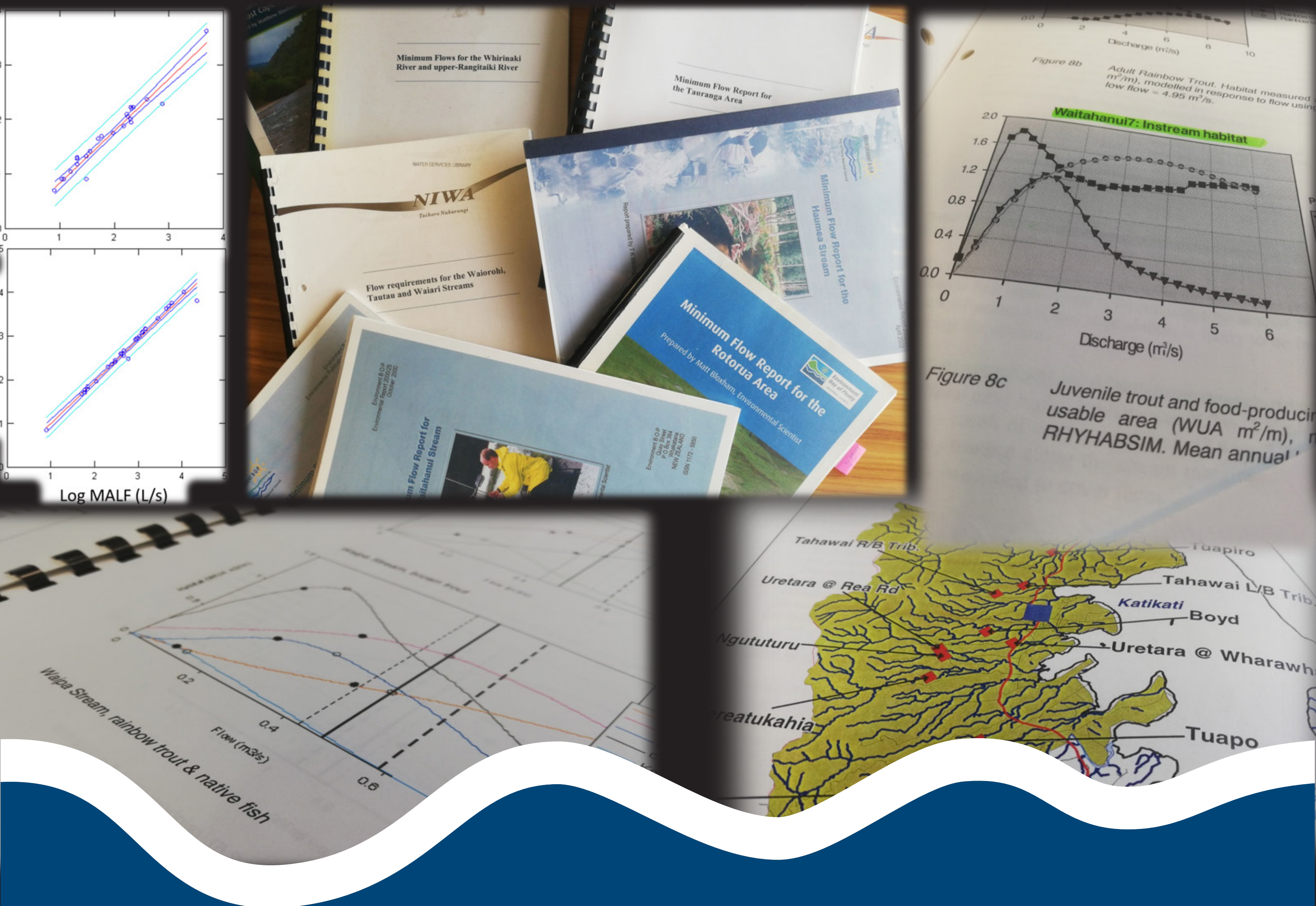


BAY OF PLENTY
REGIONAL COUNCIL
TOI MOANA

Revision of calculated IFIM derived minimum flows in the Bay of Plenty

Bay of Plenty Regional Council
Environmental Publication 2019/05
June 2019

Prepared by Alastair Suren, Environmental Scientist

5 Quay Street
P O Box 364
Whakatāne
NEW ZEALAND

ISSN: 1175-9372 (Print)
ISSN: 1179-9471 (Online)

Acknowledgements

This work relies heavily on previous information obtained during the numerous IFIM surveys conducted by Bay of Plenty Regional Council (BOPRC) staff and others in previous years. These surveys were either conducted or managed by Thomas Wilding and Matt Bloxham, with assistance from the Environmental Data Services Team as well as external contractors such as Bente Clausen and staff at NIWA Hamilton. Thanks also to Nicola Green, Glenys Kroon and Gemma Moleta (BOPRC), and Eleanor Gee (NIWA Hamilton) for review comments to this report.

Executive summary

1 *There is increasing water demand throughout the Bay of Plenty for a variety of out-of-stream uses such as irrigation, frost fighting, milk cooling/dairy shed washdown, industrial, domestic and municipal water supply. To manage the demand for abstraction, whilst minimising adverse effects to other values, Bay of Plenty Regional Council (BOPRC) has introduced a region-wide default allocation regime (Proposed Plan Change 9) and will follow that with more specific catchment scale limits.*

2 *Under the National Policy Statement for Freshwater Management (NPSFM), regional councils need to set freshwater objectives and water resource use limits for all freshwater management units. Water quantity limits must consist of at least a minimum flow limit (the flow below which no further water is to be taken for out-of-stream use) and a total allocation limit (the maximum quantity of water available for abstraction). BOPRC is responsible for setting these limits in the Bay of Plenty region, and the Regional Natural Resources Plan (RNRP) contains policies, rules and methods to achieve these.*

3 *Under the Proposed Plan Change 9 (Regional-wide Water Quantity), water allocation in the region is governed by a region-wide set of default rules. Under these rules, an interim allocation limit of 10% of the Q_5 7-day low flow has been identified, as well as a minimum flow of 90% of the Q_5 7-day low flow. This uniform hydrological approach ensures a level of protection of river flows, but also:*

- *sets minimum flows independent of stream size, and does not recognise that larger rivers are less susceptible to abstraction pressure than smaller rivers, so potentially more than 10% of the Q_5 7-day flow can be allocated;*
- *does not accommodate the different flow requirements of different fish species, but assumes that a blanket minimum flow of 90% Q_5 7-day flow is adequate for all species;*
- *requires a stream's Q5 7-day flow regime to be known or calculated.*

4 *Site specific assessments of minimum flow for ecological purposes have been made using the Instream Flow Incremental Methodology (IFIM) in 60 streams throughout the region, between 2001 and 2013. The majority of these (27 studies) were done in the Tauranga Harbour Water Management Area (WMA), followed by the Rangitāiki and Rotorua Lakes WMAs (eight studies each) and the Kaituna, Maketu and Pongakawa WMA (seven studies). Instream minimum flow requirements (IMFRs) were assessed for selected target fish species using the software program RHYHABSIM, which is a modelling tool that assesses changes to a stream's hydraulic habitat conditions as flows reduce. This information, when combined with habitat suitability curves for a variety of target fish species, allows assessments to be made of how habitat suitability for the target fish can change with flow reductions.*

5 *A slight shortcoming in the methodology of calculating these IFIM minimum flows meant that some IMFRs were greater than a river's Mean Annual Low Flow (MALF)[1]. Having an IMFR higher than MALF serves no useful ecological purpose, because fish*

[1] There are two commonly used statistics to calculate minimum flows: the Q_5 7-day flow, and MALF. While these are calculated slightly differently, there are generally very close correlations between the two.

communities in that stream would already be adapted to flows as low as MALF. This problem was remedied by requiring any new IMFR to retain a percentage of habitat at the MALF, and to omit consideration of habitat at median flow from the method. The change to the amount of habitat at MALF is called ΔH, and is based on the requirements in the RNRP for protection of a specific proportion of habitat at MALF (Method 178). New IMFRs were subsequently recalculated using the same data collected previously, but ensuring that the new IMFR retained a specific amount of habitat relative to that at MALF. These minimum flows (expressed as a % of MALF) were then compared between different stream types, and between different fish groups.

6 *The 60 IFIM sites were spread throughout the region, with most sites in the western and central part of the region. The cumulative area of all the catchments above each IFIM site was 5,035 km^2, or about 40% of the region. IMFRs were recalculated for 56 of the rivers from where previous IFIM surveys had been done, based on retaining a specified percentage of habitat at MALF. Four sites surveyed by NIWA (Tautau, the Upper Rangitāiki at Galatea, Waiari and Waiorohi) were not recalculated, as we were unable to obtain the original RHYHABSIM data files. Of the 56 IMFRs recalculated, nine used different target fish species from the original reports, as these had a higher flow requirement for habitat protection relative to habitat at MALF.*

7 *The most common fish group used in the recalculated IMFRs was the adult rainbow trout group (15 sites), followed by bullys (11 sites) and brown trout (10 sites). The catchments where these IMFRs were done were spread throughout the region. A fish group consisting of banded kōkopu, inanga and smelt (termed the "Lowland_Slow" group) was used at nine sites, mainly in the western part of the region.*

8 *The calculated IMFRs were expressed as a percentage of MALF. This was called the Q_{min} – a term used throughout this report to refer to the stream's minimum flow to protect a specific proportion of hydraulic habitat for selected fish species. On average, Q_{min} was 77% of MALF at each site, although there was a wide range in values (23% to 98%). Thirty-two had calculated values of Q_{min} > 90% of the Q5 7-day flow (the current regional default), 24 of which provided habitat protection for either rainbow or brown trout. These fish are generally very "flow hungry", which may help explain the high value of Q_{min}. In contrast, of the six streams with the lowest Q_{min} (<50% of MALF), four had target species that were native fish (either banded kōkopu, redfin bully or torrentfish).*

9 *Analysis of Variance (ANOVA) showed that there were no differences in values of Q_{min} between different biophysical classes for rivers, or the target fish species. This most likely reflected the highly variable Q_{min} values in some of the biophysical classes, or fish groups.*

10 *Because it is not possible to undertake detailed IFIM assessments on all reaches within the region, relationships between a stream's measured MALF and the resultant IMFR were examined. If such relationships existed, then new IMFRs could be estimated for the same target fish species in streams where detailed IFIM assessments have not been done, based simply on the value of MALF of a particular stream. Analysis of covariance (ANCOVA) was used to assess relationships between a stream's MALF and the calculated IMFR. ANCOVA was used as any relationships between MALF and the calculated IMFR may have been influenced by either the biophysical class of a stream, or by the target fish species. A similar ANCOVA was done using data from two other regions (Canterbury and Wellington) to assess whether observed relationships were similar.*

