Minimum Flow Report for the Tauranga Area

NIWA Client Report: HAM2003-043
May 2003

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Prepared for

Environment Bay of Plenty

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Contents

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Executive Summary

Water takes from streams in the Bay of Plenty region supply irrigators, industry and municipal schemes. Taking this water potentially conflicts with the flow requirements of fish and other stream life. Environment Bay of Plenty set up a project to assess how much flow is needed to adequately protect aquatic ecosystems. Instream habitat modelling (RHYHABSIM) was used to model change in fish habitat with flow, following requirements to use objective scientific methods as set out in the Proposed Regional Water and Land Plan (Bay of Plenty). Deriving an IMFR (instream minimum flow requirement) from the modelling output followed a standard method. The method, in short, allows a percent reduction in habitat dependent on the significance of each fish species. Environment Bay of Plenty staff, including the author prior to his move to NIWA, completed the fieldwork. Dr Bente Clausen (Consultant) undertook much of the RHYHABSIM modelling, before NIWA was commissioned to complete the analysis and reporting.

Assessing minimum flows in every stream reach potentially affected by water abstraction would be an overwhelming task. Therefore the intention is to generalise results from assessed reaches to others in the region. Grouping streams with similar habitat characteristics increases the success of this approach. The Tauranga area is the focus of this report. The ignimbrite geology of this area produces stable flows and predominantly sandy run habitat.

Twenty-five stream reaches were surveyed in the Tauranga area between December 2001 and March 2002. IMFR's were calculated for 17 of the 25 reaches (Table 1). For the remaining 8, estimates of the natural flow statistics, which are required for calculating the IMFR, were not available. The predictive analysis highlights the consistency of results from this and other studies, and therefore allows confident application to flow allocation. Three equations were developed for predicting IMFR's, and which equation is used depends on the aquatic ecosystem present. All are based on the Q_5 (five year low flow). (A guide for applying these equations is provided in Appendix IX.) The equations are:

$\mathrm{IMFR} = (0.8835 \times Q_5) + 1.5241$ Native fish, $Q_5 < 250$ L/s

$\mathrm{IMFR} = (0.1909 \times Q_5) + 172.94$ Native fish, $Q_5 > 250$ L/s

$\mathrm{IMFR} = 1.4483 \times Q_5^{0.9255}$ Adult rainbow rout

As flows are reduced there is a potential for water temperatures to increase and dilution of pollutants to decrease. However, many Tauranga Streams are spring-fed and this maintains cool water temperatures. With few exceptions, dissolved oxygen and ammonia were not predicted to become a problem.

Table 1: IMFR (instream minimum flow requirement) and Q_5 (1 in 5-year 7-day low flow) for streams assessed in the Tauranga area (L/s).

Stream	IMFR	Q_5
Whatakao	85	150
Waipapa Trib. Plummer Rd	28	25
Waipapa Trib. Jeffco Farm	4	5
Mangawhai	12	7
Te Puna at rapids	115	130
Te Puna Trib.	3	9
Oturu	12	10
Ohourere	120	230
Kopurereroa	1200	1335
Omanawa	890	1045
Joyce	15	20
Waitao	125	150
Raparapahoe at No. 4 Rd	480	550
Raparapahoe at No. 3 Rd	230	250
Ohineangaanga	170	200
Mangorewa	4325	5450
Pongakawa	3050	4350

1. Introduction

1.1 Background

Water abstraction from streams in the Bay of Plenty region supplies irrigators, industry and municipal schemes. The Proposed Regional Water and Land Plan has stipulated that minimum flows be set using objective scientific methods, such as the Instream Flow Incremental Methodology (IFIM), to model changes in fish and invertebrate habitat with flow. A project was set up to objectively evaluate minimum flows in rivers based on ecological values. The first step in this project was to review the ecological effects of water abstraction and methods for setting minimum flows (Wilding 1999).

Reduced flows can affect the ecology of a stream by:

- reducing water velocities and depth
- reducing the area of wetted habitat
- reducing dilution of contaminants (e.g., ammonia)
- increasing accumulation of sediment and algae
- reducing re-aeration and hence oxygen concentrations
- increasing water temperatures
- impeding fish passage by shallowing riffles or increasing period/frequency of stream mouth closure.

Modelling packages are available to evaluate changes in habitat and water quality with flow. RHYHABSIM was chosen and is used in this study of streams in the Tauranga area. Central to the implementation of this project was the development of instream management objectives. These were developed to allow consistent interpretation of the habitat modelling results across the Bay of Plenty. The approach follows concepts advocated by the Ministry for the Environment (MfE 1998) to implement regional plan objectives, and is explained in Appendix I. The objective is to provide adequate protection for aquatic ecosystems and this is achieved by identifying a primary flow for each species and then scaling this by an appropriate protection level. That level is determined by the significance of the given fish population. The recommended minimum flow, termed the IMFR (instream minimum flow requirement), is based on the species with the highest flow requirement. This approach has been applied to other streams in the Bay of Plenty region, as detailed in earlier reports (Wilding 2000, 2002a, 2002b).

1.2 IMFR and Water Allocation

As set out in the Proposed Regional Water and Land Plan, the IMFR is used to set surface water allocation limits. The IMFR sets the level below which the stream shall not be taken by abstraction. It also determines the allocatable flow (the sum of consented takes) for two abstraction scenarios – termed low flow allocation and high flow allocation. The low flow allocation is calculated by subtracting the IMFR from the Q_5 (one in 5-year 7-day low flow). The Q_5 is the management level established in the Proposed Regional Water and Land Plan. Using the Q_5 figure provides water to abstractors, on average four years out of five before natural drought conditions would require them to stop taking water (to prevent the stream flow dropping below the IMFR). This provides some degree of certainty for water abstractors. The high flow allocation (water harvesting) is available when stream flow is above the Q_5, where the take is of short duration and does not compromise the IMFR. A consent is required for both high and low flow allocation takes.

These methods of restricting takes are termed the allocation method. The reader is referred to the Proposed Regional Water and Land Plan for a full explanation. But the intention of the allocation method is to set an environmental standard which allows for reliable surface water abstraction, while ensuring that adverse effects on aquatic habitats (and other values) are avoided, remedied or mitigated.

1.3 Tauranga Streams

Assessing minimum flows in every stream reach potentially affected by water abstraction would be an impractical task, particularly for small streams which are more numerous and offer lower economic returns to abstractors. The intention therefore is to be able to generalise results from assessed reaches to others in the region. The likelihood of this approach succeeding is increased by generalising only to streams with similar habitat characteristics, in particular stream morphology.

In previous reports this approach was applied to streams of the Kaimai area and the Haumea catchment, where the relationship between the IMFR and the Q_5 ($R^2 > 0.99$) was used to predict flow requirements of other streams (Wilding 2002a, 2002b). Jowett (1993a, 1993b) likewise found a good relationship between stream flow (MALF) and instream flow requirements for brown trout of the Wellington and Taranaki regions. A more recent North American study compared a range of potential predictor variables, (including elevation, location, flow, gradient, distance to sea), and found flow (mean annual discharge) to be the best predictor of optimum habitat for various species and life stages of trout (Hatfield & Bruce 2000).

The Tauranga area (Figure 1.1) is typified by soft igneous rock called ignimbrite, (Briggs et al. 1996, Healy et al. 1964, Houghton & Cuthbertson 1989). This porous rock formed from compacted/welded pumice, produces streams with sandy runs plus occasional bedrock and cobble. Flows are relatively stable. The pumice soils and permeable rock allow rapid infiltration of rainfall, so a large portion of the flow comes from groundwater.

Streams of the Maketu Plains that originate from ignimbrite catchments usually retain their upland character, whereas those that originate on the plains are typically artificial drains and are not covered by this report.

Scattered throughout the Tauranga area are harder volcanic rock forms (volcanic domes of rhyolite and andesite), such as the Papamoa Range and Minden Peak. A few smaller stream catchments are dominated by such hard rock geologies. Here we expect to see hard cobble substrates and variable flows, more akin to streams of the Kaimai area (Wilding 2002b).

Diversity and abundance of native fish is typically moderate to high in the Tauranga streams. The lower reaches within close proximity to the sea and harbours have the highest diversity. For example, the Mimiha Stream provides habitat for 10 species of native fish. Rainbow trout are widespread and some streams also support brown trout. Anglers commonly visit the Wairoa, Ngamuwahine and other streams.

Land use in the Tauranga area ranges from dairy pasture and drystock, to forestry, horticulture (kiwifruit) and native forest. Most water takes in the area are for irrigation of dairy pasture and horticulture. Several municipal takes provide water to people living in Tauranga and Te Puke. Municipal takes often place the greatest demand on stream flows, while pressure on the resource from orchard irrigation and dairy intensification is more widespread and growing.

1.4 Scope

The scope of this report is to determine minimum flow requirements for a selection of Tauranga streams based on fish habitat modelling, and investigate options for generalising these results to other reaches in the area. The potential for water quality and temperature to become a critical issue was also investigated where data were available. Other issues not covered in this report that may influence the minimum flow are included in the bullet points in section 1.1. However, it is considered that physical habitat will be the critical issue for minimum flows in most situations.

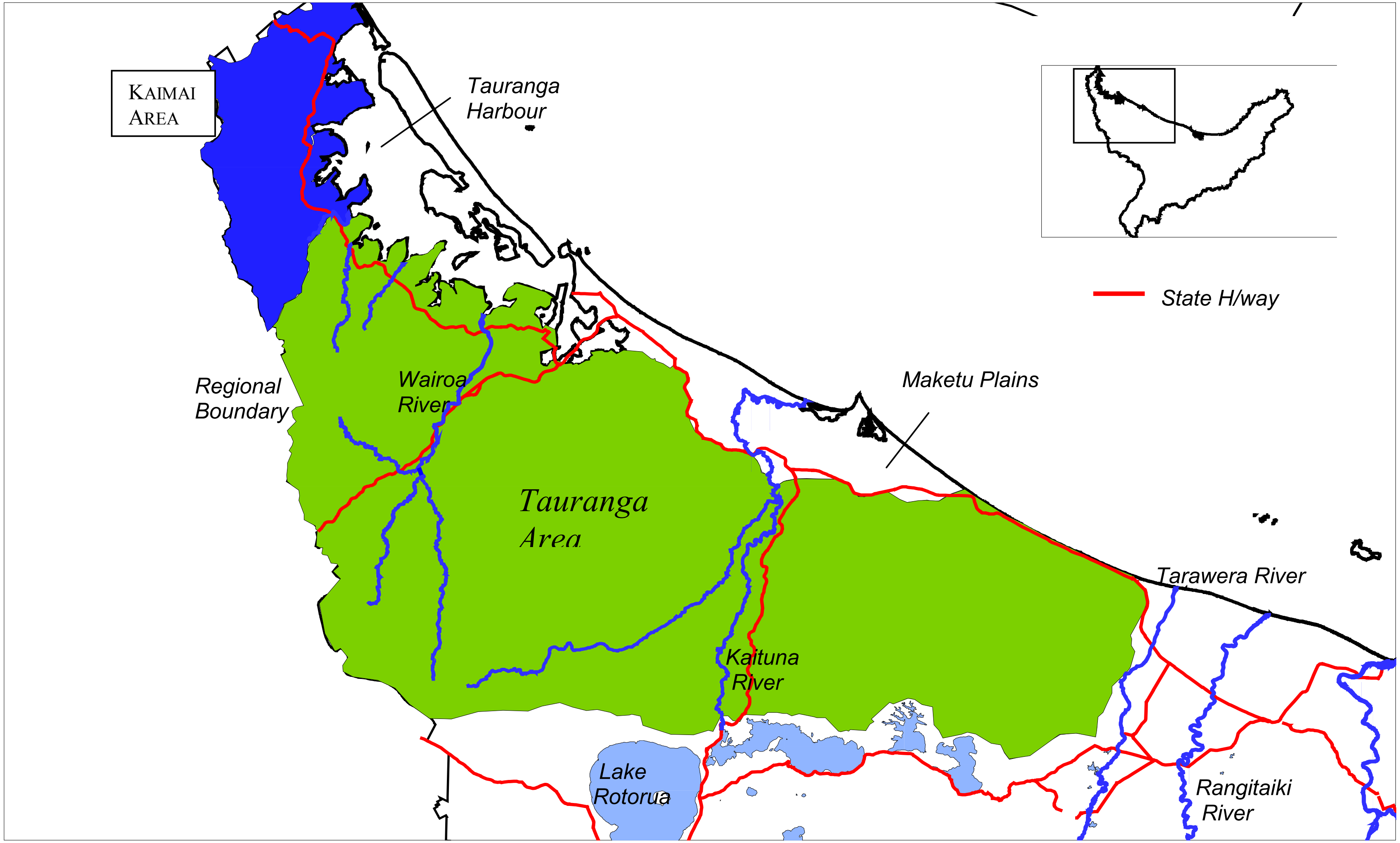

Figure 1.1: The Tauranga area, in green, is the focus of this report. Inset shows location within the Bay of Plenty Region.

2. Methods

2.1 Sites

To assess minimum flows for streams in the Tauranga area, 25 reaches were selected to represent a range of stream sizes and habitat conditions (Table 2.1, Figures 2.1 to 2.3, photos in Appendix II). Streams subject to significant abstraction pressure (following Hodges & Gordon 1999) were selected in the first instance. Flow parameters are summarised in Table 2.2. Estimates could not be obtained for 8 of the reaches using available flow data, so minimum flow analysis was not completed for these reaches. They will be dealt with in a later report once sufficient flow data are obtained.

2.2 Habitat Survey

The physical habitat component of IFIM (instream flow incremental methodology) was used to evaluate change in fish habitat with flow. This method focuses on depth, velocity and substrate as determinants of habitat suitability. Cross-section surveys were carried out between December 2001 and February 2002. Specific dates for this and follow up gauging work are provided in Appendix IV.

Data were collected following the habitat mapping method described by Jowett (1996) and are summarised in Appendix III. Tauranga Streams vary in habitat form. The ignimbrite geology most commonly produces sandy runs, but also produces bedrock chutes, cobble and boulder riffles. Where pool/riffle/run sequences were present, we aimed for 5 cross sections per habitat type. For some streams, the three habitat types were distinct but the ratios strongly biased, typically to sandy runs. In this case more cross-sections were placed in the more common habitat type. Where habitat types were not distinct, the 15 cross-sections were spaced evenly. For the Mangorewa, cross-sections were placed to represent the diversity of run habitat present (differing depths and widths). At Oturu Stream spacing was fairly even (average 10 m), however the placement of many cross-sections was determined by access. The Oturu Stream is an excavated drain passing through a willow wetland, so cross-sections represent pools and slow runs.

Habitat mapping looks at the proportion of each habitat type and each cross-section is weighted accordingly for the analysis. For the Ohourere Stream, habitat weightings changed between the establishment of cross-sections and when habitat mapping was undertaken (flows dropped changing runs to riffles). I therefore decided to weight each cross-section evenly. In future, habitat mapping should be undertaken on the same day as the labelling of cross-sections (as pool, riffle or run). A summary of cross-section placement for each reach is given in Table 2.3.

Table 2.1: Reaches assessed in the Tauranga area. Upstream and downstream bounds (top and bottom of reach) defined as New Zealand Map Grid coordinates (easting and northing respectively). Instream minimum flow requirements could not be calculated for streams marked *, because of difficulties deriving accurate natural flow estimates.

	Stream	Reach	Top of Reach	Bottom of Reach
1	Whatakao	Walford Rd	2,770,039 6,392,389	2,769,894 6,392,688
2	Waipapa*	Waipapa Block Road	2,774,225 6,388,080	2,774,455 6,388,523
3	Waipapa Tributary	Plummer Road	2,775,182 6,387,109	2,775,130 6,387,310
4	Waipapa Trib.	Jeffco Farm	2,774,496 6,384,537	2,774,416 6,384,815
5	Mangawhai	SH 2	2,776,743 6,387,588	2,776,738 6,387,734
6	Te Puna	Rapids	2,776,893 6,385,181	2,776,987 6,385,371
7	Te Puna Trib.	Arondale Farm	2,775,769 6,384,319	2,775,893 6,384,361
8	Oturu	Paparoa Rd	2,780,579 6,387,146	2,780,610 6,387,294
9	Ohourere	Municipal Take	2,779,993 6,380,631	2,780,353 6,380,442
10	Wairoa*	SH 29	2,778,972 6,375,435	2,778,978 6,375,578
11	Kopurereroa	SH 29	2,784,157 6,380,190	2,784,284 6,380,575
12	Omanawa	Lawry Rd	2,781,388 6,373,974	2,781,257 6,374,181
13	Joyce	Joyce Rd	2,785,193 6,376,530	2,785,171 6,376,611
14	Waitao	Waitao Rd	2,794,724 6,380,326	2,794,710 6,380,505
15	Raparapahoe	No. 4 Road	2,800,451 6,372,259	2,800,240 6,372,605
16	Raparapahoe	d/s No. 3 Road	2,796,740 6,369,183	2,796,998 6,369,037
17	Ohineangaanga	Whitehead Rd	2,801,864 6,373,569	2,801,801 6,373,417
18	Mangorewa	u/s Kaituna confluence	2,807,604 6,368,362	2,808,612 6,369,118
19	Parawhenuamea* Trib.	Bart Orchard	2,805,515 6,369,287	2,805,575 6,369,537
20	Puanene*	Old Coach Rd	2,815,140 6,367,746	2,815,300 6,367,957
21	Pokopoko*	Old Coach Rd	2,811,027 6,368,598	2,811,298 6,368,898
22	Waiari Trib.*	Mystery Valley Rd	2,812,152 6,362,590	2,812,078 6,362,660
23	Wharere*	Old Coach Rd	2,816,354 6,367,924	2,816,437 6,368,188
24	Pongakawa	Old Coach Rd	2,818,714 6,366,120	2,819,104 6,366,204
25	Pikowai*	Pikowai Rd	2,830,938 6,362,175	2,831,014 6,362,401

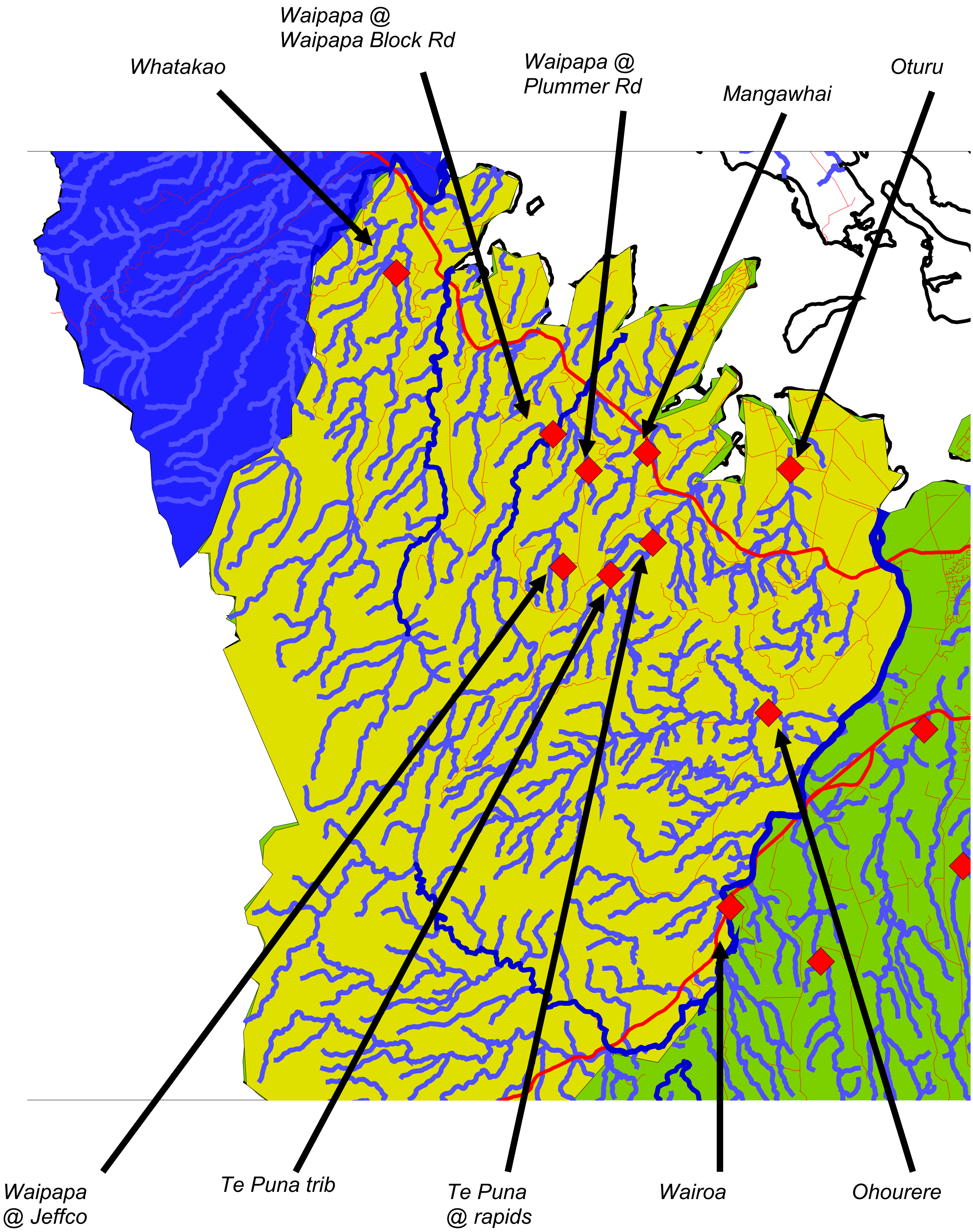

Figure 2: Study reaches northwest of the Wairoa River (see Figure 1).

