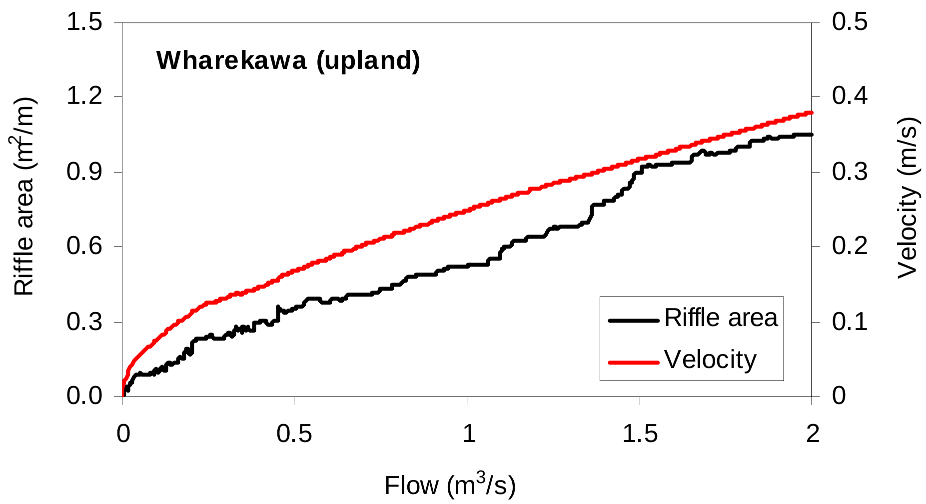

Tapu
Width (m)
Depth (m)
Flow (m3/s)
Width
Depth
0
2
4
6
8
10
0
0.1
0.2
0.3
0.4
0.5
0
0.2
0.4
0.6
0.8
1

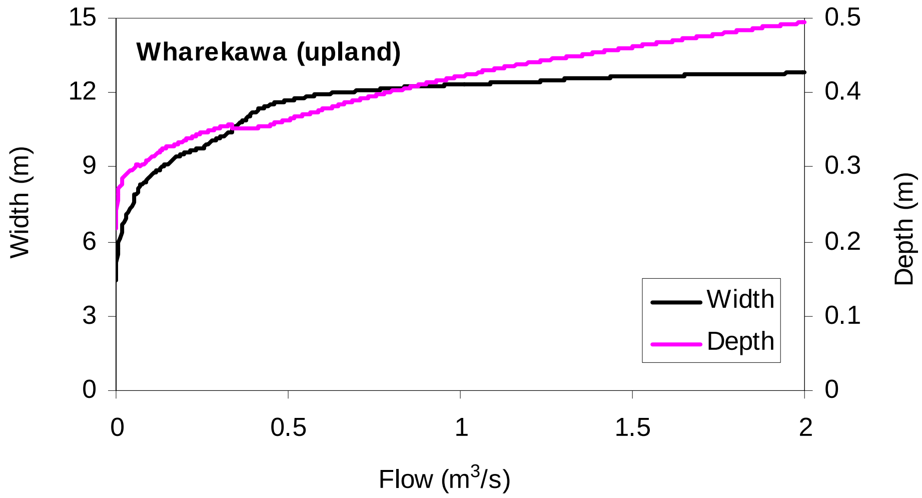

Waiomu Stream
Riffle area (m2/m)
Velocity (m/s)
Flow (m3/s)
Riffle area
Velocity
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
0.1
0.2
0.3
0.4
0.5


Waiomu Stream
Width (m)
Depth (m)
Flow (m3/s)
Width
Depth
0
1
2
3
4
5
6
7
0
0.1
0.2
0.3
0.4
0.5


Wharekawa (midland)
Riffle area (m2/m)
Velocity (m/s)
Flow (m3/s)
Riffle area
Velocity
1.5
1.2
0.9
0.6
0.3
0.0
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2


Wharekawa (midland)
Width (m)
Depth (m)
Flow (m3/s)
Width
Depth
15
12
9
6
3
0
1
0.75
0.5
0.25
0
0
0.5
1
1.5
2


Wharekawa (upland)
Riffle area (m2/m)
Velocity (m/s)
Flow (m3/s)
Riffle area
Velocity
1.5
1.2
0.9
0.6
0.3
0.0
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2


Wharekawa (upland)
Width (m)
Depth (m)
Flow (m3/s)
Width
Depth
15
12
9
6
3
0
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2

12. Appendix 6: Temperature modelling parameters.

12.1 Waiomu Stream

Observed parameters

Observed upstream temperature (at E2735742 N6460638) for period 13/03 to 12/04/06:

- 24-hour mean 16.4°C.
- 24-hour maximum (average) 17.6°C.
- Flow 0.078 m3/s from gaugings at start and end of period.

Observed 2.1 km downstream temperature (SH25) for period 13/03 to 12/04/06 after removing high tide seawater influxes (3 hours before and after high tide):

- 24-hour mean 17.4°C.
- 24-hour maximum (average) 19.9°C.