11 *Highly significant relationships were found between the IMFR and MALF, and this relationship did not appear to be affected by either the stream's biophysical class, its region, or what fish group was being used to set the IMFR. However, a fourth ANCOVA of IMFR against MALF using the "Native" versus "Salmonid" classification, showed highly significant differences in these relationships. Thus, IMFRs derived for salmonids were significantly higher for a given MALF than IMFRs derived for native fish. Again, this emphasises the greater flow requirements of salmonids than native fish. Such strong relationships between calculated IMFRs and MALF suggest that IMFRs could be calculated for other streams where IMFR surveys have not been done from the observed regression equations, and that such relationships are generally independent of biophysical class or fish group. However, because of the significant differences in regressions derived from data using native fish as the target species, or salmonids, any IMFRs calculated from these regressions need to consider whether low flow objectives are to protect either native fish, or salmonids.*

12 *Although the IFIM approach is arguably one of the most robust ways of setting Q_{min} for ecological purposes, it is designed only to set a minimum flow regime in streams. The IFIM approach does not allow any assessments to be made of other important flow-setting attributes such as the amount of water that can be allocated, as well as what the reliability of supply is for a given minimum flow limit. However, NIWA has developed a model called Environmental Flow Strategic Allocation Platform (EFSAP) to examine the consequences of various Q_{min} allocation regimes on both in-stream values (i.e. protection of fish habitat (ΔH)), and resource use (e.g. the amount of water allocated (ΔQ), and the reliability of supply (R)).*

13 *Given that we have IFIMs for streams across about 40% of the land area in the region, it may be possible to combine the advantages of both the IFIM approach and EFSAP. In this way, individual EFSAP analyses can be done on all NZReaches in catchments above where IFIM assessments have been made. By doing this, it should be possible to examine the consequences on allocation and reliability of supply within each of these specific catchments for a given minimum flow that has been defined using IFIM. Furthermore, in sites where IFIMs have not been conducted, new IMFRs could be derived from the above regression analyses, and these IMFRs could also be used in other EFSAP analyses to identify the implications of these IMFRs on allocation and reliability of supply. This approach could only work where there are multiple reaches above a specific site of interest, as EFSAP is not designed to analyse individual reaches.*

14 *This information can feed into the community engagement process as part of the PC12 process. Discussions with the community groups need to emphasise there are three techniques to help set minimum flows, as well as allocation limits and reliability of supply measures. These methods are 1) The default hydrological method (for example 90% of Q_5); 2) IFIM at individual reaches; 3) EFSAP, which can be used either above each IFIM site, or regionally, or in each WMA. Final choice of limits is a policy decision which will consider a variety of factors including existing uses, reliability required for users, as well as cultural and social considerations. These different approaches are all regarded as more robust than the current default hydrological methods supporting regional wide minimum flow and allocation limits. Information on the ecological effects of a particular allocation regime is critical to informing the limits being set.*

Contents

Part 1: Introduction

There is increasing water demand throughout the Bay of Plenty region for a variety of out-of-stream uses such as irrigation, frost fighting, milk cooling/dairy shed washdown, industrial, domestic and municipal water supply. As more and more water is abstracted from rivers and streams, there is an increasing potential for adverse effects to occur. Such effects include effects on recreation, aesthetic, cultural, and ecological values. For example, abstracting too much water from a popular fishing or jet boating river may reduce the ability to undertake these activities. Excessive water abstraction may also change the in-stream hydraulic habitat of streams which is likely to affect fish and invertebrates, as these have distinct depth and velocity preferences. Excessive abstraction may also result in increased amounts of plant growth in rivers with subsequent detrimental effects. To manage the demand for abstraction, whilst minimising adverse effects on other values, BOPRC needs an allocation regime that, when implemented, should enable appropriate water use while providing for in-stream values, particularly when the National Policy Statement for Freshwater Management (NPSFM, MfE2014) highlights that councils have a legal requirement to maintain or improve instream ecological values.

1.1 National context

To help deal with managing the demand for abstraction, whilst minimising adverse effects to other values the NPSFM requires regional councils to set freshwater objectives and water resource use limits for all freshwater management units. Water quantity limits must consist of at least a minimum flow limit (the flow below which no further water is to be taken for out-of-stream use) and a total allocation limit (the maximum quantity of water available for abstraction). The Bay of Plenty Regional Council (BOPRC) is responsible for setting these limits in the Bay of Plenty region.

In 2008, the Ministry for the Environment released a proposed National Environment Standards (NES) on Ecological Flows and Water Levels. Although this has not advanced to date and is now under review, aspects of these proposed standards are still relevant as guidance. For example, it identifies three distinct elements in setting environmental flows and water levels:

- a robust scientific methodology for assessing the ‘ecological needs of freshwater ecosystems’ over a range of flow and seasonal conditions;
- methods for assessing how other values (including recreational, amenity and tangata whenua values) change over a range of flow and seasonal conditions; and
- a clear approach to assessing the extent to which an environmental flow or water level will provide for natural and development values attributed to a water body by Māori and the wider community.

This report concerns only the first element: that of identifying the ecological flow needs of freshwater ecosystems. The proposed NES suggested that technical methods to determine ecosystem flow requirements be based initially on the risk of deleterious effects on in-stream habitat according to the species present and natural mean stream flow. It also emphasised that small streams are more sensitive to abstraction in terms of availability of suitable hydraulic habitat than larger streams and rivers, and that different fish species have different susceptibilities to alterations in flow regime. For example, the risk of adverse effects caused by reducing in-stream hydraulic habitat for fish such as inanga, upland bully and banded kōkopu would be considered low in all but very small streams, whereas the risk to adult trout, torrentfish and bluegill bully is considered relatively high in all but very large streams. The proposed NES went on to present a table showing the interaction of the degree of hydrological alteration and significance of in-stream values, and which particular method should be used to help set in-stream minimum flows. Thus, for streams with only a low degree of hydrological alteration, and a low to medium in-stream value, analysis of historic hydrological data and setting minimum flows based on maintaining a proportion of a defined minimum flow statistic (e.g. MALF or Q_5 7-day) would be considered adequate. In contrast, streams with a high degree of hydrological alteration and with medium to high in-stream values would require more complex methods such as 1 or 2D hydraulic habitat modelling. Such hydraulic habitat modelling forms the basis of the Instream Flow Incremental Methodology (IFIM), which models the hydraulic habitat requirements of target fish and shows how the amount of available habitat changes with flow.

1.2 Minimum flows in the Bay of Plenty

1.2.1 The Regional Natural Resources Plan

The proposed NES methodology of setting minimum flows using more rigorous techniques as the degree of hydrological alteration increases is consistent with the operative Regional Natural Resources Plan (RNRP[2]). Here, a default allocation limit of 10% of the $Q_5$7-day flow was established, and a minimum flow of 90% of the Q_5 7-day flow (Method 179). In streams where there are large abstractions and low residual flows, or streams under significant abstraction pressure, or streams with significant ecological, landscape or recreational values, the more robust in-stream minimum flow requirement (IMFR) methodology is to be used to determine the minimum flow (Method 177) via subsequent plan changes. Under Method 177 of the operative RNRP, the minimum flow requirement for a species (i.e. the primary flow) was the flow that provides a percentage of maximum habitat when the flow that provides maximum habitat is less than the median flow. Where the flow equating to the optimal habitat exceeded the streams median flow, the mean annual low flow (MALF) was to be used as the primary flow. A central part of this method was the inclusion of specified protection levels for aquatic life, where protection levels for the primary habitat were defined (Method 178). Species with higher conservation values such as short-jawed kōkopu or giant kōkopu were given 100% protection of their primary habitat, whereas other (less endangered and more common) indigenous species as well as migratory pathways of trout listed in schedule 1D were given only 85% habitat protection.

Between 2001 and 2013, eight separate Instream Flow Incremental Methodology (IFIM) studies (following Method 177) were done on 60 rivers throughout the Bay of Plenty region (Table 1). The majority of these (27 studies) were done in the Tauranga Harbour Water Management Area (WMA), followed by the Rangitāiki and Rotorua Lakes WMAs (eight studies each) and the Kaituna, Maketu and Pongakawa WMA (seven studies). It is not clear why particular sites were selected, but it is likely that some of these sites were selected in rivers where water was at or near full allocation. Such selection would have been consistent with Method 154 of the

[2] Incorporating and replacing the former Regional Water and Land Plan (RWLP) as of September 2017.

operative RNRP. Minimum flows were assessed for selected target fish species using the software program RHYHABSIM (Jowett 2010). RHYHABSIM is a modelling tool that allows us to assess changes to a stream's hydraulic habitat conditions as flows reduce. This information, when combined with habitat suitability curves for a variety of target fish species, allows assessments to be made of how habitat suitability for different fish species can change with reductions in flow. This allows models to be developed showing changes in the weighted usable area of suitable habitat for different flows. These models are then used to help set minimum flows, based on the concept of retaining a known proportion of the hydraulic habitat that is present at low flow.

The bulk of these 60 studies were written up as Environmental Publications (Wilding 2002a, 2002b, 2002c, 2003, 2004; Bloxham 2005, 2008) but the majority of these minimum flows were not incorporated into Scheduled 7 of the RNRP. Thus, for the purposes of current water allocation management, the default limit for an IMFR of 90% of Q_5 7-day low flow is still applied. Only the Waitahanui, from the confluence of the Whakahuapapa Stream to the stream mouth was assigned an IMFR of 3.8 m^3/s (Wilding 2000) in the RNRP.

Table 1 Summary table of IFIM studies done in the Bay of Plenty region between 2000 and 2013.

Study	WMA	Total
Bloxham 2005	Rotorua Lakes	8
	Tarawera	1
Bloxham 2008	East Coast	1
	Tarawera	2
	Waioeka and Otara	3
	Whakatane and Waimana	2
NIWA 2001	Kaituna, Maketu and Pongakawa	1
	Tauranga Harbour	2
NIWA 2004	Rangitāiki	2
Wilding 2000	Kaituna, Maketu and Pongakawa	1
Wilding 2002	Rangitāiki	6
	Tauranga Harbour	10
Wilding 2003	Kaituna, Maketu and Pongakawa	5
	Tauranga Harbour	13
Suren 2013	Ohiwa	1
	Tauranga Harbour	2

Application of the original Method 177 as given in the original RWLP showed that it could give unreasonable results in some circumstances (Jowett 2012), depending on the natural flow regime of the river and the fish species present in that river. For example, when this method is applied to small streams and rivers with relatively stable flows, the maximum habitat for torrentfish (a potential target species for protection) was usually higher than the median flow, so that the method uses 90% of the habitat at the MALF. However, in some rivers where the ratio of the median flow to the MALF is high, flows that provide maximum habitat can be just under the median flow, resulting in an IMFR that can be considerably greater than the MALF.

A minimum flow higher than the MALF serves no useful ecological purpose, because fish communities in that stream will arguably already be adapted to flows as low as MALF. Thus, the minimum flow requirement could be somewhat less than MALF to help achieve a balance between ecological protection and out-of-stream uses of water.

Jowett (2012) recommended that this problem with Method 177 was easily remedied by requiring the minimum flow to retain a percentage of habitat available at MALF and to omit consideration of habitat at median flow from the method (Table 2).