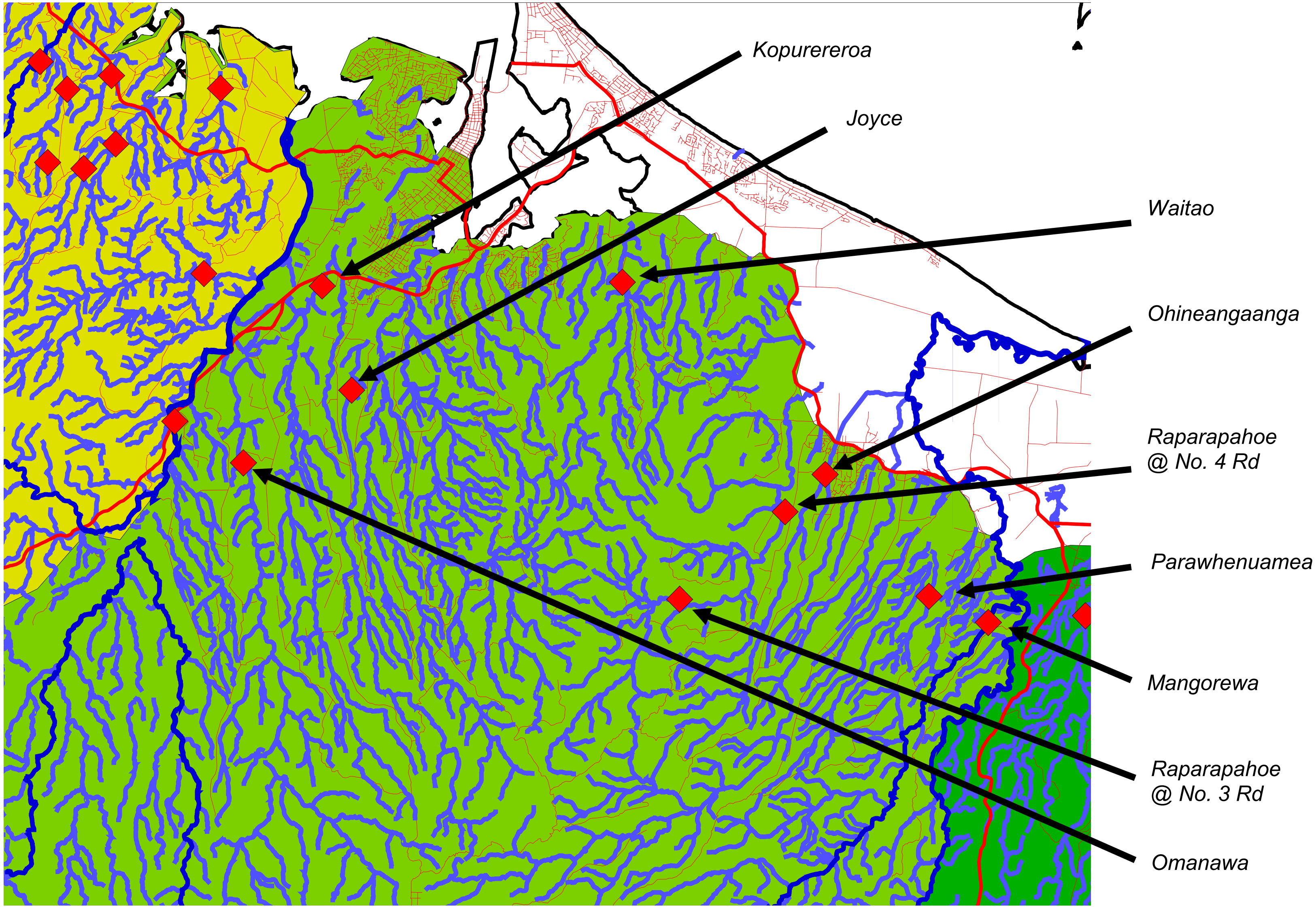

Figure 3: Study reaches between the Wairoa and Kaituna River (see Figure 1).

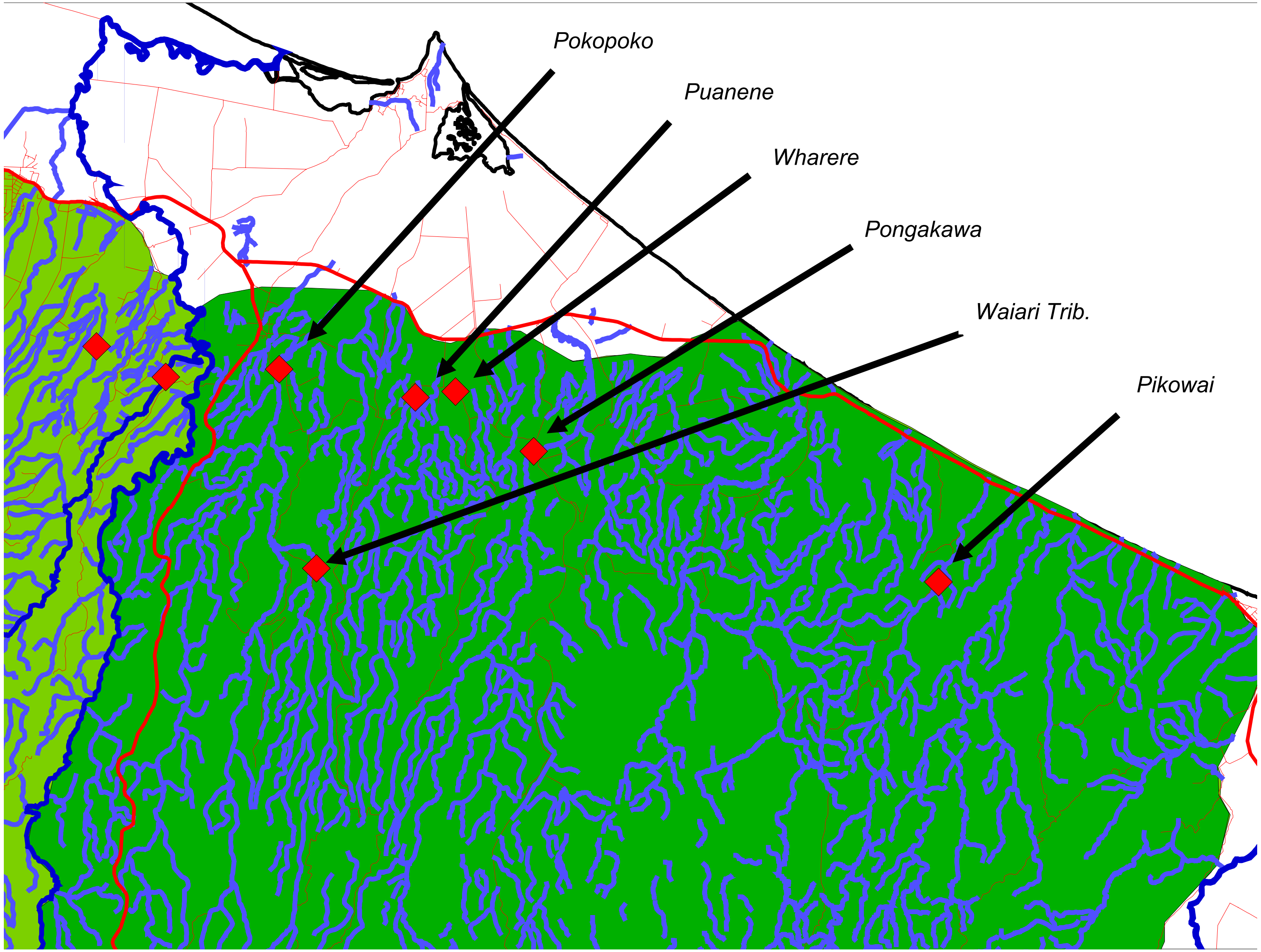

Figure 4: Study reaches east of the Kaituna River (see Figure 1).

Table 3: Natural flow estimates for the 17 assessed Tauranga reaches, as at November 2002, (natural flow meaning in the absence of abstraction). Q_5 is the one in 5-year 7-day low flow. MALF is the 7-day mean annual low flow.

	Stream	**Reach**	**Q_5 (L/s)**	**MALF (L/s)**	**Median Flow (L/s)**
1	Whatakao		150	180	700
3	Waipapa Tributary	Plummer Road	25	30	110
4	Waipapa Trib.	Jeffco Farm	5	7	20
5	Mangawhai		7	10	39
6	Te Puna	Rapids	130	150	350
7	Te Puna Trib.	Arondale Farm	9	11	30
8	Oturu		10	20	100
9	Ohourere		230	250	500
11	Kopurereroa		1335	1490	1748
12	Omanawa		1045	1075	1130
13	Joyce		20	30	50
14	Waitao		150	170	425
15	Raparapahoe	No. 4 Road	550	600	900
16	Raparapahoe	No. 3 Road	250	300	575
17	Ohineangaanga		200	250	300
18	Mangorewa		5450	6000	6750
24	Pongakawa		4350	4450	4700

Table 2.3: Cross-section placement and habitat mapping for the 17 Tauranga reaches.

	Stream	Reach	No. of cross-sections assessed	No. of cross-sections analysed	Placement	Analysis weighting
1	Whatakao		15	15	5 Pool, 5 Riffle, 5 Run	Habitat mapping
3	Waipapa Trib.	Plummer Road	15	14	5 Pool, 5 Riffle, 4 Run	Habitat mapping
4	Waipapa Trib.	Jeffco Farm	15	15	5 Pool, 5 Riffle, 5 Run	Habitat mapping
5	Mangawhai		15	15	5 Pool, 4 Riffle, 6 Run	Habitat mapping
6	Te Puna	Rapids	15	15	5 Pool, 5 Riffle, 5 Run	Habitat mapping
7	Te Puna Trib.	Arondale Farm	15	14	5 Pool, 5 Riffle, 4 Run	Habitat mapping
8	Oturu		15	15	spaced at ~10m intervals	Evenly weighted
9	Ohourere		15	15	5 Pool, 6 Riffle, 4 Run	Evenly weighted
11	Kopurereroa		15	15	spaced at 25m intervals	Evenly weighted
12	Omanawa		15	13	6 Pool, 2 Riffle, 5 Run	Habitat mapping
13	Joyce		15	15	5 Pool, 5 Riffle, 5 Run	Habitat mapping
14	Waitao		15	12	3 Pool, 3 Riffle, 6 Run	Habitat mapping
15	Raparapahoe	No. 4 Road	15	14	1 Pool, 3 Riffle, 10 Run	Habitat mapping
16	Raparapahoe	No. 3 Road	15	15	6 Pool, 5 Riffle, 4 Run	Habitat mapping
17	Ohineangaanga		15	14	3 Pool, 1 Riffle, 10 Run	Evenly weighted
18	Mangorewa		15	15	15 runs	Evenly weighted
24	Pongakawa		15	15	spaced at 30m intervals	Evenly weighted

2.3 Data Analysis

The data were analysed using RHYHABSIM version 3.0 (Jowett 2001). RHYHABSIM stands for River Hydraulics and Habitat Simulation. Habitat mapping was undertaken to determine the weighting given to pool, riffle and run cross-section data in the analysis. Deriving minimum flows from habitat-flow response curves followed specific instream management objectives, which were developed for application to the wider Bay of Plenty region. 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 streams natural flow (median flow) and is therefore unreasonable. In the latter case use the MALF as the primary flow.

2. Multiply habitat at the primary flow by the appropriate protection level to obtain a minimum flow for each species. Protection levels are scaled according to population/ecosystem significance (given in Appendix I).

3. The species with the highest minimum flow determines the IMFR.

This approach is explained in greater detail in Appendix I.

A range of different habitat criteria have been developed for rainbow and brown trout, both in New Zealand and America. Which criteria are chosen will affect the minimum flow value because, generally speaking, larger trout have higher flow requirements. After recommendations by Hayes (2000) and Ian Jowett (NIWA *pers. comm.*), the favoured criteria are presented in Table 2.4, with trout size determining which criteria are used in each case.

Table 2.4: Trout habitat criteria for use with RHYHABSIM based on size range of fish present in the study reach.

Species	Size	Habitat Criteria
Brown Trout	Adult (>40cm)	"Brown trout adult (Hayes & Jowett 1994)"
	Yearling (15-25cm)	"Brown trout yearling (Raleigh 1986)"
	Fry (<15cm)	"Brown trout fry to 15cm (Raleigh 1986)"
Rainbow Trout	Medium adults (30-45cm)	"Rainbow trout feeding (30-40cm Cheeseman Bovee)"
	Juvenile (<20cm)	"Juvenile rainbow trout feeding (Cheeseman Bovee)"

2.4 Fishing

A range of fishing methods was used to determine what species are present, and hence which habitat suitability curves to use for modelling. Electric fishing was carried out in the smaller streams using a Kainga EFM300 set with hand and stop-nets (single pass). In streams less suitable for electric fishing other methods were used including fyke nets, beach seine net and drift diving. Drift diving followed methods of Hicks & Watson (1985) and Kusabs (2000). Water clarity did not always meet the minimum recommended by these authors for abundance estimates (2 m); however the method still provided useful information on the species and size range present. Existing records from the New Zealand Freshwater Fish Database were available for some sites. Sampling methods and effort at each site are detailed in Table 2.5.

Table 2.5: Sampling methods used for the Tauranga sites.

Stream	Reach	Electric fishing area (m^2)	Drift dive distance, No. of divers & black disc clarity	Number of fyke nets	Fish database records
Whatakao		50			
Waipapa Tributary	Plummer Road	50			
Waipapa Trib.	Jeffco Farm	Yes (area not measured)			
Mangawhai					Yes
Te Puna	Rapids		3 divers 3.07m BD		
Te Puna Trib.	Arondale Farm	100			
Oturu		85		4	Yes
Ohourere			390 m, 3 divers 1.5m BD		Yes
Kopurereroa			400 m 3 divers 1.1m BD	6	
Omanawa			440 m 4 divers 2m BD		
Joyce		50			
Waitao		60			
Raparapahoe	No. 4 Road		480 m 3 divers 2.6m BD		
Raparapahoe	No. 3 Road	60			
Ohineangaanga		80			
Mangorewa			2000 m 5 divers 7.2m BD		
Pongakawa			410 m 4 divers 3m BD		Yes

3. Results

3.1 Fishing

Fish surveys were carried out in the assessed reaches to determine which habitat suitability curves to use for calculating minimum flows (Table 3.1). A range of fishing methods was used, though for some sites no one method was entirely satisfactory. For example, the Kopurereroa was too deep for electric fishing, too swift for fykes, too incised for the beach seine and had insufficient clarity for drift diving. Where some species may have been missed, minimum flows for those species I expected to find (from observations of similar streams) are added for reference.

Native fish diversity in the Tauranga streams increases closer to the sea and harbour, where access is easier for whitebait and other juveniles returning from the sea. Redfin bullies and eels were found in most reaches. Trout were found in the larger streams, (predominantly rainbows). Common smelt were fairly widespread and other native species encountered include torrentfish, inanga, common bully, giant bully and banded kokopu.

3.2 Reach Calibration

A rating curve is the relationship between flow and water level. It is derived for each cross-section in order to predict water depths, velocities and hence habitat at each point across the cross-section. The modelling package RHYHABSIM presents three options for calculating rating curves:

1. log-log least squares fit through points and measured SZF (stage of zero flow);

2. log-log least squares fit through points with best SZF (estimated as a free parameter);

3. hydraulic rating (using Manning's equation).

The fitted SZF rating (1st option) was used as the default to calculate minimum flows. Deviations from this option are given in Appendix V. For many reaches deriving sensible rating curves was not straightforward. There were commonly two causes for this: firstly channel shape changing between gaugings, which meant the points on the stage discharge plot did not form a smooth curve; and secondly stable flow conditions which meant the points were clustered in a small area.

Changes in channel shape often resulted from weed growth or bed aggradation/degradation. The sandy pumice bed of volcanic plateau streams can be relatively mobile, and this caused problems for earlier studies (Wilding 2000, 2002a). The geology of the area often produces stable flows. The pumice soils and ignimbrite bedrock allow rapid soil infiltration and little surface runoff as a result. The predominant flow source is therefore from groundwater aquifers with long residence times. Measuring water levels over a wide enough range of flows to generate accurate rating curves is difficult when flow varies little and channel shape changes rapidly. Re-surveys are likely to encounter the same problems so are not recommended. Modifications were made to the data where this was sensible (Appendix VI). For two reaches, ratings were particularly troublesome. For the Mangorewa and Joyce Stream, the data were analysed with two different rating exponents (sensitivity analysis using flow exponents of 2 and 3) and minimum flows calculated for both exponents. In deciding which of the two exponents to use, plots used for the predictive analysis, (IMFR vs. Q_5, see section 3.4) indicated which of the two estimates was closest to that expected. An exponent of 2 was chosen for the Joyce Stream and 3 for the Mangorewa River.

Some temporary staff gauges were lost before sufficient follow-up gaugings were undertaken, and these cross-sections had to be omitted from the analysis. Table 2.3 shows the number of cross-sections surveyed versus those analysed. The difference between the two is the number of temporary staff gauges lost or where data for the cross-section were otherwise unsuitable.

Table 3.1: Fishing results for assessed reaches. (* electric fishing; ° drift dive; x fyke net; s beach seine; + observed during field work; # from New Zealand Freshwater Fish Database records at same site).

	Stream	**Reach**		
1	Whatakao		Longfin eel* Shortfin eel* Inanga*	Redfin bully* Giant bully* Koura*
3	Waipapa Trib.	Plummer Road	Longfin eel* Shortfin eel*	Redfin bully* Koura*
4	Waipapa Trib.	Jeffco Farm	Longfin eel* Shortfin eel*	Banded Kokopu* Koura*
5	Mangawhai		Longfin eel$^{\#}$ Mosquito fish$^{\#}$ Torrentfish$^{\#}$	Redfin bully$^{\#}$ Common bully$^{\#}$ Giant bully$^{\#}$
6	Te Puna	Rapids	Shortfin eel° Common smelt° Inanga°	Redfin bully° Giant bully°
7	Te Puna Trib	Arondale Farm	Longfin eel* Banded kokopu*	Koura*
8	Oturu		Longfin eel^{x} Shortfin eel* Common smelt* Inanga*	Mosquito fish* Redfin bully* Common bully$^{\#}$ Giant bully^{x}
9	Ohourere		Longfin eel$^{\#}$ Shortfin eel° Banded kokopu$^{\#}$	Rainbow trout° (350mm) Redfin bully° Koura°
11	Kopurereroa		Longfin eel^{x} Common smelt°	Redfin bully ^{s} Koura^{x}
12	Omanawa		Longfin eel° Common smelt°	Rainbow trout^{+} (250mm) Redfin bully°
13	Joyce		Longfin eel* Banded kokopu*	Koura*
14	Waitao		Longfin eel* Shortfin eel* Common smelt*	Inanga* Redfin bully* Common bully*
15	Raparapahoe	No. 4 Road	Rainbow trout° (400mm)	
16	Raparapahoe	No. 3 Road	Longfin eel*	Rainbow trout^{+} (500mm)
17	Ohineangaanga		Longfin eel* Shortfin eel* Torrentfish*	Redfin bully* Koura*
18	Mangorewa		Common smelt°	Rainbow trout° (500mm)
24	Pongakawa		Longfin eel° Common smelt° Inanga$^{\#}$	Rainbow trout° (500mm) Giant bully$^{\#}$

3.3 Habitat Response

The relationship of habitat with flow was modelled using RHYHABSIM for species found in each reach, (except giant bully, for which no habitat suitability data were available), as well as those species potentially present but not caught. Minimum flows were derived for each species, in short, by allowing a percent reduction in habitat (the reduction, termed the protection level, is dependent upon the species significance). The IMFR is based on the species with the highest minimum flow (Appendix I).

Following the significance criteria in Appendix I, native fish were given a protection level of 85%, the one exception being banded kokopu, which were given a 95% protection level, (no streams were considered Criteria 4-diverse fish communities). Trout in all reaches were given the 85% protection level. None of the reaches are considered regionally significant recreational trout fisheries. Most reaches where trout were found are fished to some extent (Richardson et al. 1986, Proposed Regional Water and Land Plan 2002, Schedule 1D). The Raparapahoe Stream at Number 3 Road is unlikely to be fished; however, it is representative of downstream reaches where fishing may take place.