Calibration parameters (defaults used unless specified)

Meteorology averaged over monitoring period from measurements at Whitianga, if available, otherwise from Auckland airport:

- 24-hour maximum air temp. (average) 22.4°C (Whitianga).
- 24-hour mean air temp. 18.1°C (Whitianga).
- Radiation 138.5 J/sm^2 (Auckland).
- Humidity 80% (Auckland).
- Day number 86 (mid-monitoring period).
- Latitude 37°.

Site information; 35 m altitude (from REC data), gradient 0.03 m/m (from REC data).

To calibrate model to observed 24-hour maximum temperature at upstream and downstream sites, the following settings were used:

- Upstream reach: bed temperature 15°C; canopy angle 100°; fraction through canopy 10% (native forest upstream).

- Downstream reach: bed temperature 18°C; canopy angle 85° (includes 35° bank/topography shade); fraction through canopy 40%.

Modelling parameters

The following parameters were changed from that specified above to simulate typical summer conditions (using long-term average climate data for the month of February from Auckland airport):

- 24-hour maximum air temp. (average) 23.8°C.

- 24-hour mean air temp. 20°C.

- Radiation 200.5 J/sm$^{2.}$

- Day number 45 (mid-February).

12.2 Tapu River

Observed parameters

Observed upstream temperature (at E2737558 N6464558) for period 13/03 to 11/04/06:

- 24-hour mean 15.9°C.

- 24-hour maximum (average) 17.1°C.

- Median flow for monitoring period (from Environment Waikato flow recorder) 0.29 m^3/s.

Observed 6.5 km downstream temperature (Environment Waikato flow recorder) for period 13/03 to 11/04/06:

- 24-hour mean 18.1°C.

- 24-hour maximum (average) 19.9°C.

Calibration parameters (defaults used unless specified)

Meteorology averaged over monitoring period from measurements at Whitianga, if available, otherwise from Auckland airport:

- 24-hour maximum air temp. (average) 22.4°C (Whitianga).
- 24-hour mean air temp. 18.1°C (Whitianga).
- Radiation 138.5 J/sm^2 (Auckland).
- Humidity 80% (Auckland).
- Day number 86 (mid-monitoring period).
- Latitude 37°.

Site information; 100 m altitude at top of reach and 50 m mid-reach (from REC data), gradient 0.015 m/m (from REC data).

To calibrate model to observed 24-hour maximum temperature at upstream and downstream sites, the following settings were used:

- Upstream reach: bed temperature 15.5°C; canopy angle 90°; fraction through canopy 13% (native forest upstream).
- Downstream reach: bed temperature 19.2°C; canopy angle 90° (includes 32° bank/topography shade); fraction through canopy 50%.

Modelling parameters

The following parameters were changed from that specified above to simulate typical summer conditions (using long-term average climate data for the month of February from Auckland airport):

- 24-hour maximum air temp. (average) 23.8°C.
- 24-hour mean air temp. 20°C.

- Radiation 200.5 J/sm^2 .
- Day number 45 (mid-February).

12.3 Wharekawa River

Observed parameters

Observed upstream temperature (at E2761984 N6446421) for period 14/03 to 13/04/06, excluding data for the duration of floods (26/03 to 7/04/06):

- 24-hour mean 16.9 °C.
- 24-hour maximum (average) 17.7 °C.
- Flow 0.486 m^3/s from Env. Waikato recorder.

Observed temperature 1.2 km downstream (Env. Waikato recorder) for period 14/03 to 13/04/06, excluding data for the duration of floods (26/03 to 7/04/06):

- 24-hour mean 19.4 °C.
- 24-hour maximum (average) 20.33 °C.

Calibration parameters (defaults used unless specified)

Meteorology averaged over monitoring period from measurements at Whitianga, if available, otherwise from Auckland airport:

- 24-hour maximum air temp. (average) 22.4°C (Whitianga).
- 24-hour mean air temp. 18.1°C (Whitianga).
- Radiation 138.5 J/sm^2 (Auckland).
- Humidity 80% (Auckland).
- Day number 86 (mid-monitoring period).
- Latitude 37°.

Site information; 20 m altitude (from REC data), gradient 0.004 m/m (from REC data).

To calibrate model to observed 24-hour maximum temperature at upstream sites, the following settings were used:

- Upstream reach: bed temperature 15.9 °C; canopy angle 50°; fraction through canopy 70%.

As discussed in the report (Section 3.5), reach parameters from the Tapu River were used to calibrate the model, as observed temperature increase was unlikely:

- Downstream reach: bed temperature 19.2 °C; bank/topography angle 32° canopy angle 45°; fraction through canopy 50%.

Modelling parameters

The following parameters were changed from that specified above to simulate typical summer conditions (using long-term average climate data for the month of February from Auckland airport):

- 24-hour maximum air temp. (average) 23.8°C.
- 24-hour mean air temp. 20°C.
- Radiation 200.5 J/sm^2.
- Day number 45 (mid-February).