Table 2 Summary of changes between the current Method 177 of the RNRP and those recommended by Jowett 2012.

Old Method 177	**Jowett proposal**
Use a scientifically accepted ecological assessment method, such as Instream Flow Incremental Methodology (IFIM) or similar. In assessing the effects on instream aquatic life, the method will consider factors including: (i) Hydrological parameters. (ii) Substrate. (iii) Dissolved oxygen. (iv) Water temperature.	Use a scientifically accepted ecological assessment method, such as Instream Flow Incremental Methodology (IFIM) or similar. In assessing the effects on instream aquatic life, the method will consider factors including: (i) Instream habitat. (ii) Dissolved oxygen, if applicable. (iii) Factors listed in (c) below, where applicable.
If RHYHABSIM is selected, use the following steps to interpret habitat flow response curves:	If an instream habitat modelling programme, such as RHYHABSIM, is selected, use the following steps to interpret habitat flow response curves:
Step 1: For each species present in the stream or river reach identify a primary flow where habitat is optimum (greatest). Where the flow equating to optimal habitat exceeds the stream's median flow, use the MALF as the primary flow.	**Step 1:** Identify the appropriate set of target species. For streams and rivers listed in Schedule 1D of this Plan, use trout as the target species. For all other streams and rivers, the set of target species should be a best estimate of the species present in the stream reach using any one of the following methods: • Existing records of species within the stream or river. • NIWA Freshwater Fish Database. • Predictive modelling of native fish likely to be present in the stream or river. • A fish survey of the stream or river if none of the above methods is available or suitable.

Old Method 177	Jowett proposal
Step 2: Multiply habitat at the primary flow by the protection level in Method 178 to obtain a minimum flow for each species present in the stream or river reach. The point of inflection may be used instead of the scaled primary flow in cases where this exceeds the minimum flow otherwise produced, or where any additional loss of habitat is insignificant.	**Step 2:** For each target species, identify either the amount of habitat at the 7-d MALF or the maximum amount of habitat if that occurs at a flow less than the MALF. The primary flow is either the 7-d MALF or the flow that provides maximum habitat if that occurs at a flow less than the MALF.
Step 3: Identify the highest flow of the minimum flows identified for the species present. This is the Instream Minimum Flow Requirement necessary to sustain aquatic life.	**Step 3:** Multiply habitat at the primary flow by the protection level in Method 178 and determine the flow that maintains that amount of habitat. This is the minimum flow requirement for each species in the stream or river reach.
	Step 4: Calculate the maximum of the minimum flow requirements for each target fish species. This is the Instream Minimum Flow Requirement necessary to sustain aquatic life and biotic values.

1.2.2 Proposed Plan Change 9 to the Regional Natural Resources Plan

The NPSFM was gazetted in 2011 and introduced an expectation that objectives and limits would be developed for each Freshwater Management Unit. Council decided to deliver these requirements through a staged implementation process across nine Water Management Areas. PC9 is the first step in a two-stage approach to implement the NPSFM in the Bay of Plenty. It will be followed by more specific provisions relating to each Water Management Area.

Proposed Plan Change 9 to the RNRP (PC9) amends the Region-wide Water Quantity chapter of the RNRP. PC9 is subject to environment court appeals. Relevant provisions under PC9 (decision version 8.1) for the improved management of water allocation in the region include:

- WQ Objective 7, an objective stating that limits will be set and applied instream to minimum flows for surface water bodies to safeguard (amongst other things) their life-supporting capacity, ecological integrity and significant ecological values.
- WQ Policy 2, which directs Council to work with tangata whenua, district councils, the community and other stakeholders to (among several other things) set environmental flows and levels for rivers, streams, lakes and aquifers: based on the freshwater values and objectives within each Water Management Area.
- WQ P5, which sets the following interim allocation limits, until permanent limits are set through regional and/or sub-regional plans within each Water Management Area:
  - (a) Primary instream minimum flows: 90% of Q_5 7-day low flow for each river or stream.
  - (b) Primary allocation limit for surface water: 10% of Q_5 7-day low flow for each river or stream.

PC9 also removes Methods 177 and 178 referred to above.

The default limits of PC9 will be replaced as part of the NPSFM engagement process for each Water Management Area in the region. This is currently underway in Rangitāiki and Kaituna-Maketu, Pongakawa and Waitahanui WMAs (towards Plan Change 12). Until then, the primary allocation limit of allocating 10% of the Q_5 7-day low flow and maintaining a minimum flow of 90% of the Q_5 7-day low flow will remain. More robust methods to determine minimum flow and allocation limit will be required, especially in situations where water is over allocated, or where high ecological values occur.

The IFIM studies already conducted will provide useful information to help set minimum flows in selected catchments throughout the region. As part of the PC12 process, community engagement will be undertaken to help develop more specific flow limits.

1.2.3 Summary of water allocation studies by BOPRC

The flow regime can be considered as the "master" controller of ecological processes within rivers, reflecting the importance of the frequency, timing, duration and magnitude of both high and low flows (e.g. Arthington et al 2006; Poff et al 1997; 2010; Davies et al 2013). High flood flows are responsible for maintaining and altering channel morphology and sediment movement in channels, while moderate flows are responsible for "cleansing" the stream bed of excess algal material and generally "resetting" ecosystems. Although flood flows can be altered by structures such as dams and large abstractions, in general there is little that can be done to regulate high flows from a management perspective in most rivers. During periods of low-stable flow, plant biomass can accumulate in some streams (e.g. Suren et al 2003; Suren and Riis 2010) with potentially adverse effects on ecological, recreational and visual values. Although low flows are influenced by climatic events, the magnitude and duration of these can be exacerbated by abstraction pressure. In order to minimise this pressure, low flows are often managed by the application of two resource use limits: minimum flows and a total allocation (Snelder et al. 2013). These resource limits are managed in a way to maximise beneficial outcomes for both environmental and resource use objectives. These objectives can include determining a maximum level of habitat loss in order to maintain fish habitat for selected species, as well as maintaining a maximum and a minimum level of reliability of supply. There is however a complex interaction between how water quantity objectives are defined. Key considerations behind water quantity management objectives include:

- Relationships between habitat and flow, which differs according to fish species.
- The critical instream value (e.g. cultural, a specific fish species, recreational use or natural character) and need to maintain it at a suitable level.
- The reliability of takes.
- The flow regime and the allocation rate and volume.
- Out of stream use values.

A key part of habitat for fish is that of hydraulic habitat suitability (characterised by the combination of a river's width, depth and velocity). Because of this, most flow management decisions are concerned with maintaining ecosystem values for fish, based on maintaining adequate hydraulic habitat. It is however recognised that other instream values can have higher flow requirements than fish, such as recreation activities (e.g. kayaking), maintenance of natural character, and cultural values.

Generally, the suitability of hydraulic habitat for fish is highest at some intermediate flow and decreases as flow either increases (e.g. velocities or depth become too high) or decrease (e.g. depth, width and velocity become too low). The shapes of these relationships vary for different fish species. Because abstractions reduce flows in rivers, they will also decrease the available hydraulic habitat during natural periods of low flow (generally during summer). Setting a minimum flow is therefore concerned with choosing a point on a specific habitat-flow curve at which any further reduction in hydraulic habitat due to abstraction is unacceptable. River flows naturally decrease during summer, and fish species can generally tolerate these natural low flows. The selected level of habitat availability to be maintained is therefore usually based on some percentage of hydraulic habitat available at natural low flows e.g. Mean Annual Low Flow (MALF).

Setting minimum flows in streams can therefore be seen to involve the interplay between four key variables:

- the total amount of water to be abstracted (ΔQ),
- the minimum flow (Q_{min}) at which all abstractions must cease,
- the reliability of supply (R),
- the physical change in hydraulic habitat (ΔH).

Close links exist between these variables. For example, an objective to maximise protection for certain fish species will need to minimise ΔH. This means that Q_{min} is likely to be high relative to MALF. As a consequence, ΔQ will need to be small in order to minimise changes in hydraulic habitat. If ΔQ is increased, this means that the reliability of supply (R) will be lower, as there will be more days when water is not available for abstraction as the streams minimum flow needs to be met to maintain sufficient habitat for a particular fish species.

The work by Jowett (2012) focused on determining robust ways to calculate Q_{min}, based on protecting a certain percentage of hydraulic habitat for fish species known or predicted to be in a particular stream. BOPRC has subsequently commissioned a number of further studies to help improve the processes behind water allocation within the region, and in particular to understand relationships between ΔQ, Q_{min}, R and ΔH.

NIWA has developed a model called Environmental Flow Strategic Allocation Platform (EFSAP) to examine the consequences of various allocation regimes on both in-stream values (i.e. protection of fish habitat), and resource use (e.g. the amount of water allocated, and the reliability of supply). EFSAP is based on a number of individual "components", including:

- the digital river network (REC) that provides a spatial framework;
- regional hydrology models that define flow duration curves and other hydrological estimates;
- generalised fish habitat – flow relationships (based on known habitat suitability curves as well as reach and catchment characteristics) that provide hydraulic habitat estimates for a variety of target fish species at different flows.

In other words, EFSAP effectively performs generalised IFIM assessments of all reaches throughout the region, based on modelled data of flow and river widths, and on the application of generalised fish habitat preference curves (Booker 2015). It differs from the more detailed IFIM assessments in that it provides a temporal component to the analysis, as it interrogates flow duration curves to assess what the effect of a specific minimum flow and allocation on the flow regime and reliability of supply would be.

However, the more detailed IFIM assessments specific to a site are likely to be a better representation of minimum flows for a selected target species within that particular site. This is in part because the EFSAP models of hydraulic geometry at individual reaches, and generalised physical habitat models have a number of potential uncertainties at the reach level. Such uncertainties are then propagated through the various analyses. However, EFSAP has been found to not systematically over- or under-predict change in physical habitat due to flow change, therefore it is useful for setting limits across a WMA or some geographical area.

This means that the observed patterns are probably indicative of the relative differences at a regional scale, but that the uncertainties for individual reaches could be large. Part of the work NIWA did was to firstly develop and test hydrological models for the Bay of Plenty region (Booker et al. 2013). These hydrological models were used to create flow duration curves specific to the region which were used by Booker et al (2014) in a study demonstrating the use of EFSAP throughout the region. Booker then developed more specific physical hydraulic habitat curves for fish in the Bay of Plenty region, based on data collected by Wilding et al as part of their earlier IFIM studies. They subsequently recommended that future applications requiring use of generalised physical habitat models in the region use the more up-to-date regionally specific curves.

Following this work, Snelder et al (2016) used EFSAP to help model the effects of different water allocation regimes on defined management objectives, such as the need to maintain a large amount of hydraulic habitat for fish while maximising allocation reliability. They used trout and torrentfish as critical species to define their potential objectives. These two species were chosen because they have the highest flow requirements of the many fish species found throughout the region[3]. Choosing other critical species, for example tuna that are highly valued and specifically mentioned in iwi Treaty settlement documents, would have the effect of decreasing the minimum flows and increasing the total allocation. This is because tuna generally have lower flow requirements than trout and torrentfish. In other words, using trout and torrentfish as target species for the maintenance of sufficient hydraulic habitat at low flow will provide ample flow for species such as tuna.