Minimum flows for each species and reach are summarised in Tables 3.2a and 3.2b, (habitat-flow response curves given in Appendix VII). Which species determined the IMFR, (the species with the highest flow requirement), varied between reaches. Where trout were present, they had the highest flow requirement, as is typically the case.

Some streams contained trout larger than that recommended for use with the ‘medium adult’ curves (Table 2.4). Results using the Tongariro trout suitability data are presented (Table 3.2b), but were not used as their applicability to small streams is uncertain. For the Te Puna Stream (at rapids), electric fishing was not undertaken as drift diving revealed many native species. Because riffles were too shallow for drift diving, torrentfish were not recorded. However, torrentfish are very likely to be present at this site and hence the IMFR is based on this species. For the Kopurereroa Stream, fishing did not reveal rainbow trout, however angler surveys have (Richardson et al. 1986), and hence the IMFR for this stream is based on trout with an 85% protection level. Electric fishing was not undertaken at Raparapahoe Stream Number 4 Road. Should angler use of this stream prove to be negligible, the protection level of rainbow trout should be downgraded from 85% to 15% (minimum flow using 15% protection level given in brackets in Table 3.2b). In this event a fish survey would be required to determine which native species are present and hence the appropriate minimum flow.

For the Mangorewa River, the minimum flow for rainbow trout (medium adult) was derived ignoring substrate (set as optimal). By comparison, the minimum flow using substrate in the habitat evaluation was higher (4924 L/s ignoring substrate, cf. 4326 L/s using substrate, exp. 3). It was higher because macrophytes (aquatic plants) grow along the banks of the Mangorewa, and more flow is needed to maintain the depths and velocities preferred by trout overtop of these macrophyte beds. The substrate suitability index for rainbow trout is specified as 1 for plants and 0 for sand in the Cheeseman and Bovee curves. But there is reason to doubt these habitat suitability values. From drift diving the Mangorewa we know trout occupy areas where the bed is sand. Adult trout are largely pelagic so primarily seek suitable depth and velocity, rather than a particular substrate[1]. Hence rainbow trout habitat was modelled ignoring substrate. We need to maintain macrophyte beds to provide a food source for trout (as a stable substrate for invertebrates), but these beds do not need to be directly below the trout. It is therefore worth considering the implications of reduced flow for macrophyte beds separately. Habitat was modelled for the dominant macrophyte, *Elodea canadensis*, using flow-fluctuation analysis in RHYHABSIM, (this method recognises that macrophytes cannot move to new areas of suitable habitat as flows change from the baseflow). The reduction in macrophyte habitat going from 4924 L/s to 4326 L/s was small, (i.e., changing from the trout minimum flow with substrate on to substrate off gave a 5.5% change; using median flow as baseflow), and therefore an IMFR of 4326 L/s is recommended for the Mangorewa.

For most other sites modelled for adult trout, substrate did not have a significant effect on the minimum flow, with the exception of the Pongakawa and Waitahanui (the latter used in this report only for predictive analyses). The effect of the further reduction in flow on macrophyte beds was significant for these two streams, 24% and 15% respectively, so we retain the original IMFR.

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[1] In most streams an increase in velocity is associated with an increase in substrate size. Although preference analysis may indicate a dislike for sandy substrates, this may simply be a correlate for low water velocities.

Table 3.2a: Minimum flows (L/s) for native species. IMFR (instream minimum flow requirement) is given based on the species with highest flow requirements (using native fish and trout, but only those species established as present). *Species possibly present but not caught. Q_5 is the 1 in 5-year 7-day low flow. PL is the protection level. For Joyce and Mangorewa flows are presented using rating flow exponents 2 and 3.

	Stream	**Reach**	Q_5	IMFR	Longfin Eel	Shortfin Eel	Common Smelt	Banded Kokopu	Inanga	Torrentfish	Redfin Bully	Common Bully
					(PL 85%)	(PL 85%)	(PL 85%)	(PL 95%)	(PL 85%)	(PL 85%)	(PL 85%)	(PL 85%)
1	Whatakao		150	85	41	45	115*		37		85	
3	Waipapa Tributary	Plummer Road	25	28	3	1					28	
4	Waipapa Trib.	Jeffco Farm	5	4	1	1		4				
5	Mangawhai		7	12	1	1*			3*	7	12	3
6	Te Puna	Rapids	130	115	70*	70	60		65	115	60	
7	Te Puna Trib.	Arondale Farm	9	3	3	1*		3			6*	
8	Oturu		10	12	1	1	12	6*	4		no habitat	3
9	Ohourere		230	120	0	0		28			12	
11	Kopurereroa		1335	1200	27	14*	360				41	
12	Omanawa		1045	890	145	95*	450				210	
13	Joyce		20	15	15			2				
14	Waitao		150	125	60	70	110		60		85	125
15	Raparapahoe	No. 4 Road	550	480	70*	48*	320*		65*	190*	75*	
16	Raparapahoe	No. 3 Road	250	230	80							
17	Ohineangaanga		200	170	75	70				170	42	
18	Mangorewa		5450	4326	170*	70*	760				140*	
24	Pongakawa		4350	3050	225	135*	1025		110			

Table 3.2b: Minimum flows (L/s) for trout, as per Table 3.2a. #Analysis conducted with substrate switched off. Alternative minimum flows are given in brackets for the Raparapahoe sites using a lower protection level (15%), as per text Section 3.3.

	Stream	**Reach**	**Q_5**	**IMFR (L/s)**	**Rainbow trout Adult (Tongariro)**	**Rainbow trout med. adult**	**Rainbow trout Juvenile**
					(PL 85%)	(PL 85%)	(PL 85%)
9	Ohourere		230	120		120	65
11	Kopurereroa		1335	1200		1200*	370*
12	Omanawa		1045	890		890	680
15	Raparapahoe	No. 4 Road	550	480	560	480 [20 for 15%]	350
16	Raparapahoe	No. 3 Road	250	230	270	230 [0 for 15%]	220
18	Mangorewa		5450	4325	5425	$4325^{\#}$	1100
24	Pongakawa		4350	3050	3800	3050	1125

3.4 Predicting flow requirements for other reaches in the Tauranga area

Assessing every reach potentially affected by abstraction is not feasible. It is therefore desirable to be able to use the results from assessed reaches to predict flow requirements for other streams in the Tauranga area. Generalisation of instream flow requirements relies on the assumption that stream habitat, particularly morphology, is similar within the area chosen. Hence the Bay of Plenty region was broken down into areas of similar stream habitat.

In previous studies this approach was successfully applied to streams of the Kaimai area and the Haumea catchment, employing the relationship between the IMFR and the Q_5 to predict flow requirements of other streams (Wilding 2002a, 2002b). The Tauranga area, as described in section 1.2, is larger and more diverse than areas previously investigated.

Results of other IFIM studies in the Tauranga area supplemented the dataset used for the predictive analysis. Minimum flows for the Waitahanui were assessed in an earlier study using the same approach (Wilding 2000), so could be included without modification. Eight other reaches were assessed as part of the current study, but could not be analysed because there was insufficient data to derive accurate estimates of natural flow statistics (median flow, Q_5, MALF). For the predictive analysis only, rough flow estimates were derived for seven of these streams (see Appendix VIII for calculation methods). Minimum flows were then derived and used for the predictive analyses. While these figures do not necessarily represent a precise estimate of the flow requirements of each specific reach, they do provide relative flow requirements for that stream type for the purposes of interpolation. Assessments were carried out for TDC (Tauranga District Council) by NIWA for 5 other reaches on three streams. Permission was obtained from TDC to use the data, and minimum flows were subsequently derived using the same methods prescribed for this project (Appendix I). In total, data from the 17 reaches in Table 3.2 and 12 additional reaches were used for the predictive analysis.

The predictive analysis was undertaken separately for trout and native species because of their diverging flow requirements. This allowed a more appropriate IMFR to be derived for the resident fish community of a given stream. These are discussed separately.

3.4.1 Adult Rainbow Trout

There are a number of different trout habitat suitability criteria available for minimum flow analysis, as discussed in Section 2.3. The Tauranga trout streams typically support medium size adult rainbow trout, so minimum flows derived using the Cheeseman-Bovee suitability criteria form the basis of the predictive analysis.

Many of the streams in this study do not contain trout. However, to provide more data on trout flow requirements, minimum flows for trout were calculated for all streams with flows greater than 150 L/s (Q_5). These additional streams reinforced the trendline (triangular points in Figure 3.1).

With the extra sites added some outliers become apparent. The Pongakawa, Ohourere and Wairoa have lower flow requirements than expected, that is, they sit below the trend line (Figure 3.1, square points). (Note: the Pongakawa is only visible as a pronounced outlier on a linear scale, rather than the log scale presented.) The concern is that these reaches represent different habitat types and so, by dragging the line down, flow requirements for more typical stream types could be underestimated. For the Ohourere and Wairoa there are morphological differences to explain the lower flow requirements. The Ohourere and Wairoa have large areas of bedrock which tend to form control structures at the base of pools. As the flow reduces adequate depth is maintained in the pools because the bedrock acts like a dam. Therefore the Wairoa and Ohourere were excluded from the trendline (Figure 3.1). Note that applying the resultant predictive equation to bedrock streams does not necessarily become invalid. Most bedrock streams also have long reaches with more typical pumice substrates. Therefore, while the bedrock reach might not require as much water as predicted by the equation, non-bedrock areas on the same stream will. As allocation limits need to provide for the more sensitive reach, the equation will still be valid. The Pongakawa Stream has a deep rectangular channel profile. It is deeper than what rainbow trout require and therefore a large reduction in flow is possible without having a significant effect on habitat. The channel profile is artificial and a product of realignment. It is not desirable for the predictive equation to be influenced by artificial environments, so the Pongakawa was also excluded.

The resulting trendline, with a high R^2 score, provides an equation that can confidently be used to predict flow requirements for adult trout where IFIM studies have not been carried out (Figure 3.1). It is not recommended that this equation be applied to streams with Q_5 flow less than 150 L/s or greater than 6000 L/s, as these lie outside the calibrated flow range.

Adult rainbow trout have higher flow requirements than juveniles, so it is assumed that setting an IMFR based on adults will provide for the habitat requirements of juveniles. There are some situations, however, where we wish to maintain habitat for juveniles but not adults, for example, rearing streams. The relationship between IMFR and Q_5 for juvenile rainbow trout was poor (Figure 3.2). However, to facilitate some level of water allocation, an equation was derived using only juvenile trout populations with the highest flow requirements (the square points in Figure 3.2). If the desired level of abstraction complies with the IMFR predicted by this equation, then we can be confident that the habitat requirements of juvenile trout will be met or exceeded. There could be more water available for abstraction, but an IFIM survey would be required to determine this.

3.4.2 Native Fish

The varied fish communities resulted in a wide scatter of points (Figure 3.3). Streams closer to the sea and harbours generally have, what can be termed a full complement of species because migratory access is not limiting the types of fish that can occupy available habitat. Further inland species richness gradually reduces till only the most capable migrators are present, such as eels or kokopu. Such species often have lower flow requirements, so the IMFR for an inland stream can differ from a coastal stream. Producing an equation for each species of fish would allow a minimum flow to be derived for a reach based on what species are present. However, this approach did not work for enough species to be successfully applied.

For native fish a conservative approach was therefore adopted. Streams were remodelled as if they had good access for common smelt and torrentfish, the two species most likely to determine the IMFR. All reaches had pool and run habitat that is suitable habitat for common smelt, (except Ohineangaanga). Fewer reaches provided suitable habitat for torrentfish, owing to a lack of riffle habitat. (Additional sites modelled for torrentfish were: Waipapa tributary at Plummer Rd, Te Puna trib., Joyce, Raparapahoe No. 3 Rd, Tautau, Waiari trib.)

Applying a power curve to this dataset produced a reasonable correlation with Q_5 ($R^2=0.9739$, IMFR = $2.83 \times Q_5^{0.7172}$). But the power curve significantly underestimated flow requirements for streams between 100 and 250 L/s. The data appears to have two distinct stages; a steep relationship for small streams, and a flatter curve for large streams. As presented in Figure 3.4, the data were broken into two sets and a separate linear trend line fitted to each, (note: Ohourere and Wairoa are outliers, for reasons discussed for rainbow trout, so were not used to calculate the trendlines). The flow (Q_5) at which these two trend lines intersect is 250 L/s, and so this is the cut-off for applying each equation.

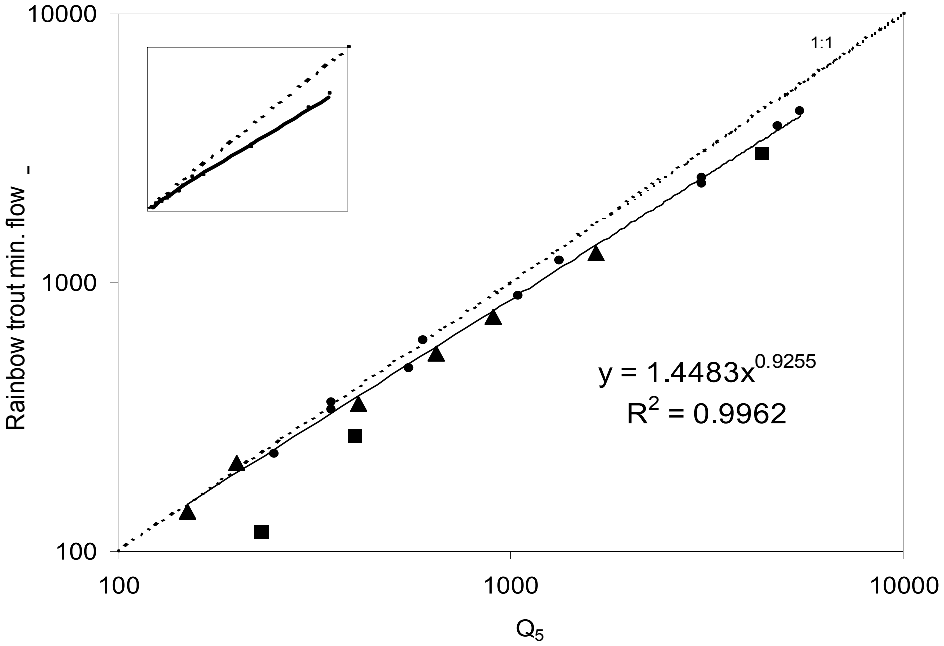

Figure 3.1: Minimum flow requirement for rainbow trout (medium adult) versus Q_5 for streams in the Tauranga area plotted on a log scale (L/s). Reaches represented as triangles are not known to support trout populations. Square points are outliers and hence the trendline was not fitted to these points. Trendline needs to be below the 1:1 line before water is available for abstraction, as per Environment Bay of Plenty allocation policy (allocatable flow = Q_5 – IMFR). Inset shows graph on linear scale, for comparison to the log-log scale presented.

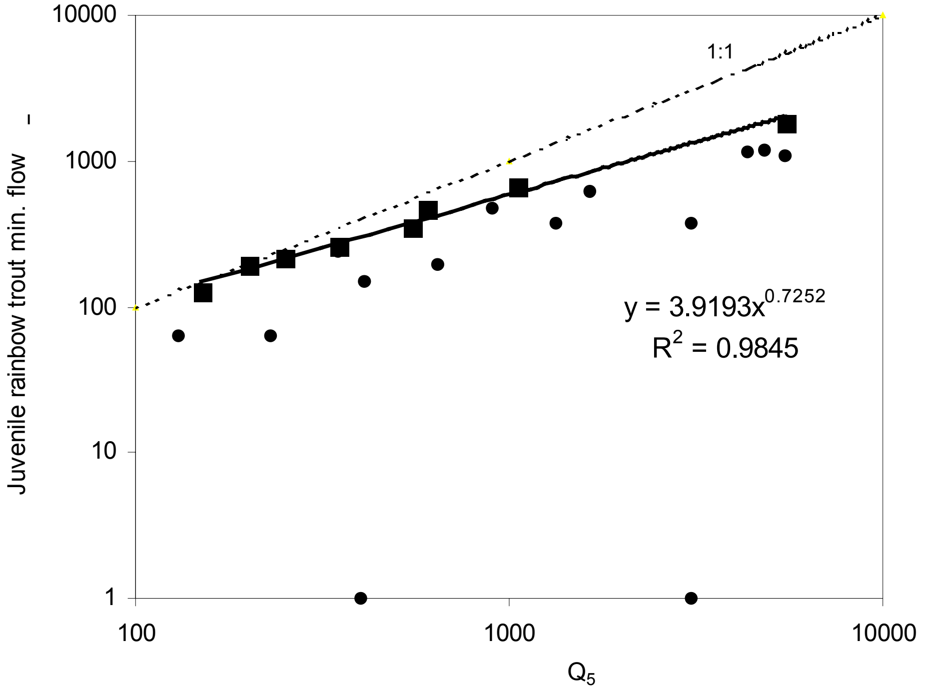

Figure 3.2: Minimum flow requirement for juvenile rainbow trout versus Q_5 for streams in the Tauranga area plotted on a log scale (L/s). The trend line is fitted to square points only (see text). The 1:1 line is as per Figure 3.1 caption.

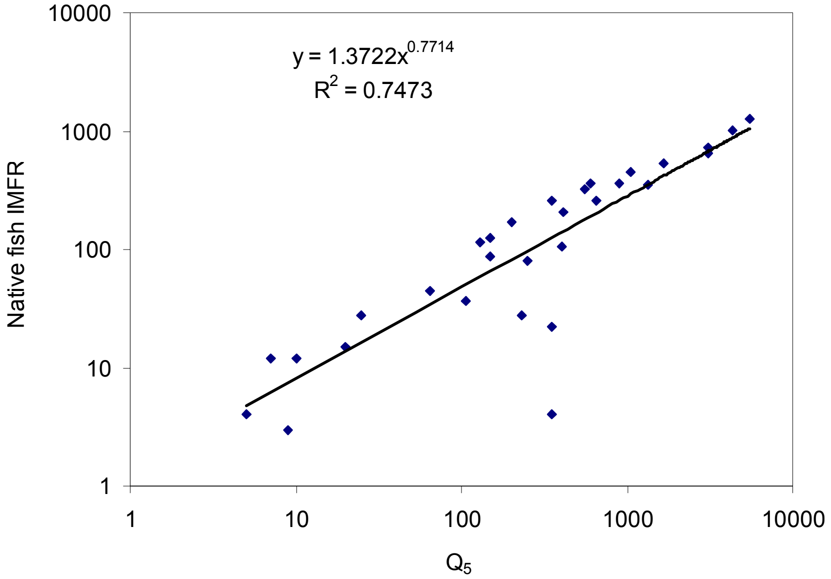

Figure 3.3: IMFR (instream minimum flow requirement) for native fish versus Q_5 for streams in the Tauranga area plotte4d on a log scale (L/s).

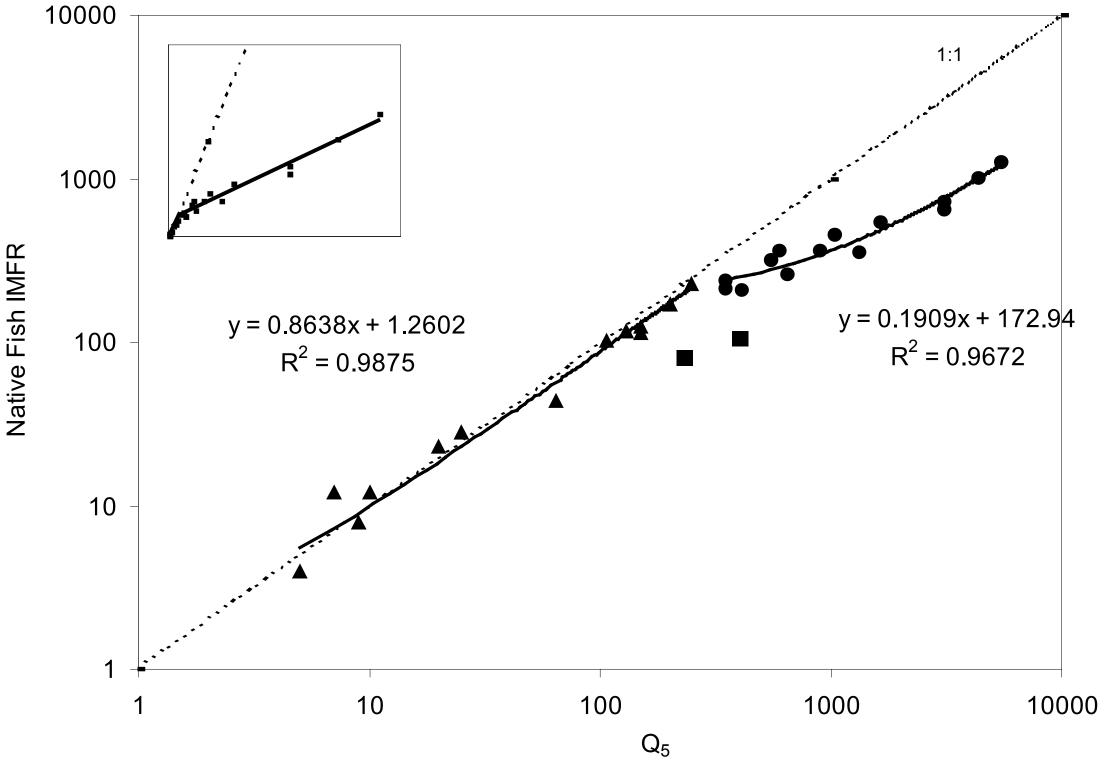

Figure 3.4: IMFR for native fish versus Q5 for streams in the Tauranga area plotted on a log scale (L/s). For this graph, sites were re-modelled assuming good migratory access, with torrentfish and/or common smelt added as per section 3.4.2. Separate trendline fitted for small and large streams. Square points represent outliers not used for trendlines (Ohourere & Wairoa). The 1:1 line is as per Figure 3.1 caption. Inset shows graph on linear scale, for comparison to the log-log scale used.

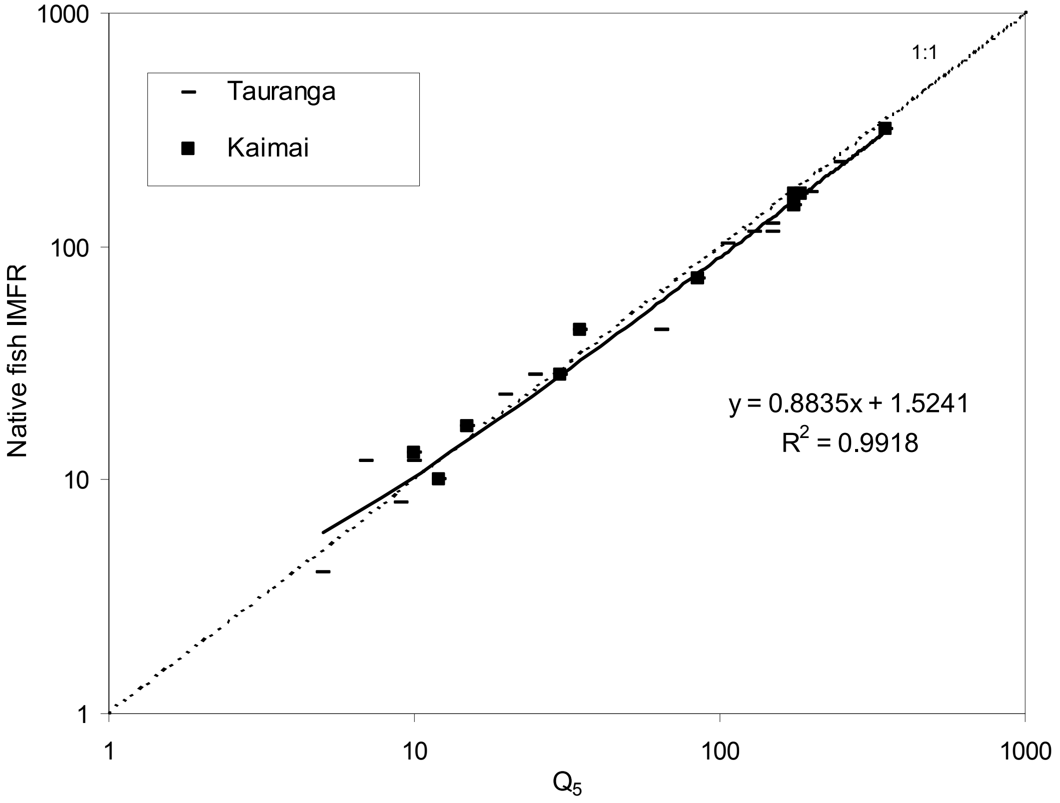

Figure 3.5: IMFR for native fish versus Q_5 (L/s). Small Tauranga streams (represented by triangles in Figure 3.4) are plotted together with results from Kaimai minimum flow assessments (Wilding 2002b). The trendline employs both data sets, and needs to be below the 1:1 line before water is available for abstraction.

The equation for the smaller streams bears close resemblance to the equation for streams of the Kaimai area, (IMFR = $0.893xQ_5$ +3.02, $R^2 = 0.996$, Wilding 2002b). In Figure 3.5 the Kaimai dataset and Tauranga small stream dataset (flow < 250 L/s) are combined, and we can see that, for small streams, native fish of the two different stream types have equivalent flow requirements. Thus the equation produced by the combined datasets can be applied to all Kaimai Streams, and to Tauranga streams with Q_5 flows less than 250 L/s, (note: IMFR's already calculated using the original Kaimai equation will deviate by little from that produced by the new equation, so do not need re-visiting).

The equations recommended for native fish populations are based on streams re-modelled as if migratory access was good. Some streams will tolerate greater flow reductions, as demonstrated by the unmodified IMFR's that sit below the trendline (Figure 3.3). For inland streams the equation may provide a conservative estimate. Should more water be needed for abstraction from inland streams, a fish survey can be undertaken. If the only native species present are low flow species, (e.g., eels, kokopu), then an IFIM investigation may find more water is available for abstraction.

To summarise, 3 equations are recommended for use in the Tauranga area, the application depending on the fish community present;

$\text{IMFR} = (0.8835 \times Q_5) + 1.5241$	Native fish, $Q_5 < 250$ L/s
$\text{IMFR} = (0.1909 \times Q_5) + 172.94$	Native fish, $Q_5 > 250$ L/s
$\text{IMFR} = 1.4483 \times Q_5^{0.9255}$	Adult rainbow rout

A guide for applying the predictive equations is given in Appendix IX.

3.5 Other Issues

3.5.1 Temperature

Reduced flows can increase water temperature potentially stressing aquatic life. The RHYHABSIM programme includes temperature models to predict the effects of reduced flows. Data used in the model included estimates of gradient and altitude from 1:50,000 topographical maps. Shade and wind were modified to calibrate the model at observed maximum and mean water temperatures (based on spot measurements from regional monitoring data and temperatures recorded with flow measurements). Only streams with water available for abstraction (IMFR < Q_5) were assessed because we are investigating whether the maintenance of water temperatures will require greater flows than physical habitat requirements. The temperature midway between the daily mean and maximum was used, following the recommendations of Cox & Rutherford (2000) for comparing predicted temperature with the tolerances of aquatic fauna.

Table 3.3 summarises the predicted change in temperature when flow is reduced from Q_5 to IMFR. The temperature change with abstraction was typically less than 0.5°C. This small increase means most streams remain below 20°C after abstraction, the one exception being the Waitao at 21.5°C.

The tolerances of aquatic biota can be expressed as a preferred temperature, that is temperatures they like, or alternatively as a lethal temperature, the temperature at which they die. Rainbow trout and most native fish in the Tauranga streams have preferred temperatures in the order of 20°C (Appendix 1 in Collier et al. 1995), suggesting they will not be troubled. However, invertebrates such as mayflies have lethal temperature limits of 23°C, and the preferred temperature of common smelt and banded kokopu are 16 to 17°C (Collier et al. 1995). The only stream potentially causing concern is the Waitao. Summer 24-hour temperature measurements would be needed to confirm the situation, but certainly riparian planting would reduce existing thermal stress for stream ecosystems and mitigate any increase in temperature caused by abstraction. For the other streams, temperature does not appear to be a critical issue.

Table 3.3: Predicted temperature increase going from Q_5 flow to the IMFR, for streams where IMFR < Q_5. Recorded temperature is from summer water quality monitoring and/or gauging records. The midpoint between the mean and maximum temperature is presented. Temperatures were modelled at relevant distances downstream (e.g., distance to confluence) using RHYHABSIM.

Stream	IMFR (L/s)	Q_5 (L/s)	Recorded temp. °C	Predicted temp. increase °C	Modelled distance (km)
Whatakao	86	150	18.3	0.17	5
Waipapa Jeffco Trib.	4	5	16.8	0.10	5
Te Puna	116	130	19.6	0.04	2
Te Puna Trib.	2.5	9	16.0	0.03	2
Ohourere	119	230	19.0	0.49	5
Wairoa	288	400	18.7	0.25	10
Kopurereroa	1211	1335	17.0	0.10	10
Omanawa	890	1045	18.3	0.11	5
Joyce	15	20	15.3	0.54	2
Waitao Stream	125	150	21.3	0.28	5
Raparapahoe No. 4 Rd	483	550	16.2	0.23	10
Raparapahoe No. 3 Rd	231	250	16.5	0.05	5
Ohineangaanga	171	200	18.9	0.14	10
Mangorewa	4326	5450	15.9	0.12	2
Pongakawa	3051	4350	17.3	0.16	10

3.5.2 Ammonia

Ammonia levels are well below the ANZECC (2000) threshold of 0.9 g/m^3 (total ammonia-N) for most of the sites where monitoring takes place (8 streams monitored, one-off isolated high readings were ignored). However, concentrations are periodically elevated in the Waitao and Kopurereroa Streams (Table 3.4). Ammonia is potentially toxic to aquatic life, so I investigated the effect of water abstraction on ammonia concentrations. To do this the mass flow in the stream was calculated, then the dilution afforded by the IMFR. This assumes the ammonia discharge is downstream of the point where water is abstracted. In the first instance we look at a worst-case scenario, using the highest recorded ammoniacal nitrogen concentration and assume the river was at median flow when sampled. For the Kopurereroa Stream, the predicted ammoniacal nitrogen concentration at the IMFR is 0.65 g/m^3. This is below the ANZECC threshold of 0.9 g/m^3, and so does not indicate ammonia will be a critical factor. (Note: ammoniacal nitrogen concentrations in the Kopurereroa have reduced from an average of 0.25 g/m^3 in 1991, to 0.09g/m^3 in 2001, after improved leachate treatment from the refuse tip.)

Applying the same calculation to the Waitao Stream produces a predicted ammoniacal nitrogen concentration of 1.12 g/m^3 at the IMFR, which exceeds the ANZECC threshold of 0.9 g/m^3. This is a worst-case scenario and, as the median flow was used to calculate the mass flow, it also predicts the natural Q_5 flow will have concentrations in excess of the ANZECC threshold. If instead of using the maximum ammoniacal nitrogen concentration, we work with the 95-percentile estimate, the predicted concentration at the IMFR is well below the threshold (0.438 g/m^3). While more detailed analysis is needed to quantify the level of risk posed to aquatic ecosystems, a reduction in flow can only increase the risk. One option would be to require abstractors to reduce potential ammonia sources from their properties.

Table 3.4: Ammoniacal nitrogen (NH_4-N g/m^3) statistics for the Kopurereroa and Waitao Streams, from Environment Bay of Plenty monitoring data. Kopurereroa results based on monthly monitoring, July 1990 to June 1991 & July 2001 to June 2002; Waitao quarterly monitoring 1990 to 1999.

	Median	Min.	Max.
Kopurereroa at SH2	0.137	0.044	0.454
Waitao	0.036	0.016	0.330

3.5.3 Oxygen

Maintaining adequate oxygen concentrations is necessary to support aquatic life. If oxygen concentrations fluctuate, (e.g., due to organic loading or heavy macrophyte growth), then it is possible a reduction in flow will exacerbate the problem. Dissolved oxygen data were analysed, where available, for surveyed rivers. Oxygen levels were found to be at their lowest during the January to March period, so this is the period in focus. With concentrations over 9 g/m^3, most sites are approaching saturation and are therefore not expected to present problems for aquatic life, (Table 3.5). The Waipapa River at State Highway 2 and the lower Waitao Stream do reach lower oxygen concentrations, (minimum recorded 7.8 g/m^3 and 8 g/m^3 respectively). These two sites are in the lower tidal reaches where slack water velocities may allow oxygen concentrations to drop below that more typical of the non-tidal reaches upstream. Oxygen concentrations are therefore not expected to be a critical issue for setting minimum flows in the Tauranga area.

Table 3.5: Average dissolved oxygen concentrations for the months of January, February and March, when they are typically lowest. N is the number of measurements taken. Sourced from Environment Bay of Plenty monitoring data.

		DO (g/m^3)	N
Kopurererua	S.H 2 bridge	9.3	6
	S.H 29 Bridge	10.2	12
Omanawa	S.H 29 Bridge	9.9	20
Pongakawa	S.H 2 bridge	9.5	18
Waipapa	Old Highway	9.8	7
	Goodals Rd	10.1	3
	S.H. 2	8.7	8
Wairoa	S.H. 29	9.6	7
	d/s of Ruahihi	9.6	14
	S.H. 2 bridge	9.8	4
Waitao	Welcome Bay Rd	8.7	8

4. Discussion

Minimum flows were successfully calculated for 17 of the 25 reaches in the Tauranga area. Generalisation of these results for native fish and adult rainbow trout provided equations for predicting the flow requirements of other reaches in the area. The close relationship between IMFR and Q_5 highlight the consistency of results from this and other studies, which allows confident application to flow management.

Because fish communities vary across the Tauranga area, implementing the predictive equations produced by this study will not be as straight forward compared to previous studies (Haumea, Kaimai). Where trout fisheries are present, minimum flows will need to be calculated using a different equation to that used for native fish. A guide for applying the predictive equations is provided in Appendix IX.

Small streams were found to have a smaller proportion of flow available for abstraction compared to large streams. This is consistent with previous studies (Jowett 1993a, 1993b; Hatfield & Bruce 2000). The smaller the stream the greater the reduction in habitat per unit of water abstracted. This effect was most pronounced for native fish, with a marked inflexion at 250 L/s (Q_5). This inflexion does not appear to be a product of the method used for deriving minimum flows. The shift from using MALF as the primary flow[2] to using optimum habitat occurred at higher flows and was more gradual (between Q_5 flows of 550 and 1335 L/s). It seems more likely that the inflexion reflects the shape of the habitat-flow response curves.

The region was broken down into areas of similar stream habitat (ecoregions) to better the predictive analysis. The results from the Kaimai study (Wilding 2002b) were similar to the results here for native fish of small streams (Q_5 less than 250 L/s). Within these confines a single equation can now be applied to both areas and this will simplify subsequent allocation decisions. What are the implications for future minimum flow work in the Bay of Plenty? The next minimum flow investigation covers the Rotorua area. Due to restricted migratory access, native fish populations in that area are limited, so the equation is not expected to be relevant. However, there are other areas in the Bay of Plenty region where the equation is more likely to be applicable, (e.g., small coastal streams of Whakatane to Cape Runaway). IFIM assessments will still be required to validate the equation for such areas, but fewer reaches may be needed to do so.

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[2] Primary flow is the point to which the protection level is applied, (see Appendix I).

The issue of protection levels and instream management objectives is discussed in Appendix I and does not bear repeating here. However it is worth mentioning that where trout populations are not fished a lower protection level is required. If this applies to any sites used in this study, the IMFR may need to be adjusted accordingly (typically providing for native fish instead).

In addition to assessing the habitat requirements, the potential for reduced flows to affect water quality requirements was assessed. Temperature and oxygen were rarely found to be critical issues. The high groundwater recharge for streams in the area appears to maintain reasonable temperatures for fish; exceptions being the Waitao Stream, as discussed in section 3.5. There were few streams where ammonia was an issue; the Waitao again being a possible exception. The high flow requirements for small streams also limits the potential for other issues to become critical in setting a minimum flow.

For 8 of the 25 sites surveyed, minimum flows could not be calculated because natural flow estimates were not available. Two sites have large abstractions, hence reliable estimates of natural flow statistics could not be made at this stage (Wairoa, Waipapa at Waipapa Block Road). Estimating flow statistics for the other 6 sites was complicated by limited data and poor inter-catchment flow correlations. This is often the case for volcanic plateau streams; a likely product of complex groundwater processes and unstable substrates. Analysis and reporting for these 8 sites will occur when estimates of Q_5, etc. become available. The IFIM data have been processed ready to calculate IMFRs. In fact data from these streams have already been used in the predictive analysis. So the only reporting required for these reaches will be of the individual IMFR statistics.

5. Acknowledgements

At Environment Bay of Plenty, Craig Putt and Mark Stringfellow organised field surveys. Fieldwork and data entry was also undertaken by Wayne Secker, Wiki Mooney, Mike Seabourne, Rose Woods, Glenn Ellery and Shane Iremonger. Habitat modelling and IMFR calculation was undertaken by Dr Bente Clausen (Consultant) who also peer reviewed the report.

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7. Appendices

Appendix I	**Instream Management Objectives for Bay of Plenty streams and methods for setting minimum flows**
Appendix II	**Site Photos**
Appendix III	**RHYHABSIM Field Methods Summary**
Appendix IV	**Habitat survey and calibration dates**
Appendix V	**Selected rating curve calculation methods**
Appendix VI	**Modifications to Reach Calibration Data**
Appendix VII	**Habitat-Flow Response Curves**
Appendix VIII	**Flow estimation for the predictive analysis**
Appendix IX	**Guide for determining IMFR's for streams of the Tauranga and Kaimai Area**

Appendix I: Instream Management Objectives for Bay of Plenty streams and methods for setting minimum flows

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, 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 were two people working with the same data can produce two different figures. The aim therefore is to establish an objective approach for deriving minimum flows from RHYHABSIM habitat modelling. Not only will this enable a consistent environmental outcome in setting minimum flows throughout the project but also provide external consultants with guidance for interpreting such data to the satisfaction of Environment B·O·P.

2. Objectives and Options

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

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

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

    b) Maintain identified significant values of rivers and streams.

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

    d) Avoid or mitigate adverse effects on downstream environments.

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

Features of a good instream management objective include:

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

Options for instream management objectives include:

1. Habitat remains unchanged.
2. Allow a percent reduction in habitat.
3. Allow change based on individual reach assessment, i.e., leaving it open to interpretation.

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

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

3. Recommended Approach

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

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

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

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

The minimum flow is based on the species with the highest flow requirements. An alternative approach offered by Jowett & Richardson (1994) for native fish communities, is to set minimum flows at that preferred by fish with intermediate flow requirements (redfin bully or common bully), rather than fast water species (torrentfish, bluegill bullies). While offering a compromise, Jowett & Richardson’s approach will in some cases allow large reductions in habitat for fast water species, and this does not ensure adequate protection for the existing aquatic community. The tendency for fast water species to prefer the equivalent of flood flows is circumvented here by not allowing the primary flow to exceed the median flow.

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

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

4. Other Considerations

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

5. Significance criteria and allowable habitat reductions

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

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

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

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

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

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

Table 1: Significance criteria and protection levels.

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

6. Worked Example

A change in available habitat, be it up or down, is largely unavoidable if we want to make any water available for abstraction (see Figure 1). So where possible we want to optimise habitat available in the stream. For the Tahawai Stream, optimum habitat occurs at approximately 13 L/sec for banded kokopu (Figure 1). In some cases it is

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[3] Molloy & Davis, 1994.

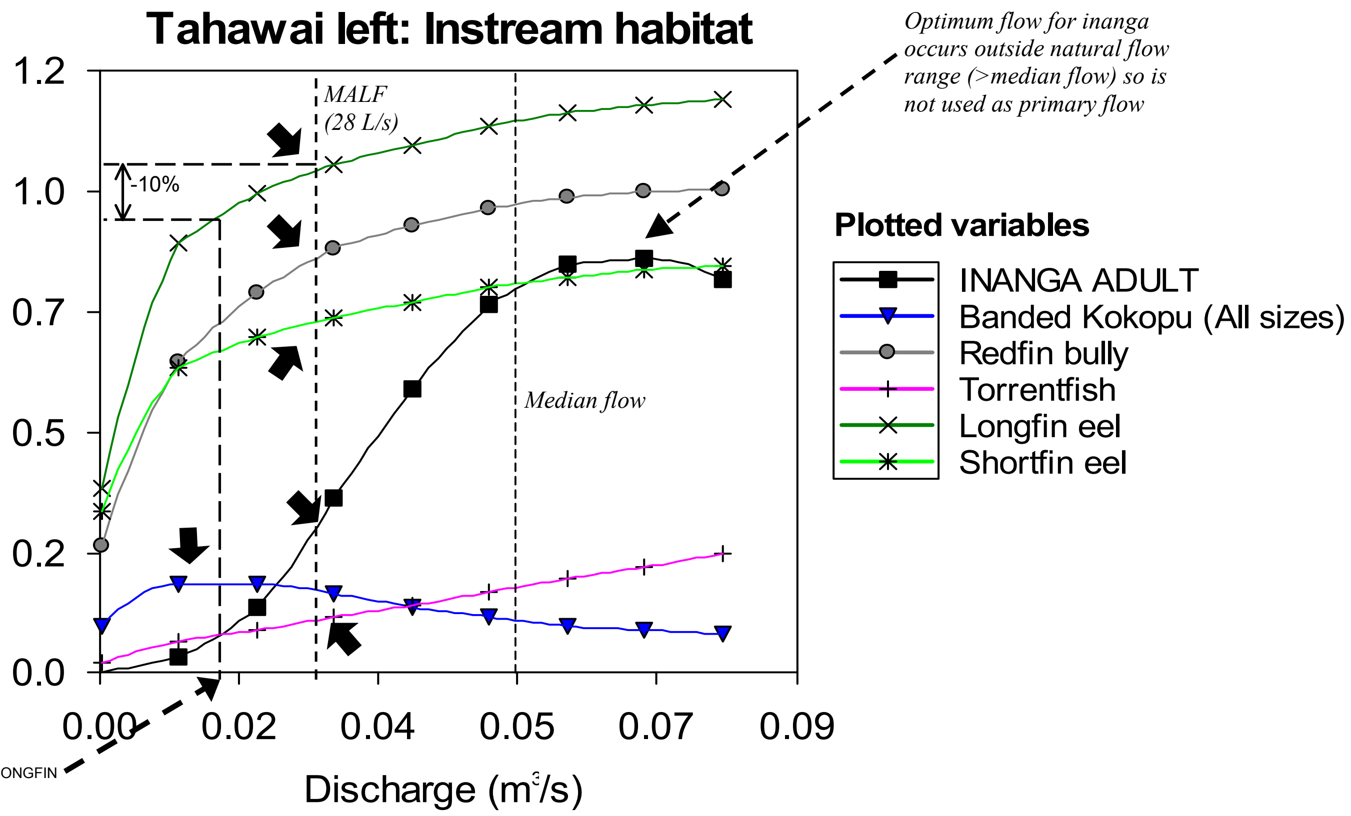
[4] Dwarf galaxias is classed as regionally threatened. The only records of this species in the Bay of Plenty are from a few streams on the Galatea Plains (an area of high abstraction pressure). These records, until recently represented the northern limit of the species.