Snelder et al (2016) developed a biophysical classification of waterways throughout the region such that waterways within each class were predicted to respond in a similar manner to water abstraction pressures. The water quantity classification was comprised of the same six classes as proposed for water quality: Non-Volcanic, Volcanic+Hill and Volcanic+Low. A further river size subdivision of "Large" (mean flow >$10m^3s^{-1}$) or "Small" (mean flow <$10m^3s^{-1}$) was then imposed on these classes, resulting in six water quantity classes for the region. The division

[3] Note that while Torrentfish have high velocity requirements, they also have shallow depth requirements. Thus, as water is drawn down out of a river, their habitat can increase rather than decrease, depending the hydraulic geometry of the river and the degree to which depth reduces when compared to reductions in velocity.

into large and small streams is also consistent with the provisional NES on ecological flows (although this used 5 m^3s^{-1} as the breakpoint between large and small rivers), and reflects the fact that relatively more water can be extracted from a large river without dramatic changes to hydraulic habitat, whereas small rivers are much more susceptible to changes in hydraulic habitat with smaller relative takes.

Snelder emphasised that, broadly speaking, surface water quantity (i.e. river flow) is managed through the application of two resource use limits: minimum flows and a total allocation. These two limits are imposed to achieve objectives that reflect both environmental and resource use objectives. These objectives effectively define the maximum level of habitat loss, total amount of allocable water, and both a maximum and a minimum level of reliability of supply. Moreover, habitat, and both allocation limit and reliability of supply can be considered as specific attributes with respect to instream values and consumptive water takes, respectively.

Finally, BOPRC commissioned NIWA to undertake a detailed EFSAP analysis of waterways in both the Kaituna-Maketu, Pongakawa and Waitahanui WMA and the Rangitāiki WMA (Gee and Dietrich 2018). This study investigated the consequences of various minimum flows and allocation takes on both reliability of supply and habitat protection for common fish species found in each of these WMAs. Decision space diagrams were subsequently created to allow a visual representation as to the effects of changing Q_{min} and ΔQ on both R and ΔH. These decision space diagrams could be used by Council and communities to determine which combinations of limits (i.e. Q_{min} and ΔQ) best satisfy different objectives (e.g. maintaining R at 90%, and minimising ΔH for various fish species).

1.3 Report purpose

The intent of this report is to present the results of the reanalysis of all the IFIM work previously conducted within the Bay of Plenty region, (based on the advice of Jowett (2012)). This reanalysis identified potential IMFRs for each stream, as well as the target fish species used to each analysis. These new IMFRs were described as a %MALF, to allow for the minimum flows to be compared between rivers of different size. These minimum flows (expressed as %MALF) were then compared between different stream types, and between different fish groups. Because it is impossible to undertake detailed IFIM surveys of all streams in the region, relationships between calculated IMFRs and stream size (MALF) were also examined. If significant relationships were found, then it may be possible to calculate new IMFRs at sites where no IFIM surveys have been undertaken.

This information will feed into the community engagement as part of the development of future sub regional plan changes for each WMA. This report also discusses the various pros and cons of the different methods currently available to BOPRC as part of setting minimum flows throughout the region, and suggests a potential workflow for using the many different methods available. While some methods such as IFIM provide very robust assessments of a stream's minimum flow, they do not provide any information as to the effect of setting such a minimum flow on reliability of supply at various allocation limits. Other more general methods such as EFSAP provide this information, but at a possible loss of accuracy if used for setting minimum flows, when compared to the more bespoke IFIM method. The final choice of methods to set water allocation is likely to involve a combination of different approaches, all of which are regarded as more robust and transparent than the current default hydrological methods.

Part 2: **Methods**

2.1 Assessments of new IMFR

As per Jowett's (2012) concerns based on the original wording of Method 177, some of the previously calculated IMFRs were higher than the river's natural MALF, which serves little ecological purpose. Because of this, all the original data from the previous studies were reanalysed to calculate a percentage of habitat relative to MALF (and not the Q_5 7-day flow). This was done by rerunning the original RHYHABSIM program to generate relationships between flow and weighted usable area (WUA) habitat at incremental flows between zero and MALF. Then the following steps were used:

- Calculate the percentage WUA at incremental flows between 0 and MALF relative to WUA at MALF.
- Determine the maximum percentage WUA between zero flow and MALF.
- Determine the flow at this maximum habitat.
- Determine the primary flow, which is the less of either the flow at the maximum habitat, or the MALF.
- Determine the habitat at this primary flow.
- Multiply the habitat at this primary flow by the recommended protection levels. The habitat retention levels ranged from 100% for species such as shortjaw kōkopu and giant kōkopu, to only 70% for smelt, torrentfish and bluegill bullies (Table 3).
- Determine the flow that meets this new, lower habitat level. This flow is the minimum flow requirement for that particular species.

These steps were run for each of the target fish species at each site. The final in-stream minimum flow requirement (IMFR) for that site was the largest of the minimum flows for the different species at each site. By selecting the largest of these minimum flows, it was assumed that the minimum flow requirements of all the other less flow-demanding species would also be met. The target fish species used at each site were those used in the original reports and were based on a mix of field observations as well as by extracting data from the New Zealand Freshwater Fish Database.

All calculated IMFRs were then expressed as a % of MALF for the stream where the IFIM survey work was done. These values are the same as the Q_{min} term used in the EFSAP analysis.

Table 3 Habitat retention protection levels for key fish species recommended by Jowett (2012) which differed slightly to those used in the original RWLP.

Target species	Habitat retention level
Shortjaw kōkopu	100%
Giant kōkopu	100%
Other kōkopu species	95%
Koaro (adult)	90%
Inanga	90%
Trout angling[1]	95%
Trout spawning/rearing[1]	95%
Bullies, excluding bluegill	90%
Eels (tuna) juvenile	80%
Eels (tuna) adult	75%
Smelt	70%
Torrentfish	70%
Bluegill bullies	70%

Note that the fish species and habitat protection levels adopted in future sub regional plan changes will need to be discussed with iwi and the community to see if they are acceptable. For example, the relatively low amount of habitat protection for tuna may be deemed unacceptable to iwi, given their taonga status. However, this current relatively low level of protection reflects that that that tuna are not particularly "flow hungry".

2.2 Summary of the % MALF set as IMFRs

Once the new IMFRs were calculated, we examined whether these differed between rivers from different biophysical classifications, or in rivers where different fish species were targeted for the objective-setting process. The 56 waterways assessed varied greatly in their MALF, ranging from a low of only 7 l/s (Waipapa tributary at Jeffco farm) to the Tarawera River (MALF = 22,549 l/s). Because of this inherently large difference in MALF, the % of MALF available for allocation (%MALF) was calculated for these comparisons by dividing the IMFR by MALF. The result of this was the Q_{min}, as used in EFSAP, expressed as a % of MALF. Analysis of Variance (ANOVA) was used to see whether Q_{min} differed between the six different biophysical units. A similar analysis was done to see whether the Q_{min} also differed between different fish classes. This was done as rivers being managed for trout may have had, for example, a higher Q_{min} than rivers where the protection of hydraulic habitat for native fish was set as an objective, as the latter fish are not as "flow hungry".

Selection of the different fish species used in each IMFR calculation was initially based on habitat suitability models used in the RHYHABSIM programme. However, many of the habitat preference curves used by RHYHABSIM were based on hydraulic preferences for different size stages of the same species, or for different activities performed by fish.

For example, there were five different suitability curves for rainbow trout:

- Rainbow trout adult (Bovee 1978).
- Rainbow trout adult (Tongariro).
- Rainbow trout adult feeding (Thomas & Bovee (1993)).
- Rainbow trout feeding (30-40 cm Cheeseman Bovee).
- Rainbow trout spawning (Tongariro).

For a better analysis of differences between the %MALF and fish species, these individual habitat suitability curves were combined into larger classes that described the main species of interest, such as Rainbow, or Brown Trout (Table 4). Other habitat suitability curves were combined when the hydraulic habitat preferences of different species appeared similar. Thus, redfin bully and common bully were combined into a single "Bully" class, while banded kōkopu, smelt and inanga were combined to form a "Lowland_Slow" class. This reflected their general preference for slow-flowing (< 0.4 ms^{-1}) and relatively deep (> 0.5 m) water. Torrentfish remained in a class of its own, reflecting their hydraulic habitat preference for shallow, fast flowing water. Note that eels were never selected as the target fish for any IMFR, as the amount flow required to maintain their % of WUA habitat relative to MALF was always less than that of the other species. These broad classes were subsequently used to assess whether %MALF differed between the different fish classes.

Table 4 List of broad fish classes used for further analyses in this report, based on the original habitat preference curves as used in RHYHABSIM, as well as the number of streams where these classes were used.

Broad fish class	Original habitat suitability class	Number of IFIM surveys
Brown trout	Brown trout adult (Hayes & Jowett 1994).	7
	Brown trout fry to 15 cm (Raleigh et al.).	2
	Brown trout spawning (Shirvell & Dungey 1983).	1
Rainbow trout adult	Rainbow adult Tongariro.	1
	Rainbow trout.	1
	Rainbow trout - adult feeding.	1
	Rainbow trout – feeding.	1
	Rainbow trout adult (Bovee 1978).	2
	Rainbow trout adult (Tongariro).	2
	Rainbow trout adult feeding (Thomas & Bovee (1993)).	4
	Rainbow trout feeding (30-40 cm Cheeseman Bovee).	2
	Rainbow trout spawning (Tongariro).	1
Rainbow trout juvenile	Juvenile rainbow trout feeding (Cheeseman Bovee).	2
	Rainbow trout juvenile feeding (Thomas & Bovee (1993)).	3

Broad fish class	Original habitat suitability class	Number of IFIM surveys
Torrentfish	Torrentfish.	4
Bully	Common bully.	3
	Redfin bully.	8
Lowland_Slow	Banded kōkopu.	5
	Inanga.	2
	Smelt.	2

2.3 Relationships between IMFR and MALF

In the original IMFR reports, Wilding et al (2003) and others highlighted that it was not possible to undertake detailed IFIM assessments on all reaches within the region, or indeed even within a single WMA. Because of this, they investigated whether there were any strong relationships between a stream's measured low flow (in their case the Q_5 7-day low flow) and the resultant IMFR, based on a defined level of habitat protection for a specific fish species. If such relationships were evident, then this may have implications for estimating new IMFRs for the same species in streams where detailed IMFR assessments have not been made, based simply on assessing the minimum flow of a particular target stream. They found that, in many cases, strong relationships existed between a stream's calculated IMFR, and its natural Q_5 7-day flow (Table 5). Based on these relationships, they suggested that it should be possible to estimate the IMFR of other streams where detailed instream habitat surveys had not been done, but where the Q_5 7-day flow was known.