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). Note that reducing the minimum flow for shortfin eel from 14 L/s, down to the point of inflexion at 11 L/s, would make no difference to the IMFR, which is based on inanga for this stream.

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

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



Optimum flow for inanga occurs outside natural flow range (>median flow) so is not used as primary flow

MIN. FLOW FOR LONGFIN = 14 L/S

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.

Appendix II: Site Photos

Plate 1: Whatakao Stream at Walford Road.

Plate 2: Waipapa Stream at Waipapa Block Road.

Plate 3: Waipapa Tributary at Plummer Road.

Plate 4: Waipapa Tributary at Jeffco Farm.

Plate 5: Mangawhai Stream at State Highway 2.

Plate 6: Te Puna Stream at rapids.

Plate 7: Te Puna Tributary at Arondale Farm.

Plate 8: Oturu Stream at Paparoa Road.

Plate 9: Ohourere Stream at municipal water take (Crawford Road).

Plate 10: Wairoa River at State Highway 29.

Plate 11: Kopurereroa Stream at State Highway 29.

Plate 12: Omanawa Stream at Lawry Road.

Plate 13: Omanawa Stream at Lawry Road viewed from top of gully.

Plate 14: Joyce Stream at deer farm (upstream of Joyce Road).

Plate 15: Waitao Stream at Waitao Road. *Photo unavailable*

Plate 16: Raparapahoe Stream at Number 4 Road.

Plate 17: Raparapahoe Stream downstream of Number 3 Road.

Plate 18: Ohineangaanga Stream at Whitehead Road.

Plate 19: Mangorewa Stream upstream of the Kaituna confluence. Drift dive team at top of reach.

Plate 20: Parawhenuamea Tributary at Bart Orchard (Craig Putt).

Plate 21: Puanene Stream at Old Coach Road.

Plate 22: Pokopoko Stream Old Coach Road.

Plate 23: Waiari Tributary at Mystery Valley Road.

Plate 24: Wharere Stream at Old Coach Road.

Plate 25: Pongakawa Stream at Old Coach Road (photo looks upstream while site runs downstream of bridge).

Plate 26: Pikowai Stream at Pikowai Road.

Appendix III — RHYHABSIM Field Methods Summary

- Choose reach typical of stream section you wish to generalise to.

- Undertake during low flows.

- Establish the habitat types present (e.g., pool/riffle/run). These will need to be represented by cross-sections.

- Measure length of stream occupied by each habitat type (habitat mapping). This is done using hip chain with lengths of each habitat type recorded.

- Choose cross-sections randomly, or start by choosing a cross-section in rare habitat and place others adjacent. Need 5 or more cross-sections for each habitat type.

- String measuring tape across stream (taught) at right angle to flow.

- True left or right bank can be set as zero, but it is better to be consistent throughout reach (i.e., start from the same bank and set tape up so off-set increases across cross-section).

- Take 10-20 spot measurements across stream (divide width by the number of points and round down).

- Additional measurements are taken at abrupt changes in depth and velocity.

- At each point measure depth, velocity, and substrate. Velocity at 0.6 if <1m deep, otherwise 0.2 & 0.8. 20 second counts. Take special care estimating low velocities. It is important to distinguish low velocities from zero velocities. Substrate assessed visually using categories below. Area assessed for substrate dependent on spacing but shouldn't exceed 0.5 m either side of measurement point or 1m up or downstream. Always note obstructions upstream for adjustment of VDF's, especially at edges and above water level.

- Substrate categories: vegetation; bedrock; boulder (>264mm); cobble (64-264mm); large gravel (8-64mm); fine gravel (2-8mm); sand; silt.

- Take measurements above water level as far as you wish to generalise (0.3-0.5m vertical distance) and be sure to include actual waters edge as a point (EWE not important). This means you must have a 0.0 water depth for both banks and on both sides of any protruding boulders.

- Use taught level tape to measure bank height above water level (negative depth). Continue substrate assessments above water level.

- Install temporary staff gauge in low turbulence part of cross-section, preferably in 10-20 cm deep water (you can hammer in until level with water surface at first visit => stage=0 mm). Record water level with units (mm easiest) and state whether this is above or below the top of the gauge peg (e.g., “12 mm below peg”). Don’t use +ve and –ve terminology for stage or SZF.

- If there is a possibility of gauge moving, level (survey) relative to two benchmarks (pegs) on bank (above flood flow). (Remember floods may alter stage-flow rating anyway.)

- If flow changes during gaugings, the stage at one site should be recorded about the time of each new cross-section.

- Measure stage at zero flow (SZF) for pools and most runs. SZF is the water level at which flow stops. It is determined by downstream low point (the highest point on the thalweg downstream of the cross-section). If there is a downstream riffle-head the SFZ is deepest point of riffle-head. Measure deepest part of downstream riffle-head subtracted from water level at temporary gauge. Record SZF with units (e.g., mm) and show calculations for converting measured thalweg depth to SZF (RL).

- Two calibration surveys are undertaken upon return visits, with flow measured at a ‘good’ gauging site and the water level also recorded for every cross-section (e.g., “12mm below peg”). The ‘good’ gauging site is to be gauged to EDS standards for flow measurement on all three occasions (including initial survey). The 1st calibration survey should be done within 2 weeks to guarantee useful data before stream character changes (e.g., flood disturbance, periphyton growth). To ensure an accurate rating curve we need measurements at a range of flows, so the next calibration survey can be undertaken later when flow has changed.

Appendix IV – Habitat survey and gauging dates

	Stream	Reach	Cross-section survey	Gauging #1	Gauging #2	Gauging #3	Gauging #4	Gauging #5	Gauging #6	Gauging #7
1	Whatakao		23-01-02	30-01-02	04-02-02	18-02-02	08-03-02	27-03-02	16-04-02	
2	Waipapa	Waipapa Block Road	14-01-02	29-01-02	04-02-02	27-02-02	08-03-02	15-04-02		
3	Waipapa Tributary	Plummer Road	14-01-02	29-01-02	04-02-02	27-02-02	08-03-02	27-03-02	15-04-02	
4	Waipapa Trib.	Jeffco Farm	14-01-02	29-01-02	04-02-02	11-02-02	08-03-02	28-03-02		
5	Mangawhai		16-01-02	08-02-02	18-02-02	27-02-02				
6	Te Puna	Rapids	15-01-02	30-01-02	04-02-02	08-02-02	01-03-02	27-03-02	15-04-02	
7	Te Puna Trib.	Arondale Farm	16-01-02	30-01-02	01-03-02	27-03-02	04-04-02	15-04-02		
8	Oturu		24-01-02	30-01-02	04-02-02	08-02-02	01-03-02	08-03-02	27-03-02	15-04-02
9	Ohourere		17-01-02	04-02-02	08-03-02	23-04-02				
10	Wairoa		24-01-02	05-02-02	28-02-02	20-03-02				
11	Kopurereroa		25-01-02	28-02-02	26-03-02	19-08-02				
12	Omanawa		14-12-01	29-01-02	28-02-02	20-03-02	22-04-02	17-05-02	27-08-02	
13	Joyce		05-02-02	18-02-02	11-04-02	27-08-02				
14	Waitao		08-01-02	25-01-02	27-02-02	25-03-02	18-04-02			
15	Raparapahoe	No. 4 Road	18-01-02	12-12-01	08-02-02	27-02-02	20-05-02			
16	Raparapahoe	No. 3 Road	09-01-02	12-12-01	08-02-02	27-02-02	20-05-02			
17	Ohineangaanga		17-01-02	17-12-01	08-02-02	25-03-02				
19	Mangorewa		31-01-02	25-02-02	08-03-02	09-05-02	28-05-02			
24	Pongakawa		19-02-02	01-03-02	08-03-02	12-04-02				

Appendix V – Selected rating curve calculation methods

	Stream	Reach	Rating Curve
1	Whatakao		Fitted SZF for all except CS 14 where Best SZF used
3	Waipapa Trib.	Plummer Rd	Fitted SZF
4	Waipapa Trib.	Jeffco Farm	Fitted SZF
5	Mangawhai		Fitted SZF
6	Te Puna	Rapids	Fitted SZF
7	Te Puna Trib.	Arondale Farm	Mannings for 7, 8, 9, 14. Best SZF for 12. Fitted SZF for remainder.
8	Oturu		Mannings
9	Ohourere		Fitted SZF
10	Wairoa		Fitted SZF
11	Kopurereroa		Fitted SZF
12	Omanawa		Mannings for 4, 11, 12. Fitted SZF for remainder.
13	Joyce		Fitted SZF
14	Waitao		Fitted SZF for all except CS2 where Best SZF used
15	Raparapahoe	No. 4 Rd	Fitted SZF
16	Raparapahoe	No. 3 Rd	Fitted SZF
17	Ohineangaanga		Fitted SZF
19	Mangorewa		Fitted SZF
24	Pongakawa		Fitted SZF

Appendix VI - Modifications to Reach Calibration Data

Whatakao

CS3	SZF created 0.7m below water level
CS6	SZF created 0.7m below water level

Waipapa Waipapa Block Road

Waipapa Tributary Plummer Road

none

Waipapa Tributary Jeffco Farm

CS1	reduced SZF from –0.510 m to –0.600 m
CS6	water level changed from –0.510 m to –0.600 m
CS9	water level at the calibration flow changed from –0.38m to –0.43m rating exponent changed to 2.0
CS14	exponent changed to 2.0

Mangawhai

CS2	SZF created –0.40 m
CS5	increased water levels for three follow-up gaugings by 30 mm
CS7	increased water levels for three follow-up gaugings by 60 mm created SZF –0.40 m.
CS8	created SZF of –0.40 m changed exponent to 2.0
CS11	created SZF of –0.50 m.

Te Puna Rapids

None

Te Puna Trib Arondale Farm

CS5	changed exponent from 5.76 to 4.5
CS6	changed SZF from –0.422 mm to –0.360 mm
CS7	changed exponent to 0.28

Oturu

None

Ohourere

CS3	created SZF of –0.7 m.
CS4	created SZF of –1.0 m.
CS5	created SZF of –0.9 m
CS6	changed SZF from –0.570 m to –0.7 m
CS10	changed water level at calibration flow from –0.458 m to –0.48
CS12	created SZF of –1.5 m
CS13	changed SZF from –0.994 m to –0.5 m.

Wairoa

CS1	created SZF of -0.338 m
CS2	created SZF of -0.70 m
CS4	created SZF of -1.0 m
CS5	created SZF of -1.0 m
CS6	created SZF of -2.0 m
CS7	created SZF of -0.70 m
CS9	created SZF of -0.80 m
CS11	created SZF of -1.0 m

Kopurereroa

None

Omanawa

CS1	changed water level at calibration flow from –0.465 m to –0.57 m Changed water level for 1.134 m^3/s gauging from –0.708m to –0.608m
CS2	changed water level at calibration flow from –0.115 m to –0.215 m
CS6	deleted one gauging (flow 1.263 m^3/s, level –0.256m)
CS7	changed water level at calibration flow from –0.21 m to –0.24 m
CS11	deleted gauging 1.318 m^3/s
CS12	deleted gauging 1.134 m^3/s changed water level at calibration flow from –0.24 m to –0.18 m

Joyce

Two models run, one with exponent set to 2 for all cross sections, and the second with the exponent set to 3.

Waitao Stream

CS10	exponent increased to 1.5
CS12	exponent increased to 1.5

Raparapahoe No. 4 Road

CS6	changed water level at calibration flow from –0.685 to –0.65

Raparapahoe No. 3 Road

CS6	changed water level at calibration flow from –0.675 m to –0.800 m
CS7	changed water level at calibration flow from –0.965 m to –0.930 m
CS8	changed SZF from –0692 m to –0.900 m
CS11	changed water level at calibration flow from –0.497 m to –0.480 m changed SZF to –0.783 m
CS14	changed SZF from –0.860 m to –1.060 m
CS15	changed water level at calibration flow from –0.534 m to –1.03 m changed SZF from –1.265 m to –1.400 m

Ohineangaanga

CS1	changed water level at calibration flow from -0.005 m to -0.050 m
CS2	changed water level at calibration flow from 0.009 m to -0.040 m
CS3	changed water level at calibration flow from 0.005 m to -0.040 m
CS4	changed water level at calibration flow from -0.029 m to -0.060 m
CS5	changed water level at calibration flow from -0.037 m to -0.060 m

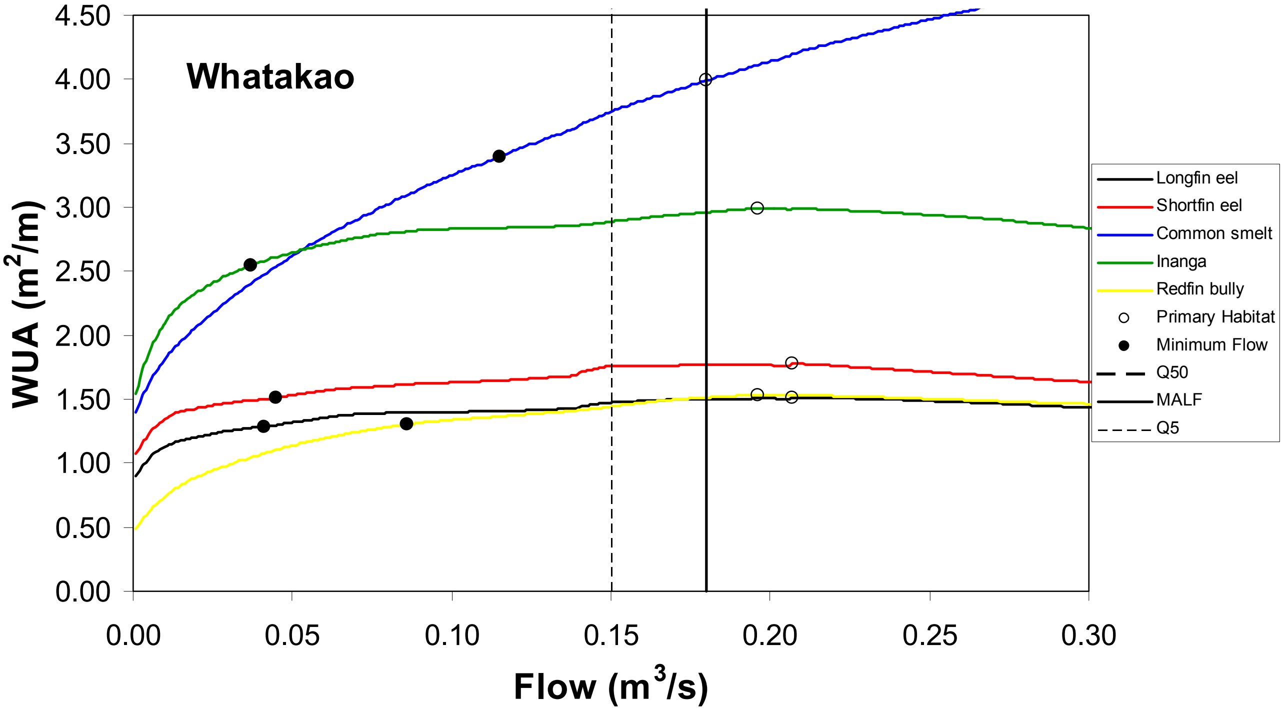
Mangorewa

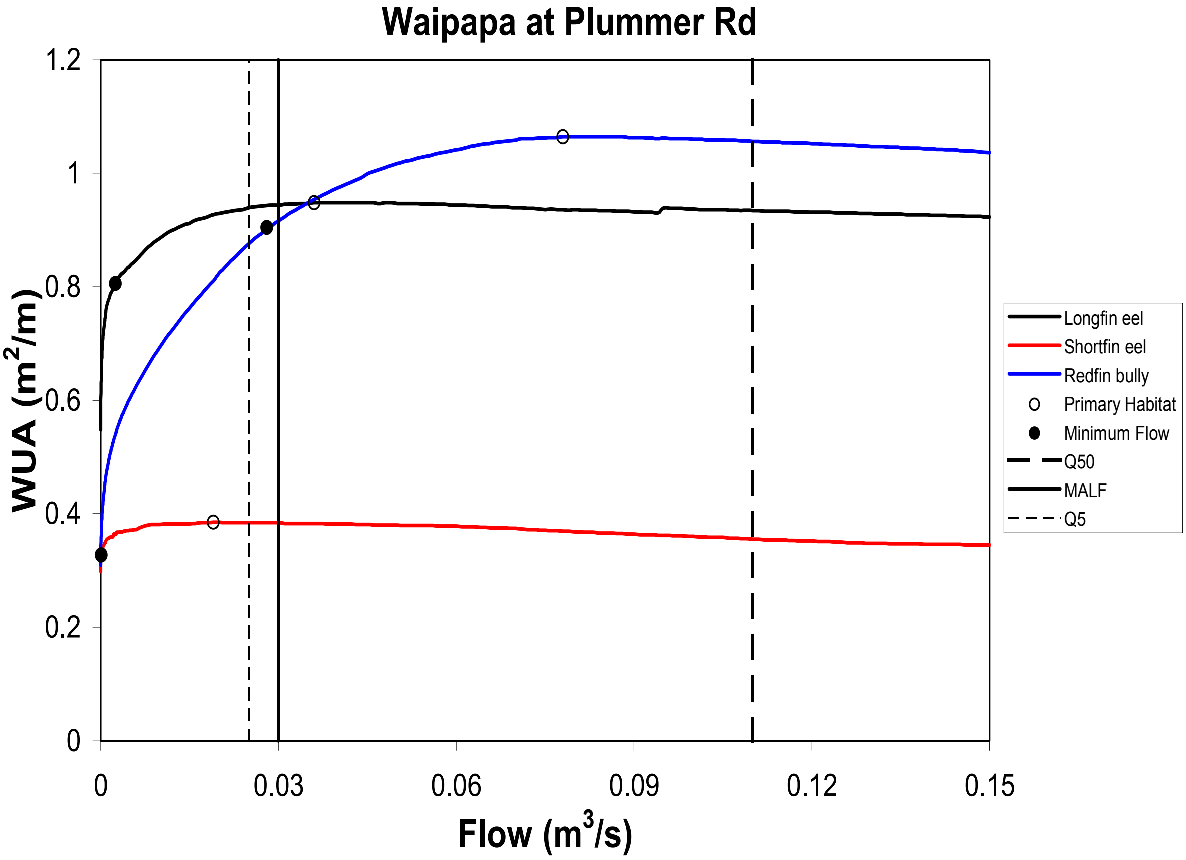
Two models run, one with exponent set to 2 for all cross sections, and the second with the exponent set to 3.

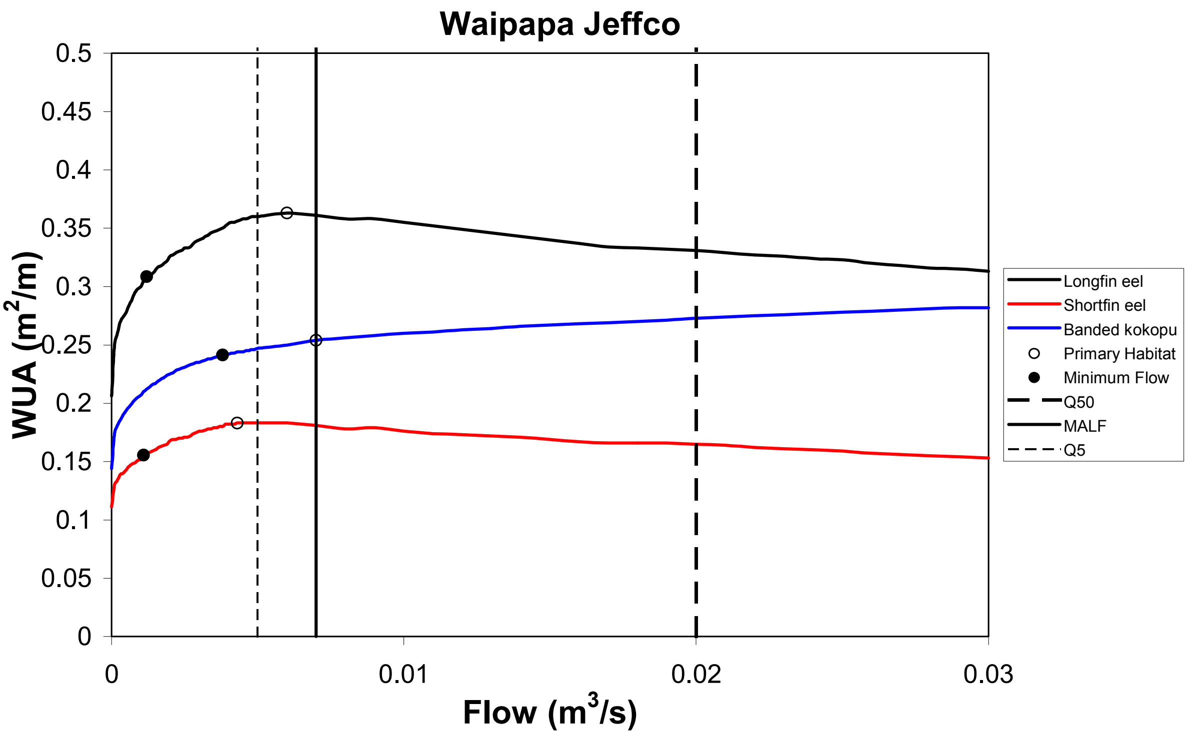
Pongakawa

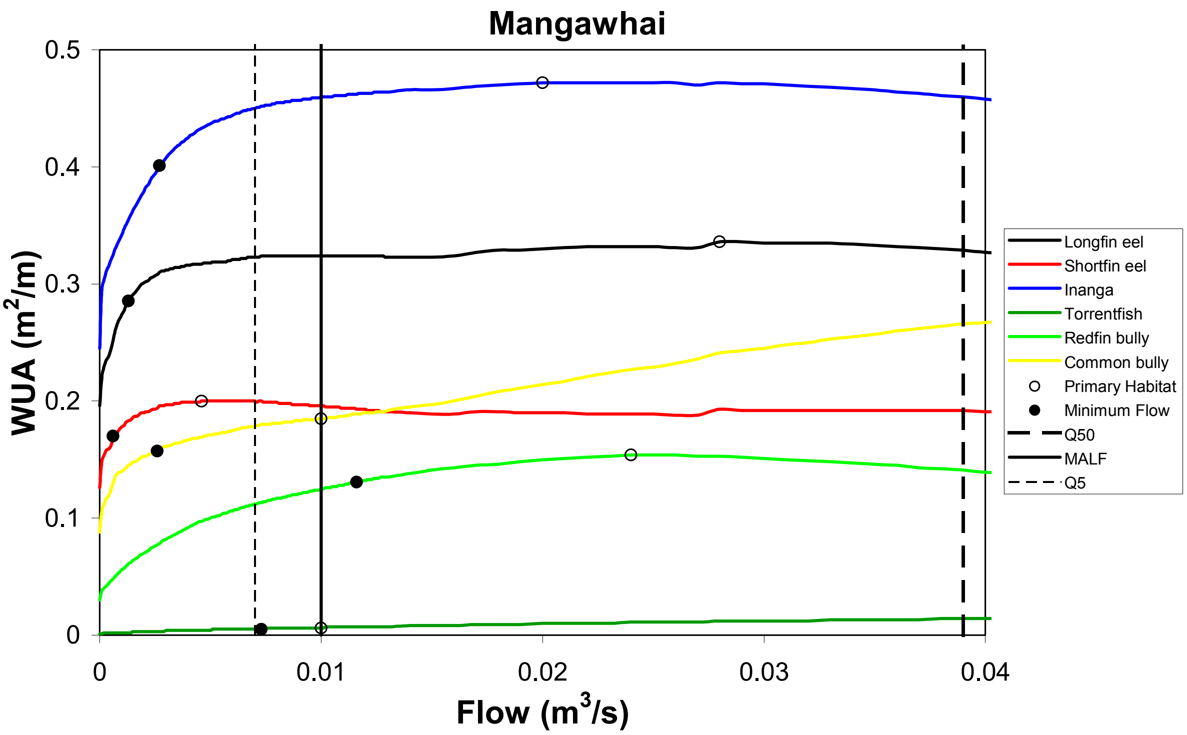
Changed exponent to 2 for all cross-sections, except those already close to it (within 0.15 units of 2).

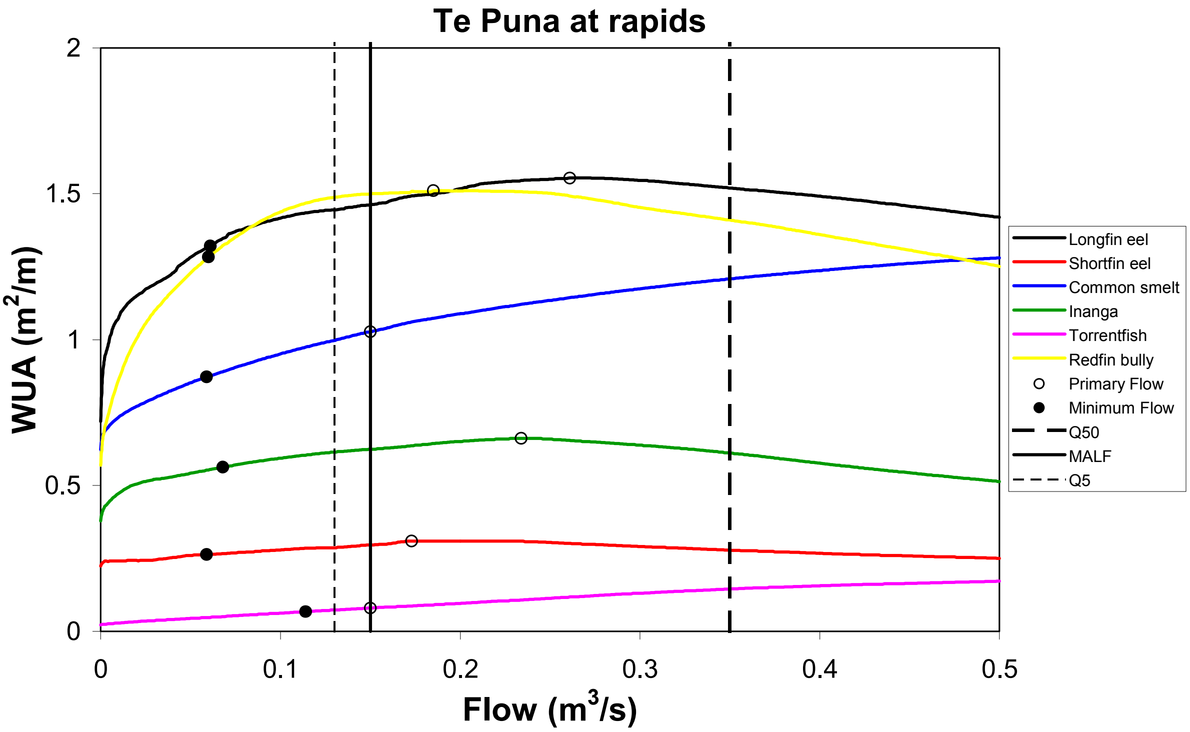
Appendix VII – Habitat-flow Response Curves

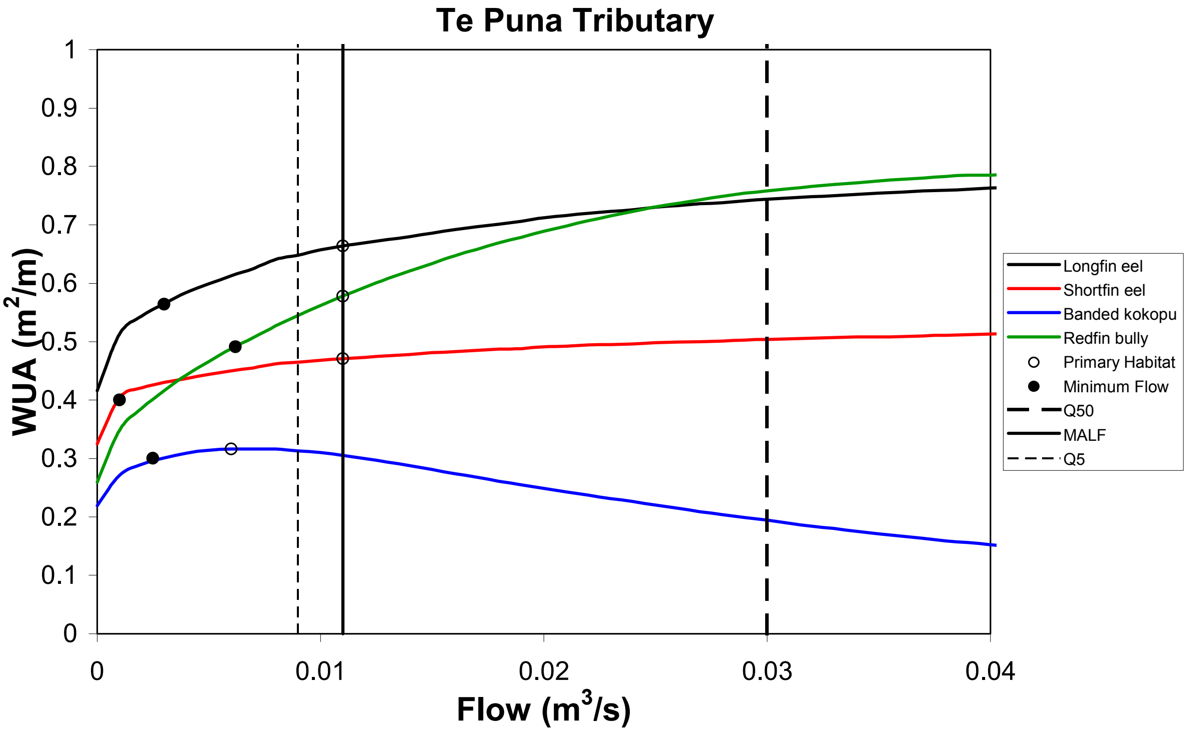


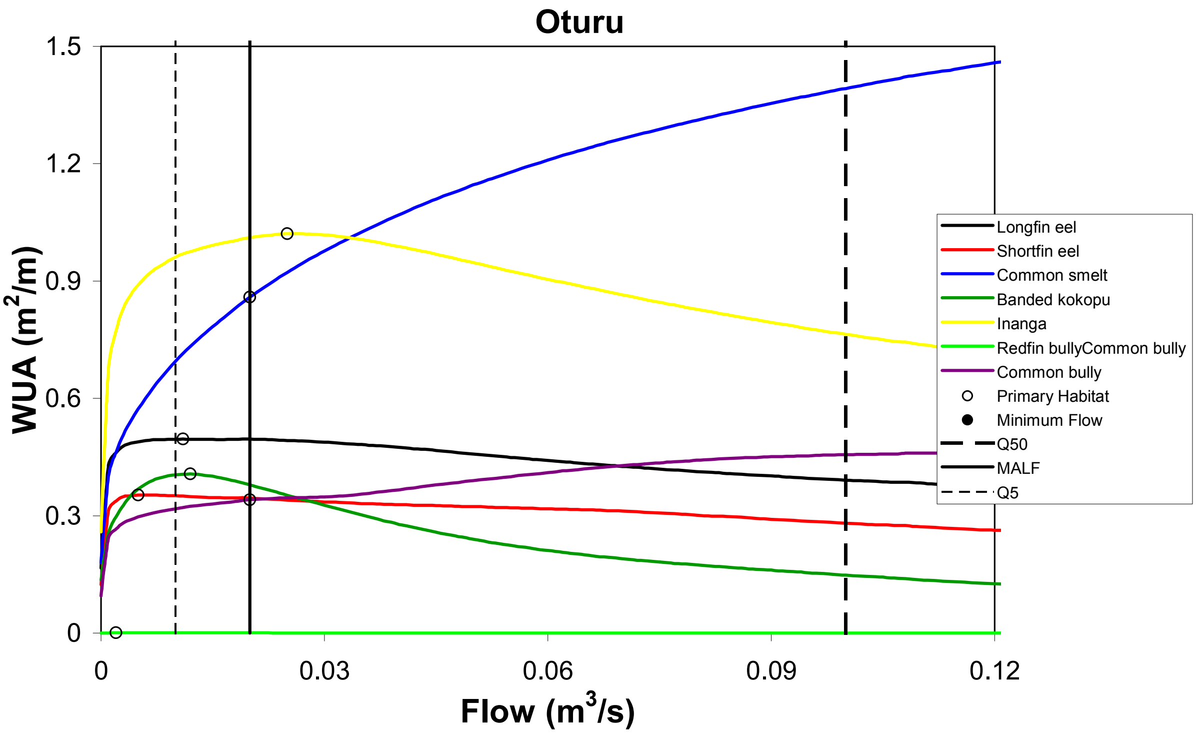


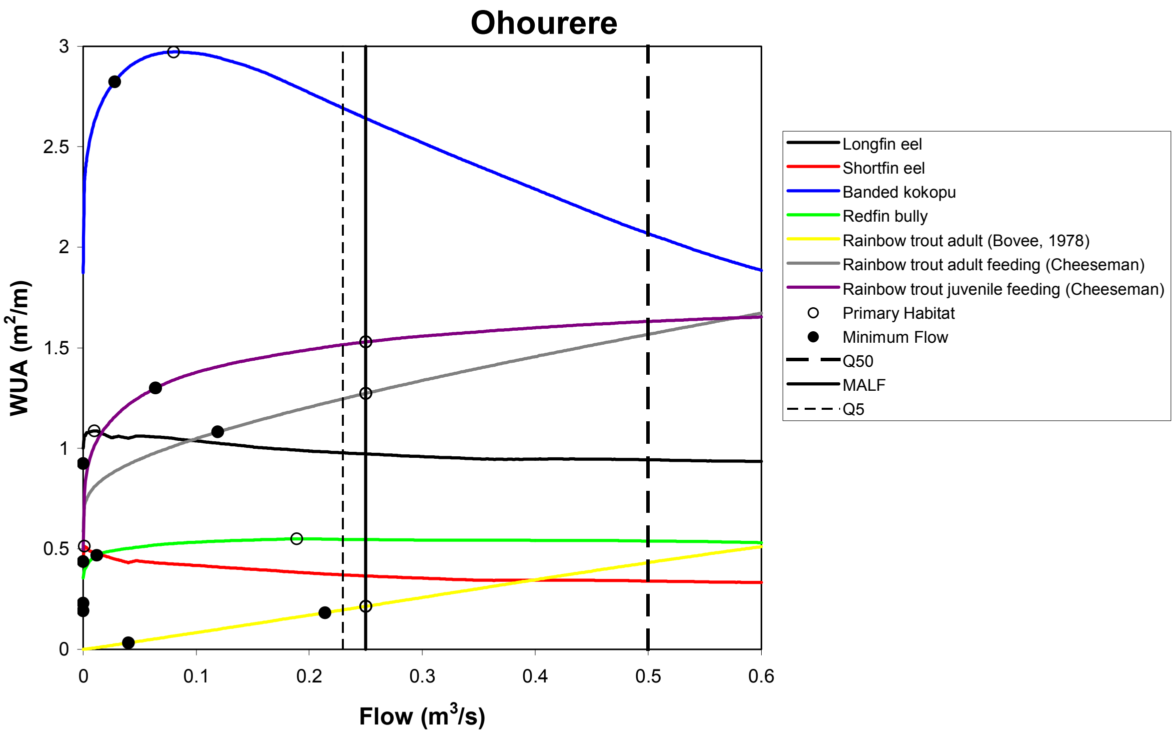

Waipapa Jeffco
WUA (m²/m)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.01
0.02
0.03
Flow (m³/s)
Longfin eel
Shortfin eel
Banded kokopu
Primary Habitat
Minimum Flow
Q50
MALF
Q5

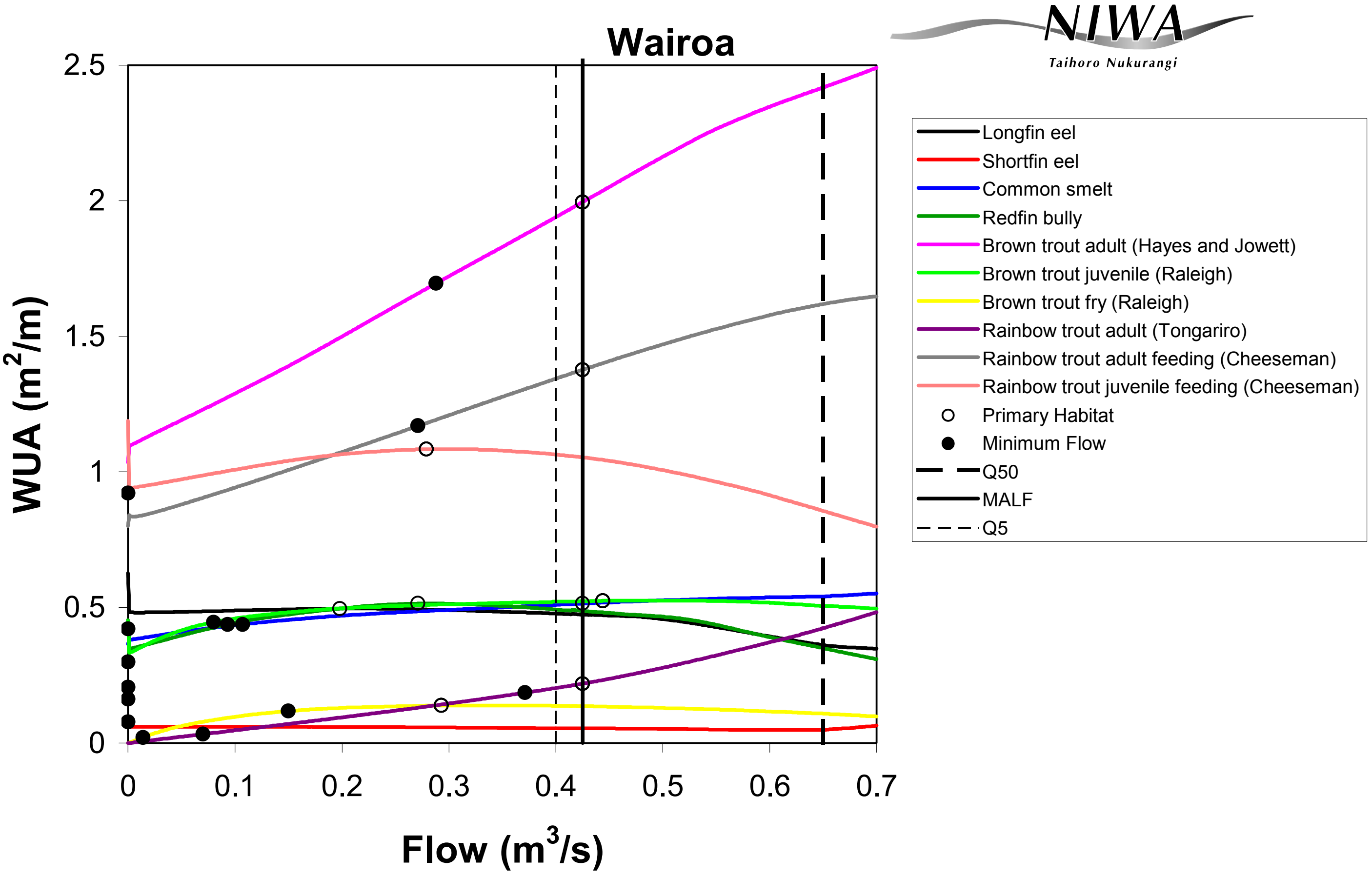

Mangawhai
WUA (m²/m)
0.5
0.4
0.3
0.2
0.1
0
0
0.01
0.02
0.03
0.04
Flow (m³/s)
Longfin eel
Shortfin eel
Inanga
Torrentfish
Redfin bully
Common bully
Primary Habitat
Minimum Flow
Q50
MALF
Q5