Table 5 Observed linear relationships between calculated IMFR and a stream's known Q_5 7-day low flow in reports previously done for BOPRC. The slope and constant are given for the equation IMFR = slope x Q_5 + constant. All these regressions were highly significant ($P < 0.001$), and explained a large amount of total variation in the data ($r^2 > 0.9$).

Report	Streams	Target fish	Slope	Constant
Wilding 2002	Haumea	Rainbow trout	0.898	16.21
Wilding 2003	Tauranga streams (29)	Native fish (small streams)	0.864	1.260
	Tauranga + Kaimai streams	Native fish	0.884	1.524
Wilding 2002	Kaimais	Native fish	0.893	3.024

A similar analysis was done with the newly calculated IMFRs, which were then regressed against each stream's MALF to determine if the same relationships existed. Wilding (2003) emphasised that the many streams that they did IFIM analyses on had very different hydrological behaviours. This meant that his regressions were performed only on streams from the same area. Because of this concern, we used analysis of covariance (ANCOVA) to assess relationships between a stream's MALF and the resultant IMFR. ANCOVA is used when a relationship between two variables (in this case MALF and IMFR) may be influenced by a particular grouping (in this case the stream type, or target fish species), and assesses whether the slopes and the Y-intercepts of the relationship between MALF and IMFR are the same between specified groups. More details of ANCOVA are in Appendix 3.

This analysis was also repeated using data gleaned from Environment Canterbury (15 rivers) and Greater Wellington Regional Council (20 rivers) to see whether similar relationships existed between IMFRs derived at these sites and their MALF. ANCOVA was used to determine if these relationships differed between the three regions.

Finally, a third ANCOVA was done using the different target fish species used to find IMFRs in each site, to see whether relationships between the calculated IMFR and MALF differed between fish species. If observed relationships between calculated IMFRs and MALF differed between different stream types or fish species, then this would have major implications for developing IMFRs in ungauged catchments.

Part 3: **Results**

3.1 Assessments of new IMFRs

The 60 IFIM sites were spread throughout the region, with most sites in the western and central parts (Figure 1). Only a single site (the Puremutahuri) was located in the East Coast WMA. More detailed maps showing the location of each site are shown in Appendix 1. The cumulative area of all the catchments above each IFIM site was 5,035 km^2. Given that the Bay of Plenty region has a total land area of 12,279 km^2, this means that about 41% of the region's land area (not stream length) has in effect had an IFIM done on them to define the minimum flow for the protection of aquatic life. Calculations of the length of waterways above each of the IFIM sites showed a similar result. Thus, of the 18,462 km of waterways in the region, 7,797 km (or 42%) were above sites where IFIMs had been done.

Note that this analysis has the caveat that it is assumed that the IFIM reaches are indeed representative of other reaches upstream, and that no upstream reaches will have higher minimum flows based on different fish assemblages, or different instream habitat conditions. However, it is reasonable to assume that, for the purposes of this report, the chosen IFIM reaches were indeed representative of the overall catchment conditions upstream. This means that any water takes in the upstream sites need to operate with regard to the downstream IFIM-derived IMFR. Finally, it is important to highlight that this analysis does not include the recent IMFR for the lower Rangitāiki River that has been set for the operation of the Trustpower hydroelectric power dam at Matahina. This has set a minimum flow for the river at Te Teko based not on ecological values, but on the need to maintain sufficient freshwater in the lower river to minimise the upstream movement of the salt wedge during high tides.

Although approximately 40% of the region's land area, or stream length is above sites where IMFRs have been established, it should be noted that much of the water demand is in the lower coastal parts of catchments, while many of the IFIM sites were in the upper catchments. Indeed, 31 catchments had less than half their total waterway length above the IFIM sites, and many had less than 10% (Figure 2). This means that, in many areas, the bulk of abstraction is occurring below the areas where IFIM surveys were done. This has implications on our ability to use the IFIM derived IMFR values in these lower reaches, unless suitable relationships between a stream's calculated IMFR and its low flow (e.g. MALF) can be established. If strong relationships between a stream's IMFR and its MALF are established, then IMFRs can be set in the lower reaches of these rivers. Although the remaining 60% of the region has not had IMFRs formally set, it must be remembered that a large percentage of this area is in native bush, where pressure for water takes would be considered minimal, or non-existent. It is only in other more developed parts of the region where IFIM surveys have not been done and which may be subject to abstraction pressure that IMFRs will need to be formally set.

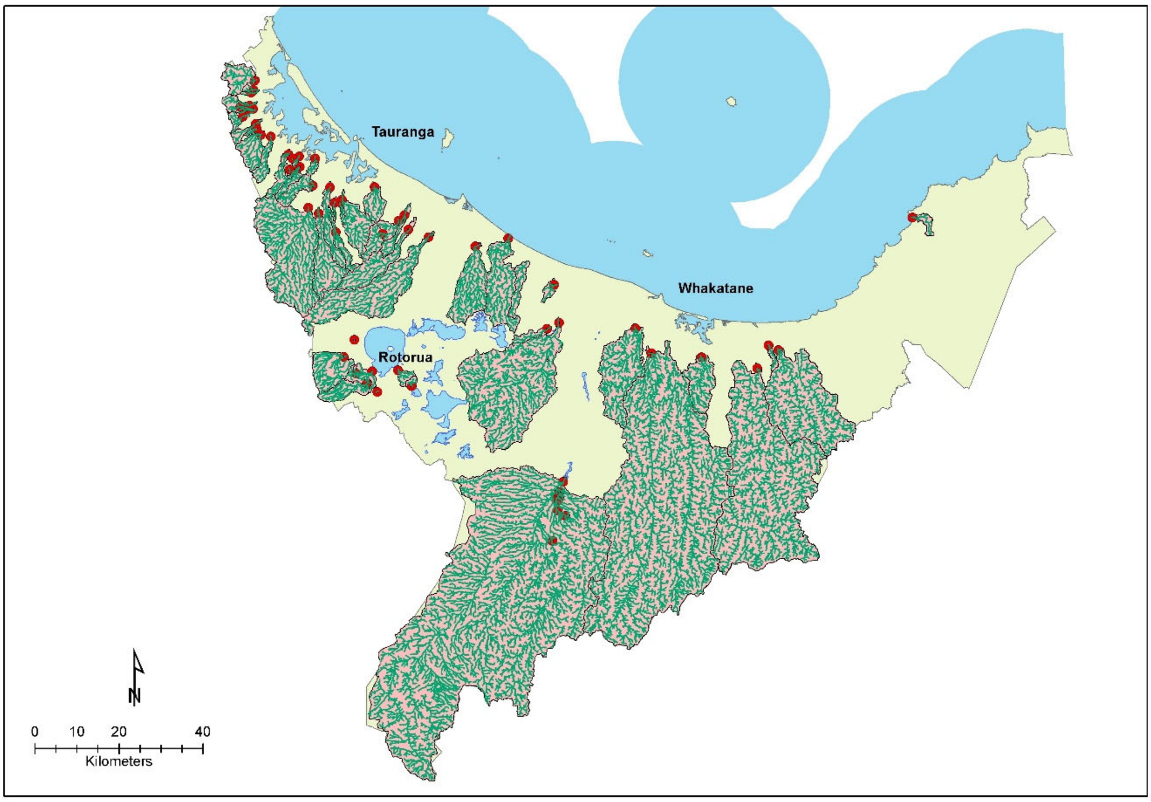


Figure 1 *Location of all 60 IFIM sites throughout the region, including all waterways in their catchments above each sampling point. Note that although smaller catchments in the Galatea Plains have their own IMFRs, these would all need to be enforced to ensure the lowest downstream IMFR is met.*

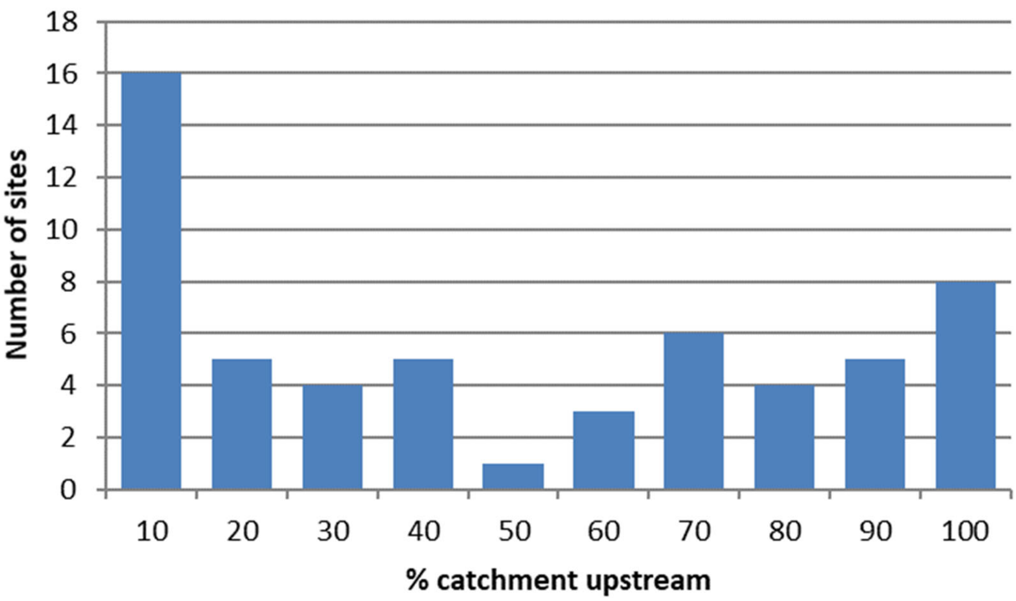


Figure 2 *The number of sites surveyed throughout the region with different percentages of total upstream waterway length above each IFIM site.*

New IMFRs were calculated for 56 of the rivers from where previous IFIM surveys had been done. The choice of fish species for each river was based on what fish were found there, either from direct observation or from interrogation of the New Zealand freshwater fish database. Four sites (Tautau, Upper Rangitāiki at Galatea, Waiari and Waiorohi) surveyed by NIWA were not recalculated, as we were unable to obtain the original RHYHBSIM datafiles. The results of these new calculations are presented in Table 6, along with the target fish species that was selected as having highest instream minimum flow requirement. Examination of the new IMFRs for these 56 rivers showed that all the recommended minimum flows were less than MALF (Table 6), which appears to fix the anomaly of the calculations of IMFRs based on the old Method 177. This reanalysis also showed that nine rivers used a different target fish for the new analysis (Table 6), as these new fish species had the greatest minimum flow requirement based on retaining a percentage of WUA habitat at MALF.

Table 6 Results of the new IFIM calculations relative to habitat at MALF[4]. Also shown are the fish species selected in each study that had the greatest flow requirement. Green shading indicates where these differed to the target fish used in the previous reports. Red shading indicates the original RHYHABSIM files are not available.

River	Study	WMA	MALF (L/s)	Old IMFR (L/s)	New IMFR (L/s)	Old fish species used	New fish species
Aongatete	Wilding 2002	Tauranga Harbour	225	169	165	Common bully.	Common bully.
Awakaponga	Bloxham 2005	Tarawera	60	46	57	Brown trout adult (Hayes & Jowett 1994).	Brown trout adult (Hayes & Jowett 1994).
Boyd Tributary	Wilding 2002	Tauranga Harbour	20	13	18	Banded kōkopu.	Banded Kokopu
Haumea at Galatea	Wilding 2002	Rangitāiki	925	706	850	Rainbow trout juvenile feeding (Thomas & Bovee 1993).	Rainbow trout juvenile feeding (Thomas & Bovee 1993).
Haumea at Magee's	Wilding 2002	Rangitāiki	475	369	300	Juvenile rainbow trout feeding (Thomas and Bouvee 1993).	Juvenile Rainbow trout feeding (Thomas and Bouvee 1993)
Joyce	Wilding 2003	Tauranga Harbour	30	15	7	Banded kōkopu	Banded kōkopu.
Kopurereroa	Wilding 2003	Tauranga Harbour	1490	1200	1420	Rainbow adult trout feeding (Cheeseman).	Rainbow adult trout feeding (Cheeseman).
Mangakakahi	Bloxham 2005	Rotorua Lakes	69	187	60	Brown trout adult (Hayes & Jowett 1994).	Brown trout adult (Hayes & Jowett 1994).
Mangakotukutuku	Wilding 2002	Rangitaiki	110	95	90	Rainbow trout juvenile feeding (Thomas & Bovee 1993).	Rainbow trout juvenile feeding (Thomas & Bovee 1993).
Mangamutu	Wilding 2002	Rangitāiki	60	45	50	Longfin eel/Rainbow trout.	Rainbow trout juvenile feeding (Thomas & Bovee 1993).
Mangaone	Bloxham 2008	Tarawera	1480	1482	1480	Rainbow trout feeding (30-40 cm Cheeseman Bovee).	Brown trout spawning (Shirvell & Dungey 1983).

[4] Note that the values of MALF used here are the same values as given in the individual IFIM reports. Some of these values have now changed as more up-to-date flow data is made available. However, the original values of MALF were used in this report to be consistent with the earlier studies.

River	Study	WMA	MALF (L/s)	Old IMFR (L/s)	New IMFR (L/s)	Old fish species used	New fish species
Mangawhai	Wilding 2003	Tauranga Harbour	10	12	7	Redfin bully.	Redfin bully.
Mangorewa	Wilding 2003	Kaituna, Maketu and Pongakawa	6000	4325	5630	Rainbow adult Tongariro.	Rainbow adult Tongariro.
Mill Stream	Bloxham 2008	Waioeka and Otara	70	40	69	Brown trout adult (Hayes & Jowett 1994).	Brown trout adult (Hayes & Jowett 1994).
Miller Road	Bloxham 2005	Rotorua Lakes	7	6	6	Brown and Rainbow trout.	Brown and Rainbow trout.
Ngongotaha	Bloxham 2005	Rotorua Lakes	1235	1160	1190	Brown trout fry to 15 cm (Raleigh et al.).	Brown trout fry to 15 cm (Raleigh et al.).
Ngututuru	Wilding 2002	Tauranga Harbour	20	17	15	Inanga.	Inanga.
Nukuhou	Suren 2013	Ohiwa	201		165		Torrentfish.
Ohinieangaanga	Wilding 2003	Kaituna, Maketu and Pongakawa	205	170	86	Torrentfish.	Torrentfish.
Ohourere	Wilding 2003	Tauranga Harbour	250	120	225	Rainbow trout adult (Bovee 1978).	Rainbow trout adult (Bovee 1978).
Omanawa	Wilding 2003	Tauranga Harbour	1075	890	980	Rainbow trout adult (Bovee 1978).	Rainbow trout adult (Bovee 1978).
Otara	Bloxham 2008	Waioeka and Otara	2864	5570	2510	Rainbow trout spawning (Tongariro).	Rainbow trout spawning (Tongariro).
Oturu	Wilding 2003	Tauranga Harbour	20	12	19	Banded kōkopu.	Banded kōkopu.
Pongakawa	Wilding 2003	Kaituna, Maketu and Pongakawa	4450	3050	4200	Rainbow trout adult (Tongariro, 1978).	Rainbow trout adult (Tongariro, 1978).
Puremutahuri	Bloxham 2008	East Coast	58	50	48	Common bully.	Common bully.
Raparapahoe number four	Wilding 2003	Kaituna, Maketu and Pongakawa	600	480	300	Small adult (Bovee).	Rainbow trout adult feeding (Thomas & Bovee (1993)).
Raparapahoe number three	Wilding 2003	Kaituna, Maketu and Pongakawa	300	230	253	Rainbow trout adult feeding (Thomas & Bovee (1993)).	Rainbow trout adult feeding (Thomas & Bovee (1993)).
Ruarepuae at Bannans Farm	Wilding 2002	Rangitaiki	50	46	46	Rainbow trout juvenile feeding (Thomas & Bovee 1993).	Rainbow trout juvenile feeding (Thomas & Bovee 1993).

River	Study	WMA	MALF (L/s)	Old IMFR (L/s)	New IMFR (L/s)	Old fish species used	New fish species
Ruarepuae at Waitaruna	Wilding 2002	Rangitaiki	300	255	276	Shortfin eel (<300 mm) (Jowett and Richardson 1995).	Shortfin eel (<300 mm) (Jowett and Richardson 1995).
Tahawai L/B	Wilding 2002	Tauranga Harbour	35	28	25	Torrentfish.	Torrentfish.
Tahawai R/B	Wilding 2002	Tauranga Harbour	15	10	10	Redfin bully.	Redfin bully.
Tarawera	Bloxham 2008	Tarawera	22549	6371	6370	Rainbow trout feeding (30-40 cm Cheeseman Bovee).	Rainbow trout feeding (30-40 cm Cheeseman Bovee).
Tautau	NIWA 2001	Tauranga Harbour		200		Juvenile rainbow trout.	
Te Puna at rapids	Wilding 2003	Tauranga Harbour	150	115	74	Redfin bully.	Redfin bully.
Te Puna tributary	Wilding 2003	Tauranga Harbour	11	3	7	Redfin bully.	Redfin bully.
Te Rereatukahia	Wilding 2002	Tauranga Harbour	95	73	55	Torrentfish.	Redfin bully.
Tuapiro	Wilding 2002	Tauranga Harbour	400	317	390	Torrentfish.	Rainbow trout – feeding.
Tuapo	Wilding 2002	Tauranga Harbour	50	44	43	Redfin bully.	Smelt.
Upper Rangitaiki at Galatea	NIWA 2004	Rangitaiki	20600	8700		Rainbow trout - medium and large.	
Uretara at Rea	Wilding 2002	Tauranga Harbour	210	167	155	Torrentfish.	Smelt.
Uretara at Wharawhara	Wilding 2002	Tauranga Harbour	200	150	100	Torrentfish.	Torrentfish.
Utuhina downstream	Bloxham 2005	Rotorua Lakes	1315	1100	1250	Juvenile rainbow trout feeding (Cheeseman Bovee).	Juvenile rainbow trout feeding (Cheeseman Bovee).
Utuhina upstream	Bloxham 2005	Rotorua Lakes	970	920	890	Rainbow trout feeding (30-40 cm Cheeseman Bovee).	Rainbow trout feeding (30-40 cm Cheeseman Bovee).
Waiari	NIWA 2001	Kaituna, Maketu and Pongakawa	3448	2500		Adult and juvenile rainbow trout.	Juvenile rainbow trout feeding (Cheeseman Bovee).
Waimapu at McCarrols Farm	Suren 2013	Tauranga Harbour	769		190		Banded kōkopu.

River	Study	WMA	MALF (L/s)	Old IMFR (L/s)	New IMFR (L/s)	Old fish species used	New fish species
Waingaehe	Bloxham 2005	Rotorua Lakes	205	186	195	Brown trout adult (Hayes & Jowett).	Brown trout adult (Hayes & Jowett).
Waioeka	Bloxham 2008	Waioeka and Otara	5136	6365	4800	Rainbow trout spawning (Tongariro).	Rainbow trout spawning (Tongariro).
Waioho	Bloxham 2008	Whakatane and Waimana	400	193	228	Redfin bully	Redfin bully.
Waiorohi	NIWA 2001	Tauranga Harbour		200		Common and redfin bully.	
Waipa	Bloxham 2005	Rotorua Lakes	480	420	460	Brown trout adult (Hayes & Jowett 1994).	Brown trout adult (Hayes & Jowett 1994).
Waipapa Tributary at Jeffco farm	Wilding 2003	Tauranga Harbour	7	4	4	Banded kōkopu.	Banded kōkopu.
Waipapa Tributary at Plumer Road	Wilding 2003	Tauranga Harbour	30	28	20	Redfin bully.	Redfin bully.
Wairoa	Wilding 2003	Tauranga Harbour	425	371	390	Rainbow trout adult (Tongariro).	Rainbow trout adult (Tongariro).
Waitahanui	Wilding 2000	Kaituna, Maketu and Pongakawa	4950	3800	4100	Rainbow trout (Wilding).	Inanga.
Waitao	Wilding 2003	Tauranga Harbour	170	125	122	Common bully.	Common bully.
Waitetī	Bloxham 2005	Rotorua Lakes	880	800	810	Brown trout adult (Hayes & Jowett).	Brown trout yearling (Raleigh et al 1986).
Whakatāne	Bloxham 2008	Whakatane and Waimana	11319	11617	10050	Rainbow trout feeding (30-40 cm Cheeseman Bovee).	Brown trout adult (Hayes & Jowett) OR Rainbow trout feeding (30-40 cm Cheeseman Bovee).
Whatakao	Wilding 2003	Tauranga Harbour	180	85	110	Redfin bully.	Redfin bully.
Whirinaki	NIWA 2004	Rangitaiki	5200	6500		Rainbow trout - medium and large.	

The most common fish group used to set IMFRs was the adult Rainbow trout group (15 sites), followed by bullys (11 sites) and brown trout (10 sites). The catchments where these IMFRs were done were spread throughout the region (Figure 3). The "Lowland_Slow" group, consisting of banded kōkopu, inanga and smelt, was used at nine sites, mainly in the western part of the region.