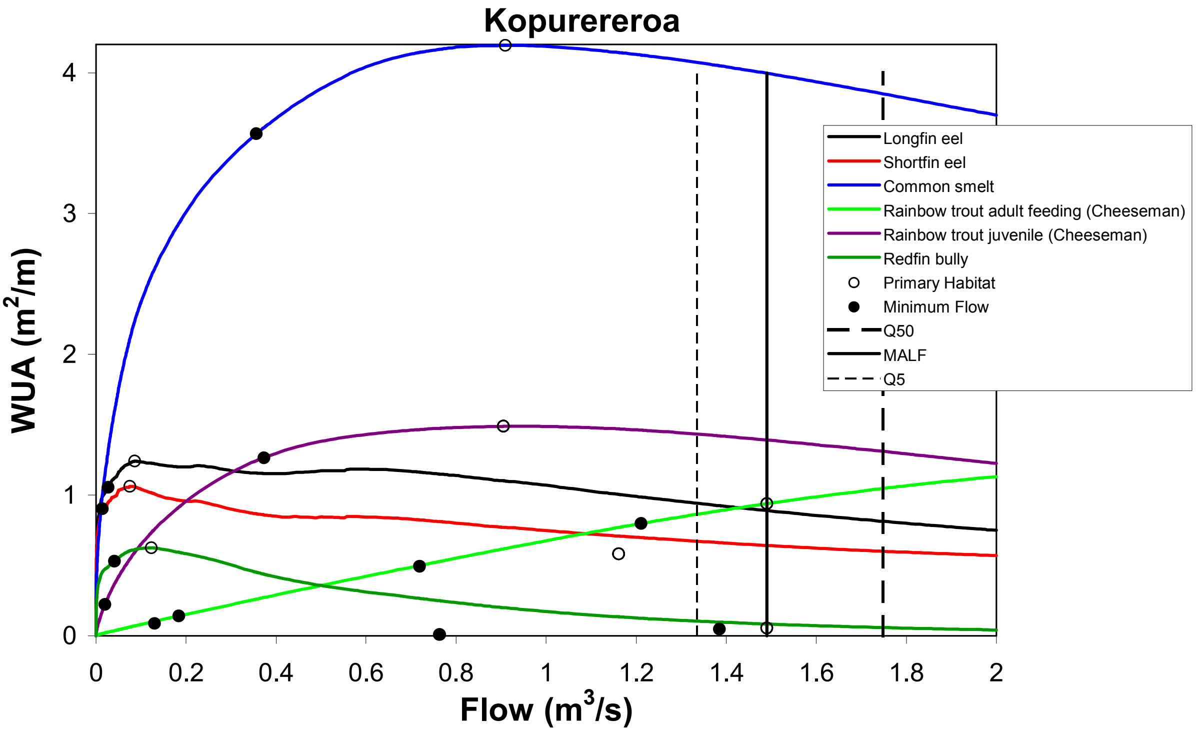

Te Puna at rapids
WUA (m²/m)
Flow (m³/s)
2
1.5
1
0.5
0
0
0.1
0.2
0.3
0.4
0.5
Longfin eel
Shortfin eel
Common smelt
Inanga
Torrentfish
Redfin bully
Primary Flow
Minimum Flow
Q50
MALF
Q5

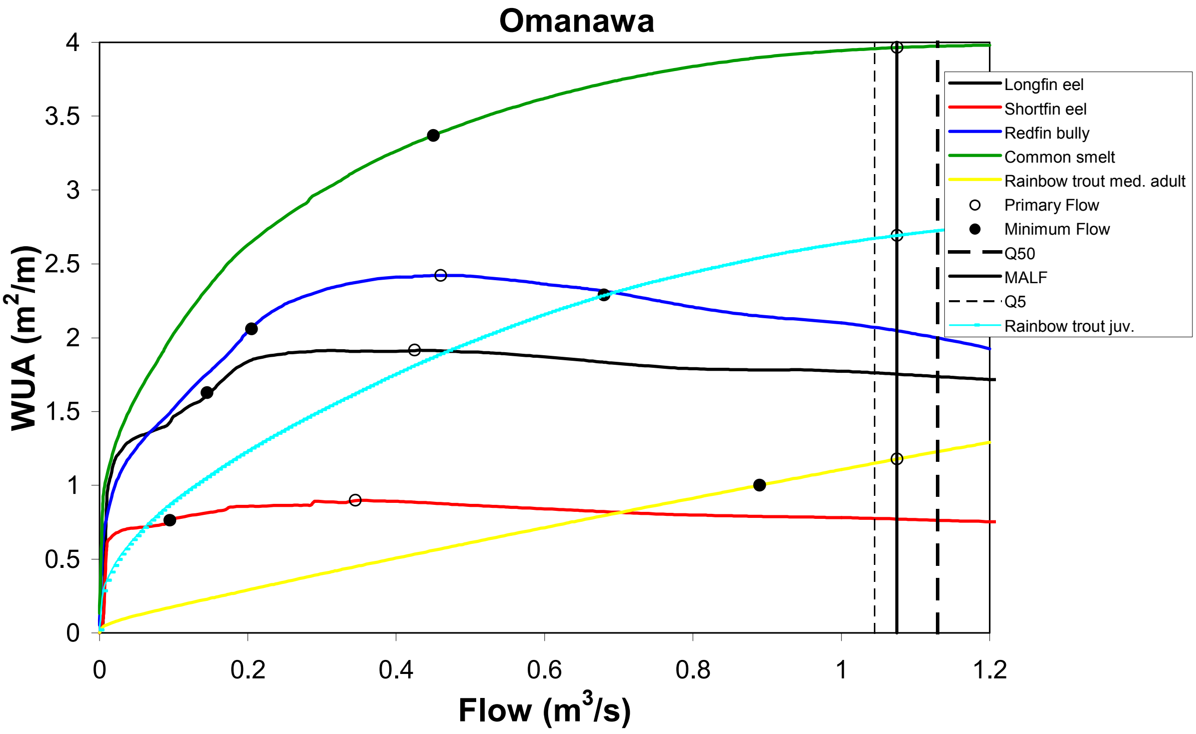

Te Puna Tributary
WUA (m²/m)
Flow (m³/s)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.01
0.02
0.03
0.04
Longfin eel
Shortfin eel
Banded kokopu
Redfin bully
Primary Habitat
Minimum Flow
Q50
MALF
Q5


Oturu
WUA (m²/m)
1.5
1.2
0.9
0.6
0.3
0
0
0.03
0.06
0.09
0.12
Flow (m³/s)
Longfin eel
Shortfin eel
Common smelt
Banded kokopu
Inanga
Redfin bullyCommon bully
Common bully
Primary Habitat
Minimum Flow
Q50
MALF
Q5

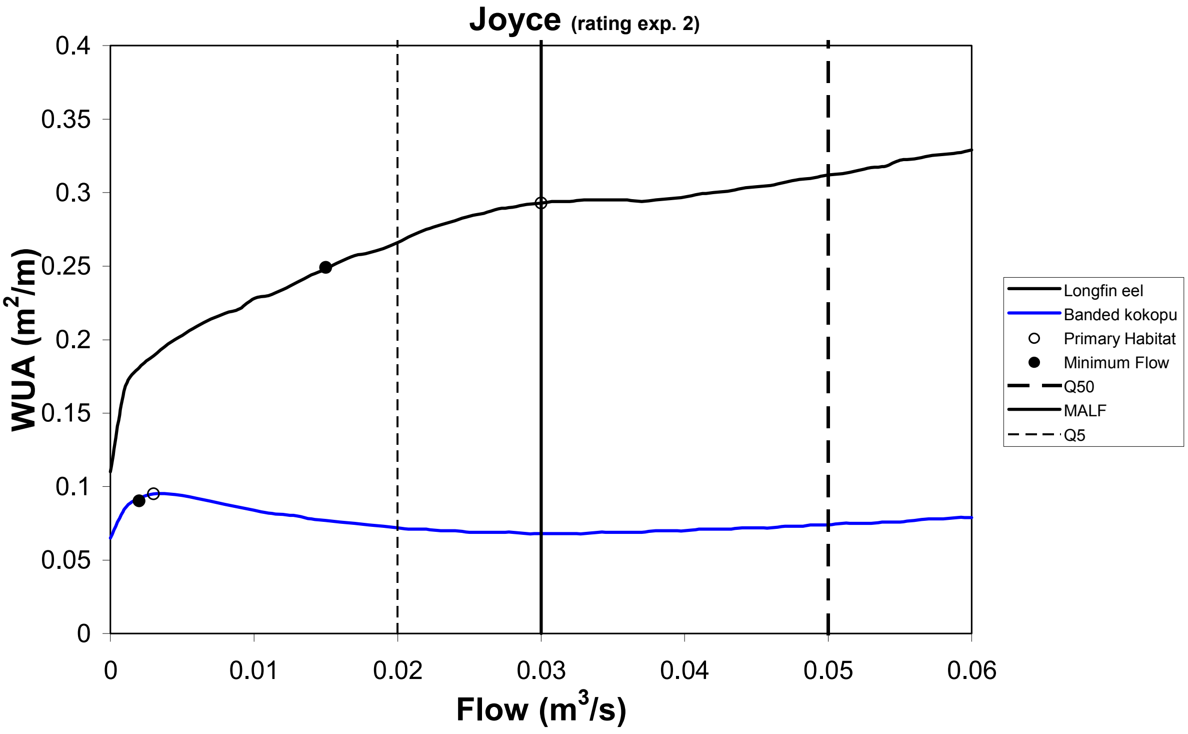

Ohourere
WUA (m²/m)
3
2.5
2
1.5
1
0.5
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Flow (m³/s)
Longfin eel
Shortfin eel
Banded kokopu
Redfin bully
Rainbow trout adult (Bovee, 1978)
Rainbow trout adult feeding (Cheeseman)
Rainbow trout juvenile feeding (Cheeseman)
Primary Habitat
Minimum Flow
Q50
MALF
Q5


Wairoa
WUA (m²/m)
2.5
2
1.5
1
0.5
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Flow (m³/s)
Longfin eel
Shortfin eel
Common smelt
Redfin bully
Brown trout adult (Hayes and Jowett)
Brown trout juvenile (Raleigh)
Brown trout fry (Raleigh)
Rainbow trout adult (Tongariro)
Rainbow trout adult feeding (Cheeseman)
Rainbow trout juvenile feeding (Cheeseman)
Primary Habitat
Minimum Flow
Q50
MALF
Q5

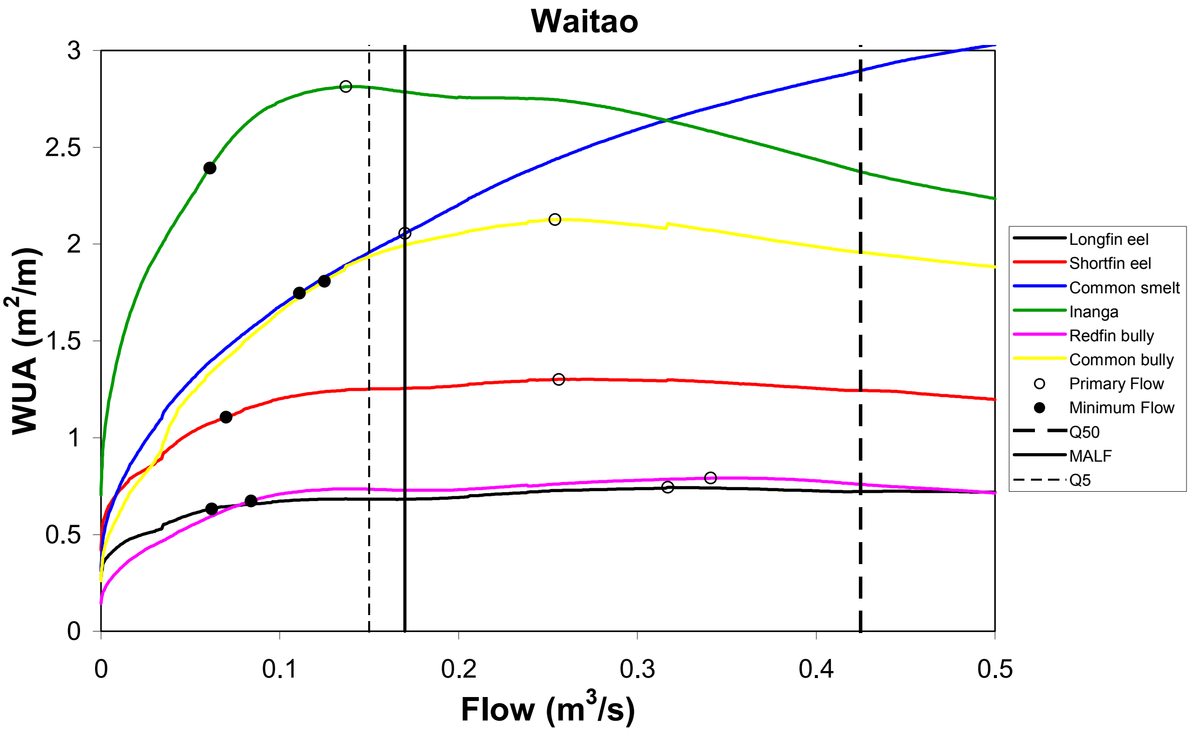

Kopurereroa
WUA (m²/m)
4
3
2
1
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Flow (m³/s)
Longfin eel
Shortfin eel
Common smelt
Rainbow trout adult feeding (Cheeseman)
Rainbow trout juvenile (Cheeseman)
Redfin bully
Primary Habitat
Minimum Flow
Q50
MALF
Q5

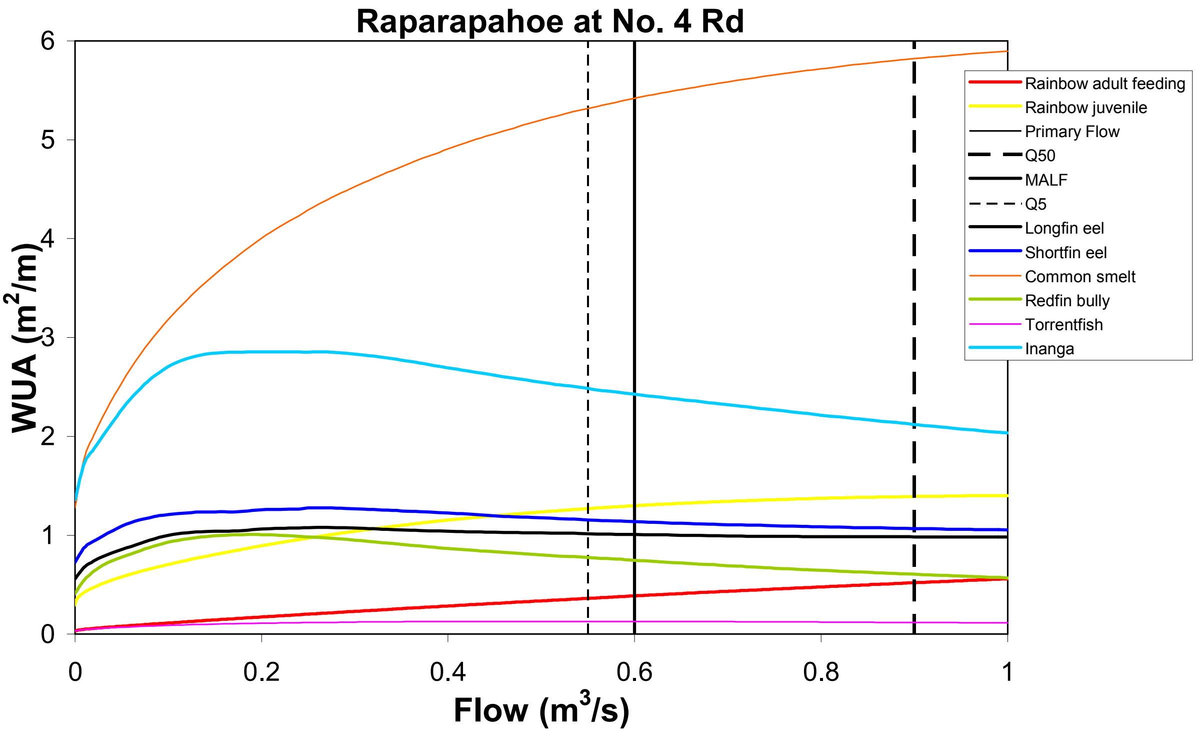


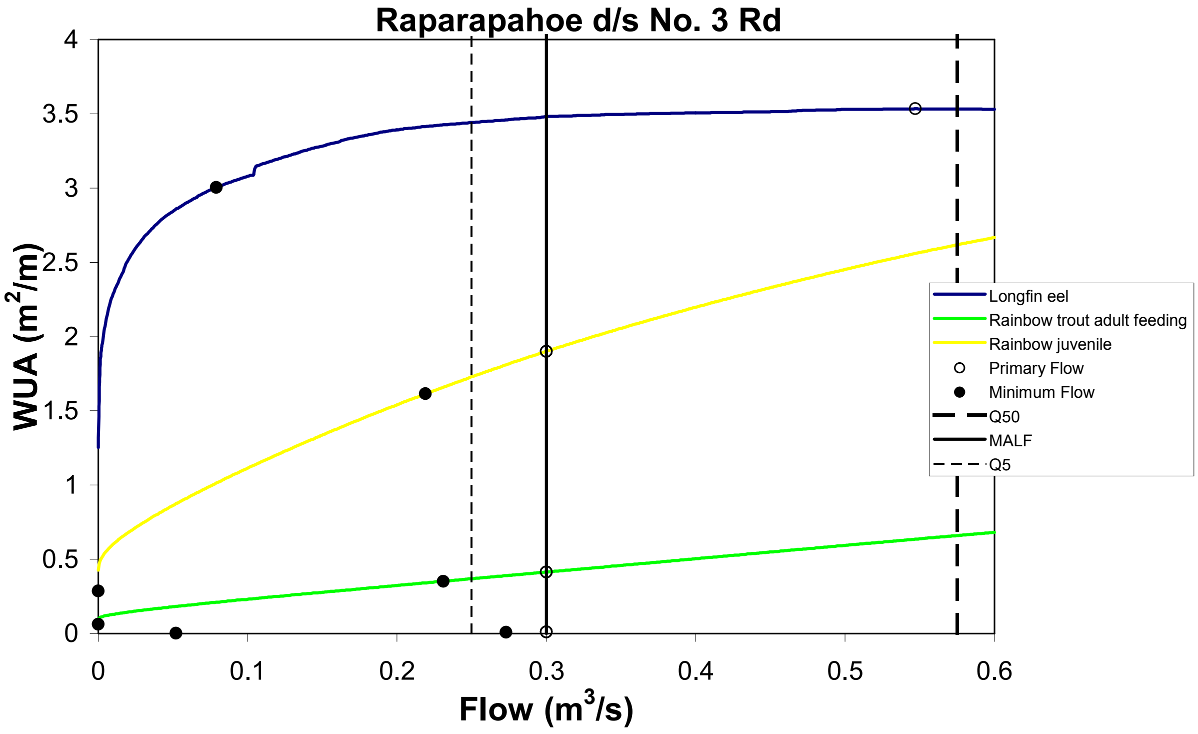
Omanawa
WUA (m²/m)
Flow (m³/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
0.2
0.4
0.6
0.8
1
1.2
Longfin eel
Shortfin eel
Redfin bully
Common smelt
Rainbow trout med. adult
Primary Flow
Minimum Flow
Q50
MALF
Q5
Rainbow trout juv.