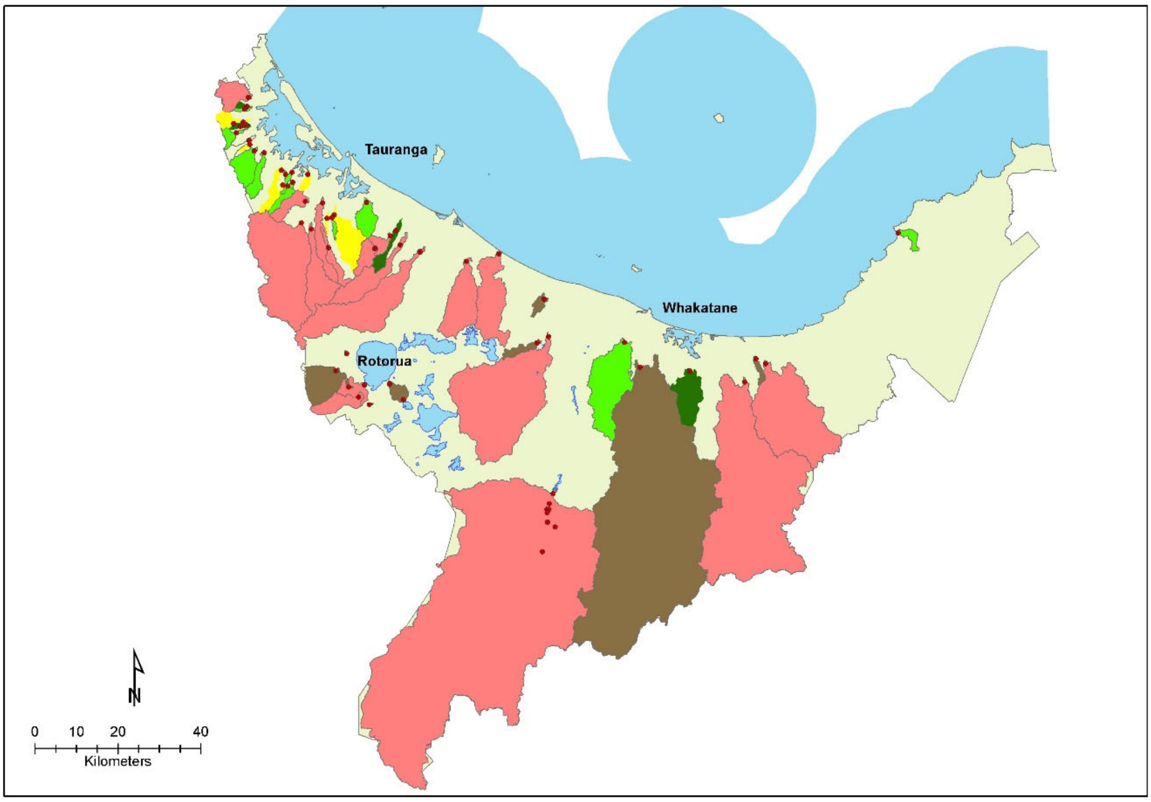


Figure 3 *Map showing the main target fish used to set the IMFRs at the sites where detailed IFIM surveys had been undertaken. (Red = Rainbow trout; Brown = Brown trout; light green = bullies, dark green = Torrentfish, yellow = Lowland_Slow). Note that all IFIM sites in the Rangitāiki catchments used Rainbow trout as their IMFR setting objective.*

3.2 Summary of Q_{min} based on IFIM calculations

On average Q_{min} was 77% of MALF, although there was a wide range in values (24% to 98%). The current default Q_{min} for waterways in the region has been set at 90% of the Q_5 7-day flow. Values of the Q_5 7-day flow were available in only 50 of the streams where IFIM surveys had been done. Thirty-two these 50 streams had calculated Q_{min} values greater than or equal to 90% of the Q_5 7-day flow. Of these streams, 24 were providing habitat protection for either rainbow or brown trout, both of which are generally very "flow hungry". In contrast, 18 streams had calculated Q_{min} values less than the 90% default limit, 16 of which had target species that were native (either banded kōkopu, bully or torrentfish). Only two streams that were providing habitat protection for trout had their calculated Q_{min} values less than the 90% default limit. This result highlights the fact that trout generally require proportionally flow in streams than native fish.

ANOVA showed that there were no differences in Q_{min} and the biophysical stream type (F = 1.01, p = 0.412) most likely reflecting the highly variable Q_{min} identified in some of the biophysical classes (Figure 4). This finding implies that the biophysical classification suggested by Snelder et al did not explain variability to Q_{min}. Gee and Dietrich (2018) reported a similar result in that EFSAP modelling for the Rangitāiki and the Kaituna-Maketu Pongakawa-Waitahanui WMA also showed a wide range of instream and out-of-stream outcomes within each reach biophysical group. However, this does not suggest that the biophysical classification is not useful.

As mentioned, calculation of Q_{min} as part of the IFIM analysis tells us nothing about the reliability of supply or the total amount of water that can be allocated. So although strong relationships exist between Q_{min} and MALF that are independent of biophysical class, the amount of water that can be available for allocation and the reliability of supply are likely to differ between streams in the different biophysical classes, especially given the different hydrological regimes in these classes (Booker 2014; Snelder et al 2016). For example, Booker (2014) showed that the proportion of time in February that flow was lower than the 7-day MALF varied across the region. Rivers to the west of the Rangitāiki River were below MALF for between 21 – 27% of the time in February, whereas rivers to the east of here were generally below MALF for only between 5 – 20% of the time). These regional differences have implications for both reliability of supply to water users and for ecological effects if minimum flow and total allocations are set as a proportion of 7-day mean annual low flow. This implies that any regression between Q_{min} and MALF can only be used to help set minimum flow in streams where IFIM surveys have not been done, but cannot be used to assess the consequences of these minimum flows.

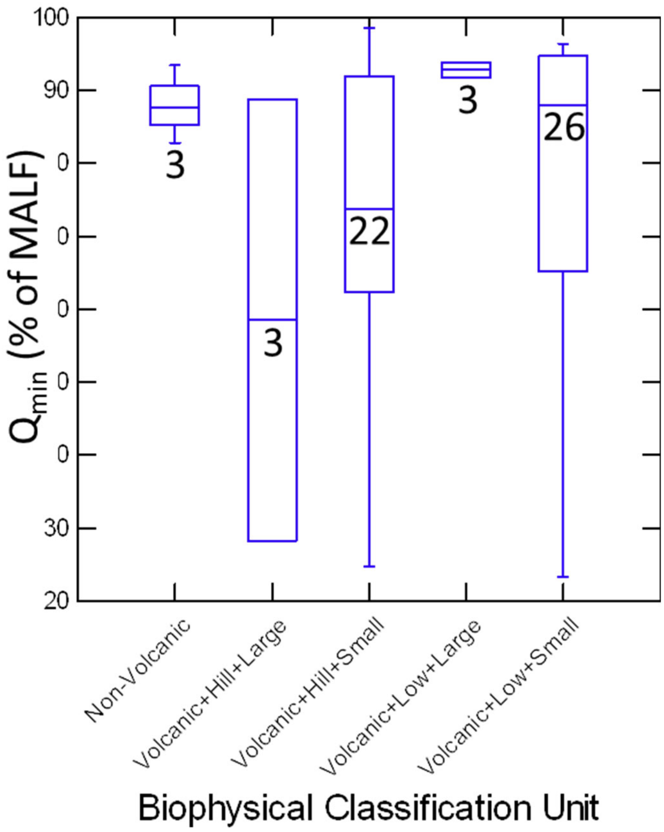


Figure 4 *Box plot of the calculated Q_{min} (as a % of MALF) in streams when grouped according to their biophysical class. Note the high variability of Q_{min} in each biophysical class. The number of reaches in each of the biophysical classes is also shown.*

ANOVA showed highly significant differences between values of Q_{min} and the target fish class used to select the minimum flow ($F = 5.93$, $p < 0.001$). Highest values of Q_{min} were observed for Brown and Rainbow trout, while the lowest values were for Torrentfish[5] and bullies (Figure 5).

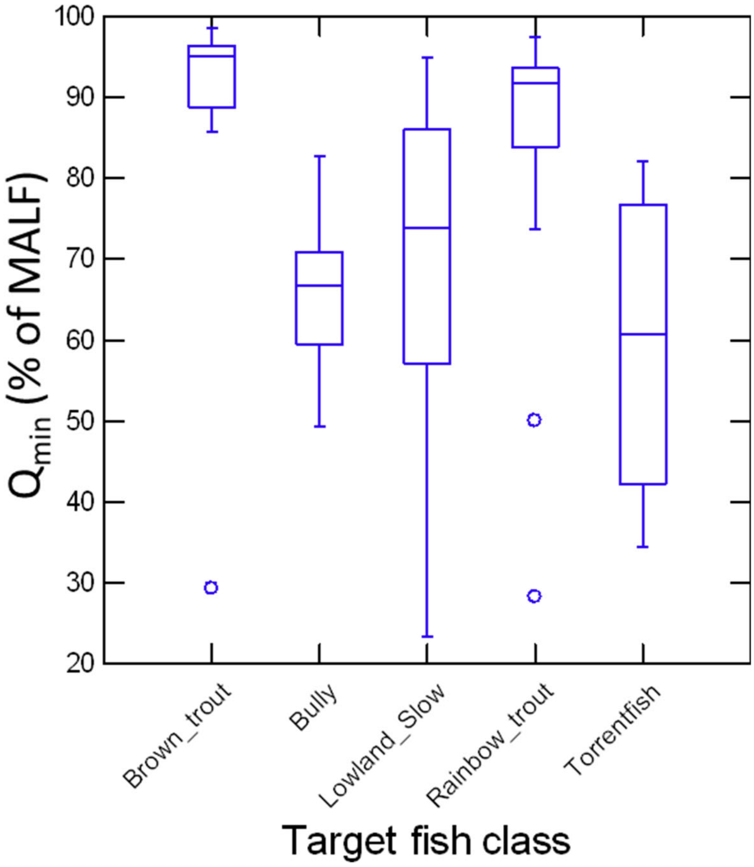


Figure 5 *Box plot of the calculated Q_{min} (as a % of MALF) in streams when grouped according to what the target fish class was selected for the choice of IMFR. Note how both Brown and Rainbow trout had the highest values of Q_{min}, followed by the "Lowland-Slow" group of fish (banded kōkopu, inanga and smelt), bullys and Torrentfish.*

If the fish classes were combined into two broader classes ("Native" and "Salmonid") then Q_{min} was significantly higher in the salmonid class than the native class ($F = 21.48$, $p < 0.001$; Figure 6). Again this reflects the more flow hungry nature of the salmonids when compared to native fish. These results suggest that when developing new minimum flows where IFIM surveys have not been done previously, it may be simpler to just calculate any new IMFR based on either "native" or "salmonid" classes using the appropriate regression equations (see below).

---

[5] Although Torrentfish generally prefer fast flowing water, they also prefer shallow water over deep water. As such, there may be apparent contradictory responses of torrentfish to reduced flows, depending on whether depth or velocities are reduced more.