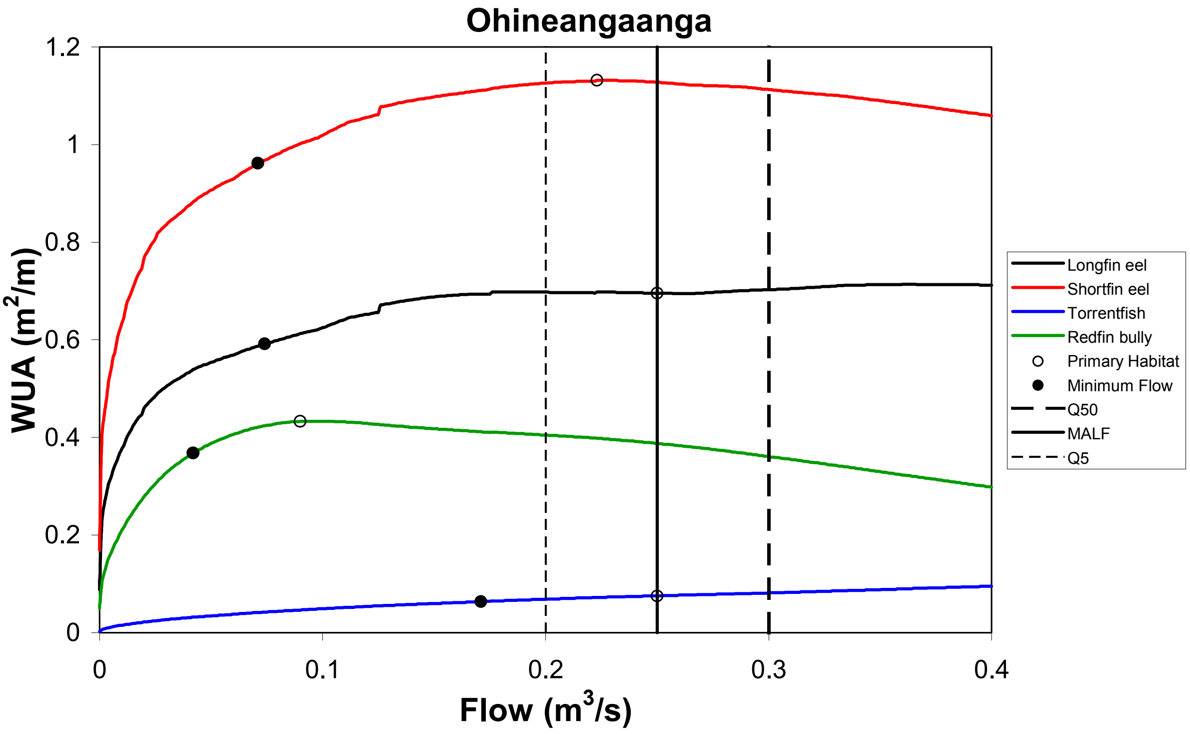


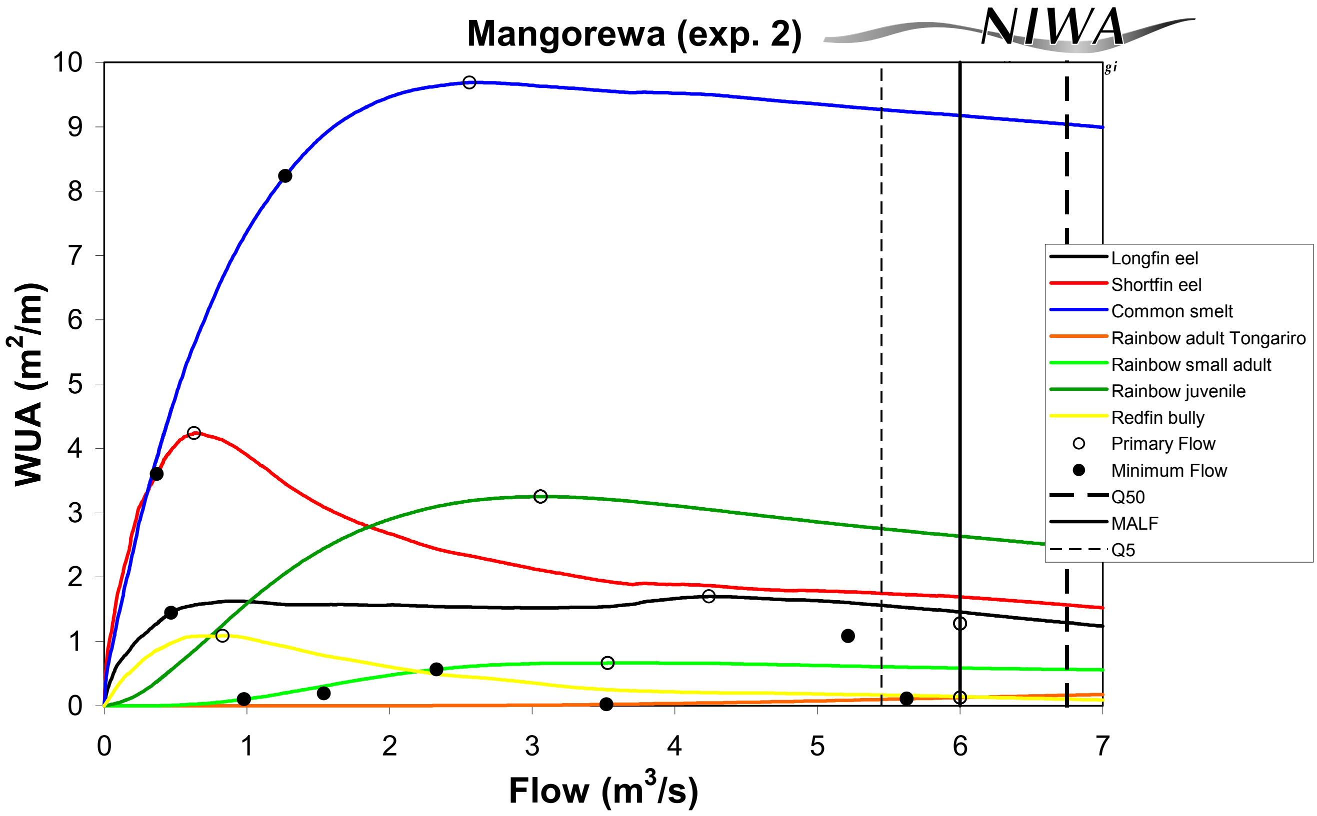
Joyce (rating exp. 2)
WUA (m²/m)
Flow (m³/s)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0
0.01
0.02
0.03
0.04
0.05
0.06
Longfin eel
Banded kokopu
Primary Habitat
Minimum Flow
Q50
MALF
Q5

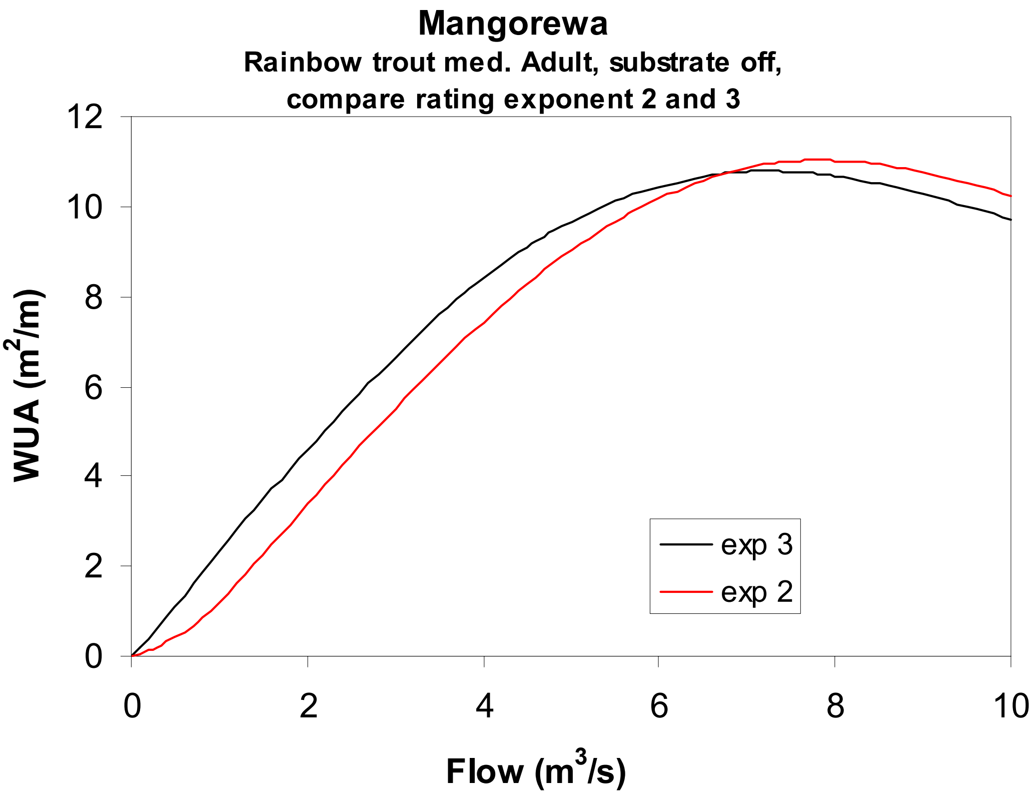

Waitao
WUA (m²/m)
Flow (m³/s)
3
2.5
2
1.5
1
0.5
0
0
0.1
0.2
0.3
0.4
0.5
Longfin eel
Shortfin eel
Common smelt
Inanga
Redfin bully
Common bully
Primary Flow
Minimum Flow
Q50
MALF
Q5

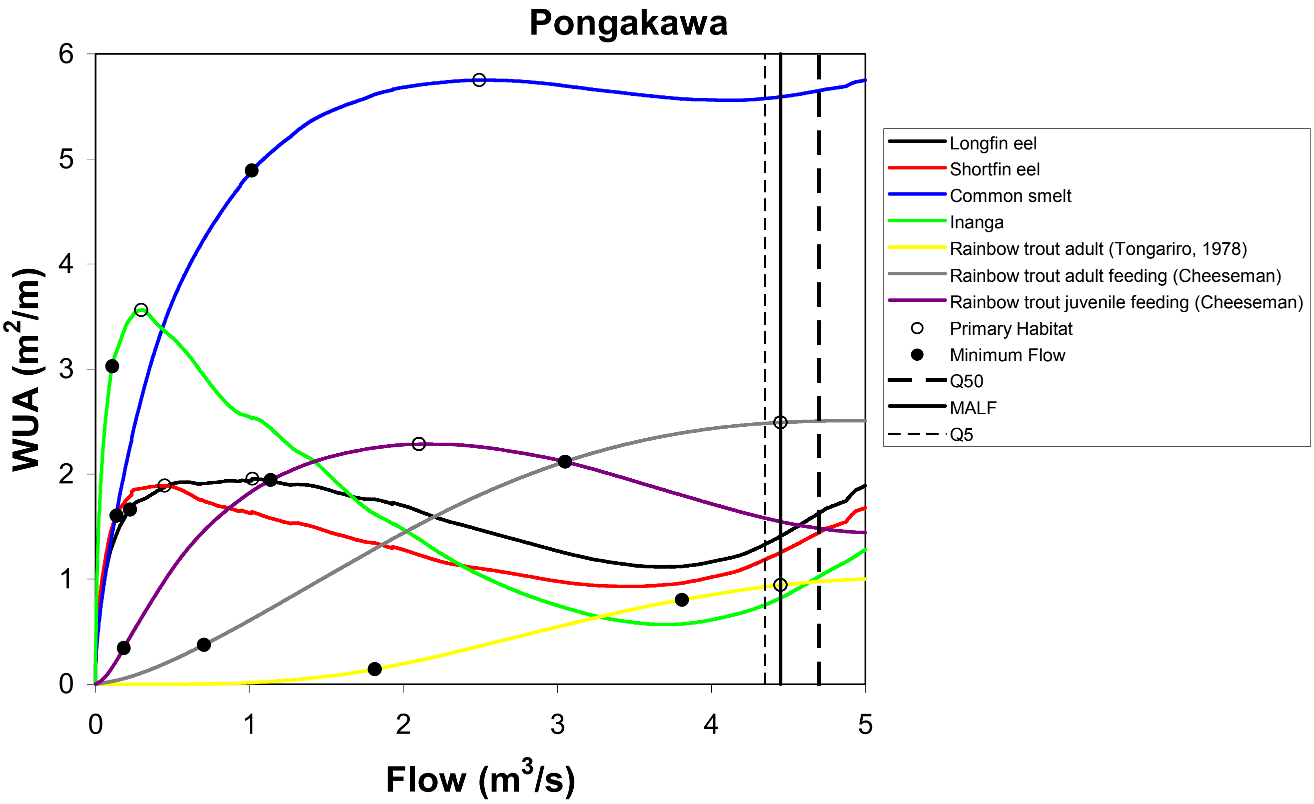

Raparapahoe at No. 4 Rd
WUA (m²/m)
Flow (m³/s)
6
5
4
3
2
1
0
0
0.2
0.4
0.6
0.8
1
Rainbow adult feeding
Rainbow juvenile
Primary Flow
Q50
MALF
Q5
Longfin eel
Shortfin eel
Common smelt
Redfin bully
Torrentfish
Inanga


Raparapahoe d/s No. 3 Rd
WUA (m²/m)
Flow (m³/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
0.1
0.2
0.3
0.4
0.5
0.6
Longfin eel
Rainbow trout adult feeding
Rainbow juvenile
Primary Flow
Minimum Flow
Q50
MALF
Q5


Ohineangaanga
WUA (m²/m)
Flow (m³/s)
0
0.2
0.4
0.6
0.8
1
1.2
0
0.1
0.2
0.3
0.4
Longfin eel
Shortfin eel
Torrentfish
Redfin bully
Primary Habitat
Minimum Flow
Q50
MALF
Q5


Mangorewa (exp. 2)
WUA (m²/m)
Flow (m³/s)
0
1
2
3
4
5
6
7
8
9
10
0
1
2
3
4
5
6
7
Longfin eel
Shortfin eel
Common smelt
Rainbow adult Tongariro
Rainbow small adult
Rainbow juvenile
Redfin bully
○ Primary Flow
● Minimum Flow
Q50
MALF
Q5


Mangorewa
Rainbow trout med. Adult, substrate off,
compare rating exponent 2 and 3
WUA (m²/m)
Flow (m³/s)
0
2
4
6
8
10
12
0
2
4
6
8
10
exp 3
exp 2


Pongakawa
WUA (m²/m)
Flow (m³/s)
0
1
2
3
4
5
6
0
1
2
3
4
5
Longfin eel
Shortfin eel
Common smelt
Inanga
Rainbow trout adult (Tongariro, 1978)
Rainbow trout adult feeding (Cheeseman)
Rainbow trout juvenile feeding (Cheeseman)
Primary Habitat
Minimum Flow
Q50
MALF
Q5

Appendix VIII - Flow estimation for the predictive analysis

Estimates of median flow, MALF and Q_5 were unable to calculated for 8 sites. One site was the Wairoa River. Estimates of flow were calculated by Environment Bay of Plenty for the existing flow scenario, with water diverted for a power scheme. Rough estimates for 6 other sites were calculated for the purposes of the predictive analysis (Table 1), as referred to in Section 3.4.

Flow data for the other 17 minimum flow sites was used in the calculation. Firstly these existing data were classified according to flow characteristics. The streams were divided into three groups as shown in the graphs over page. Those north-west of the Wairoa had the highest flow variability; those between the Wairoa and Kaituna had lower variability and those east of the Kaituna had minimal flow variability (for locations see figure 1.1). The distinction of the 3 groups using the Q_5/MALF relationship is more apparent from the trendline equations than the trendlines themselves. Oturu, Joyce and Waitao streams were omitted as outliers.

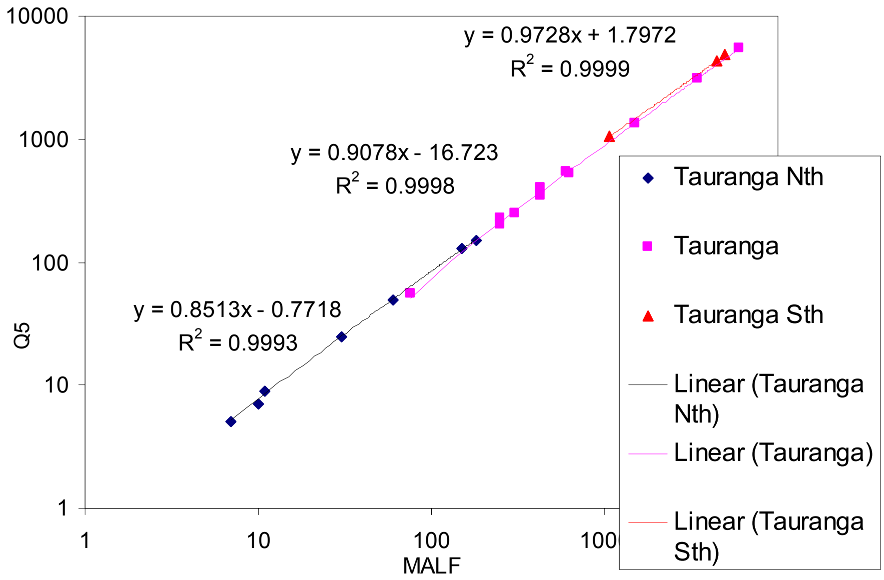
Five of the 6 sites without flow statistics occur in the eastern area. The 6th site, Parawhenuamea, is a spring fed stream more akin to the eastern sites with low flow variability, hence is treated as such (see Appendix II, plate 20). MALF was estimated by first averaging the flows measured for the IFIM study, then multiplying by 0.92, the proportion the Pongakawa average IFIM flow was of its MALF, (Pongakawa being the only eastern site with accurate flow estimates). The Q_5 was then calculated for each site as 0.974xMALF (average of Waitahanui and Pongakawa proportions). Median flows were more variable and the six sites were calculated from different references:

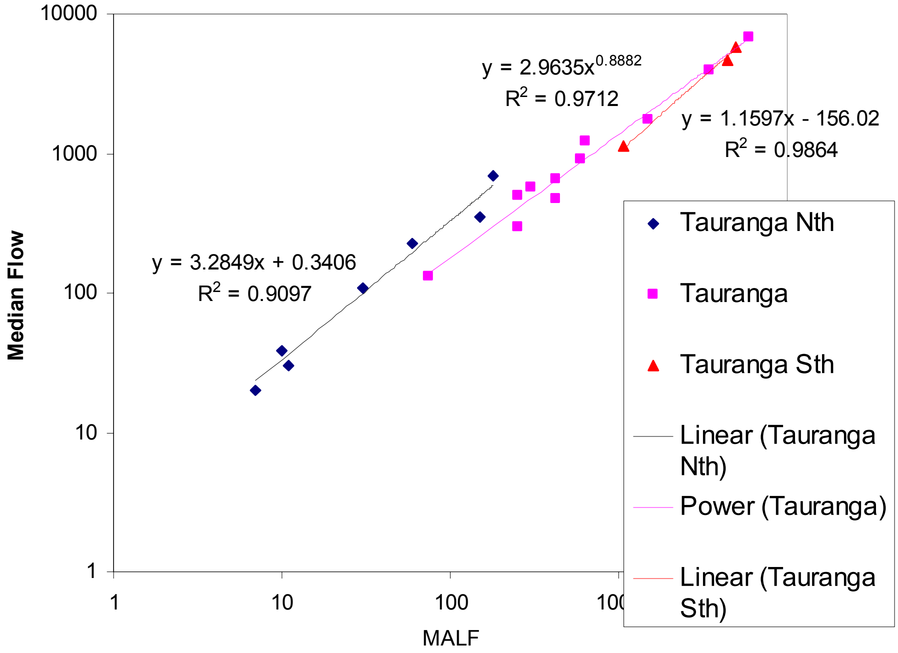
- Wharere and Parawhanuamea trib. from the Pongakawa (1.06xMALF);
- Pokopoko, Waiari and the Pikowai from the Waitahanui (1.18xMALF);
- Puanene from the average of the two (1.12xMALF).

In deciding which stream to use as a reference, channel morphology was used as a visual indicator of flow variability.

Table 1: Approximate flow estimates for 6 of the Tauranga sites for use in the predictive analysis only.

(m^3/s)	MALF	Q_5	Median
Puanene	0.066	0.065	0.074
Pokopoko	1.699	1.654	2.008
Waiari	0.109	0.106	0.129
Pikowai	0.927	0.903	1.096
Wharere	0.421	0.410	0.445
Parawhenuamea	0.665	0.648	0.703





Appendix IX - Guide for determining IMFR's for streams of the Tauranga and Kaimai Area

Step 1: Has a habitat survey (IFIM) been conducted in the reach in question?

Yes – use the IMFR calculated for that reach using the prescribed method.

No – Step 2

Step 2: If the stream is located in the Kaimai area (see Figure 1.1) use Equation 1.

If the stream is located in the Tauranga area go to Step 3.

Step 3: Does the stream support a trout fishery?

Yes – Use Equation 2

No – Step 4

Step 4: Is Q_5 less than 250 L/s?

Yes – use Equation 1

No – use Equation 3

Equation 1: $\mathrm{IMFR} = (0.8835 \times Q_5) + 1.5241$ (native fish, $Q_5 < 250$ L/s)

Equation 2: $\mathrm{IMFR} = 1.4483 \times Q_5^{0.9255}$ (trout)

Equation 3: $\mathrm{IMFR} = (0.1909 \times Q_5) + 172.94$ (native fish, $Q_5 > 250$ L/s)

Both IMFR and Q_5 are in L/s.

Situations where these equations may not apply:

- Streams outside the Tauranga and Kaimai areas (see figure 1.1), except those of the Maketu Plains which originate from, and retain the habitat characteristics of Tauranga area streams.

- Streams where the substrate is dominated by bedrock, forming deep pools (see Appendix II, Plates 9 and 10). Sections of the stream where this habitat type is present may have minimum flows overestimated by the above equations. However, the equations will apply to any reaches downstream where bedrock pools are not present. Most streams are expected to have extensive non-bedrock reaches and hence be suitable for the above equations.

- Trout streams that provide rearing habitat for juvenile rainbow trout but do not support adult trout fisheries, (juveniles that move into a nearby fishery at some point). The following equation can be used, but may overestimate flow requirements (see section 3.4); $\mathrm{IMFR} = 3.9139 \times Q_5^{0.7252}$

- Inland non-trout streams where native fish communities are restricted to low flow species such as eels and banded kokopu. IMFR may be over-estimated by the above equations.

- Regionally significant trout fisheries. The above equations will underestimate flow requirements.

- Streams where brown trout form the basis of the fishery rather than rainbow trout. Flow requirements may be over or under estimated, but are not expected to differ greatly.

- Kaimai area streams that support trout fisheries.

Some tips for determining the fish community. Most streams will support native fish and data for the stream may be available from the New Zealand Freshwater Fish database. For information on trout fisheries see also The Proposed Regional Water and Land Plan Schedule 1d, Richardson (et al. 1986), Unwin & Brown (1998), or contact Eastern Region Fish and Game. Generally speaking, if the Q_5 is less than 100 L/s it is unlikely to support a recreational fishery, though may provide rearing habitat for juveniles.