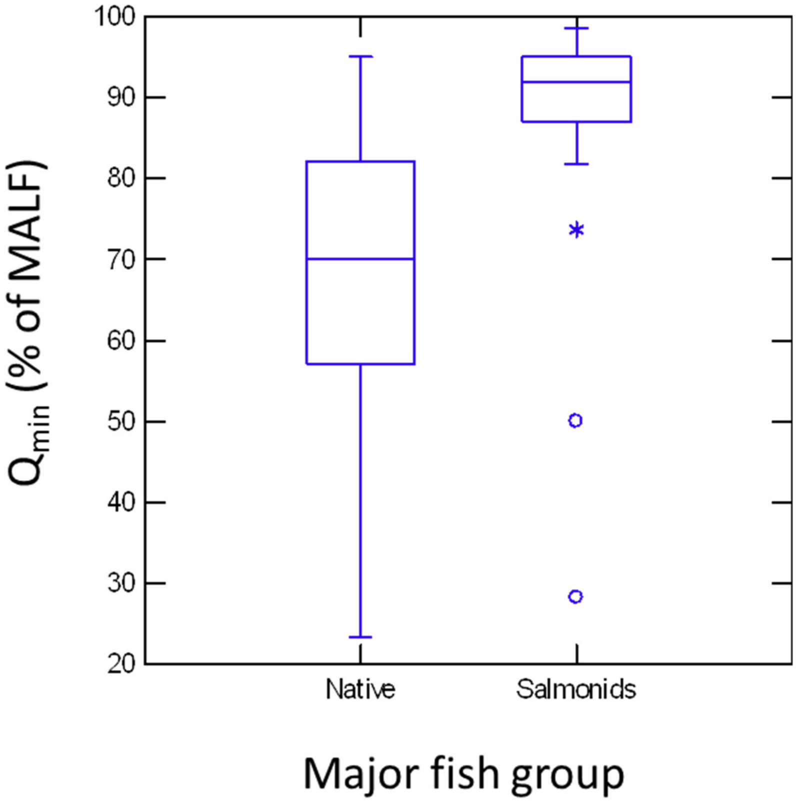


Figure 6 *Box plot of the calculated Q_{min} (as a % of MALF) in streams when grouped according to whether the target fish class were either "Salmonid", or "Native".*

3.3 Relationships between MALF and IMFR

Wilding et al (2001) reported strong relationships between a stream's Q_5 7-day low flow and the resultant IMFR. This relationship has implications for developing IMFRs in ungauged catchments where detailed IFIM surveys have not been done. To further explore the generality of these relationships, data was obtained from two other regions (Canterbury and Wellington). ANCOVA was used to assess relationships between a stream's calculated IMFR and its MALF, while factoring in any effects of the different stream biophysical classes, region, or the different fish types (i.e. nominal variables). Results of all ANCOVA's showed highly significant relationships between the IMFR and MALF in all cases, but the slopes of this regression line was always similar between classes in each of the nominal variables (i.e. there was no significant interaction effect between biophysical class, region and fish type and MALF: Table 7).

There was no significant difference in the Y-intercepts for the different stream biophysical classes (Table 7; Figure 7). A similar result was observed for the relationships between IMFR and MALF using the combined Bay of Plenty, Environment Canterbury and Greater Wellington Regional Council data (Table 7; Figure 8). These results emphasised that larger waterways simply had larger IMFRs (by flow), and that such relationships were similar between stream types, or between streams in different regions.

The third ANCOVA examining relationships between IMFR and MALF using major fish classes as a covariate showed a significant effect of the different fish species (Table 7). Here, brown and rainbow trout had higher IMFR values for a given MALF than the other fish groups. A similar result was found in the fourth ANCOVA of relationships between IMFR and MALF in either native or salmonids, where there was a highly significant difference in the slopes of these relationships between "Native" versus "Salmonid" (Table 7). Thus IMFRs derived for salmonids were significantly higher for a given MALF than IMFRs derived for native fish (Figure 9). Again, this result emphasises the greater flow requirements of salmonids than native fish. Overall, these results suggest that, not surprisingly, the larger a stream, the greater the IMFR was, but that a stream's biophysical classification nor its location influenced this relationship. However, for a given MALF, fish such as Brown and Rainbow trout had a higher IMFR than native fish.

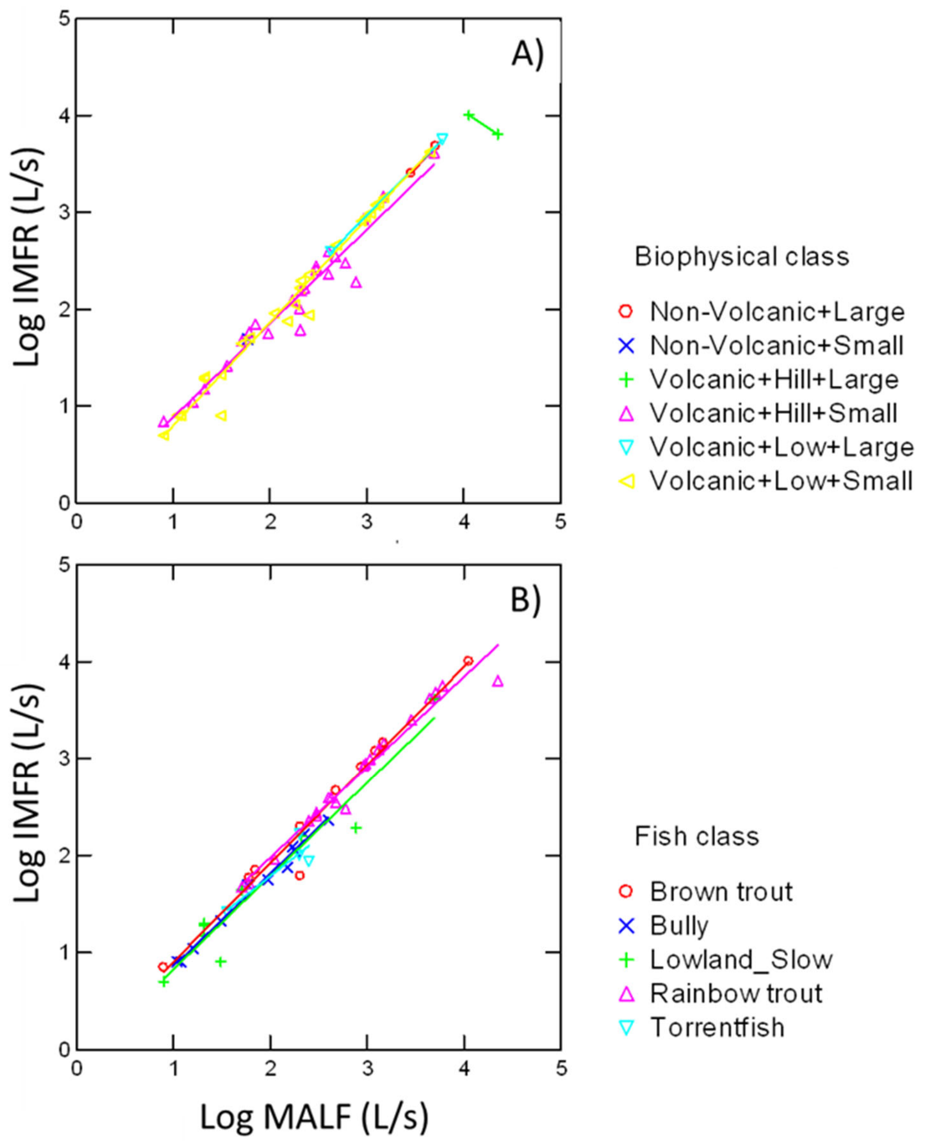


Figure 7 *Relationships between the calculated IMFR and a stream's MALF, showing how this relationship was similar between streams of A) different biophysical class, or B) between different target fish groups.*

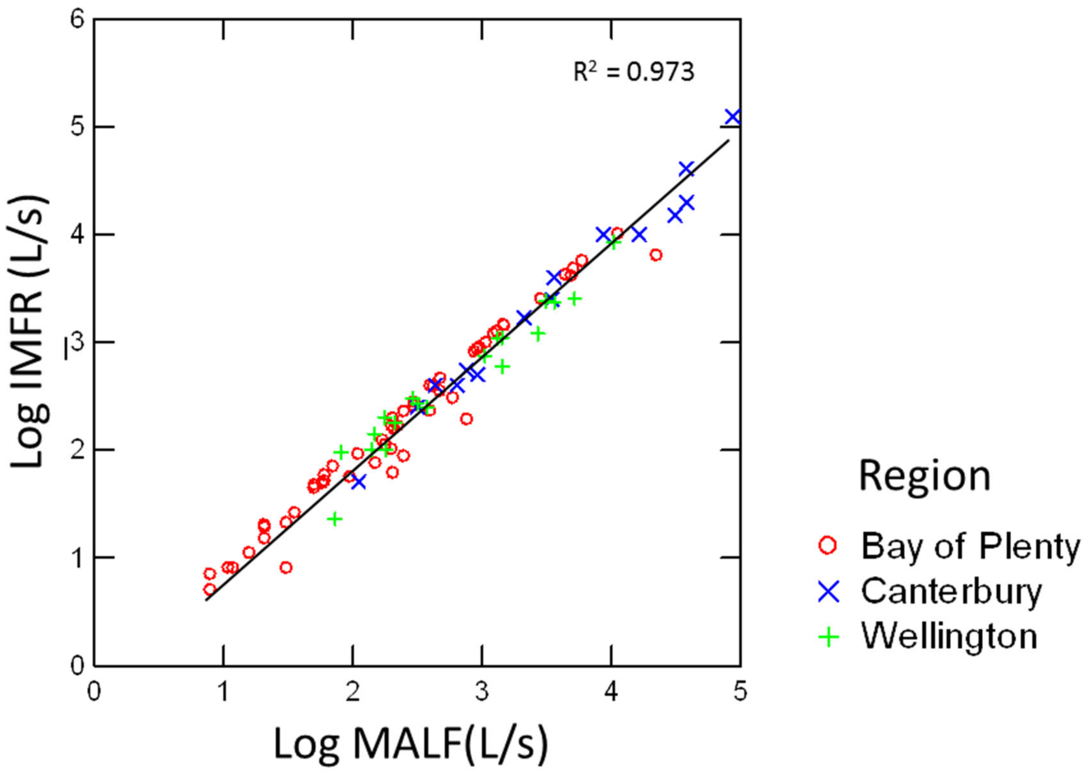


Figure 8 *Relationships between the calculated IMFR and a stream's MALF in the Bay of Plenty, Canterbury and Wellington regions. Note how this relationship was similar between streams in each region, and the very high explanatory power of the overall regression.*

Table 7 Results of ANCOVA investigating relationships between a stream's IMFR and its MALF, between the different biophysical classes. The table shows the first test of the ANCOVA to see whether the slope differs between each biophysical unit, overall effect of the covariate, as well as the independent variable (log MALF) on the calculated IMFRs. Significant relationships in bold.

Nominal variable	Testing for	Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
Biophysical unit	Slope	**LOG_MALF**	**0.477**	**1**	**0.477**	**25.721**	**0.000**
		BPU_VER2$	0.139	4	0.035	1.880	0.131
		BPU_VER2$*LOG_MALF	0.140	4	0.035	1.891	0.129
		Error	0.816	44	0.019		
	Y-intercept	**LOG_MALF**	**28.297**	**1**	**28.297**	**1420.265**	**0.000**
		BPU_VER2$	0.116	4	0.029	1.452	0.231
		Error	0.956	48	0.020		
Region	Slope	**LOG_MALF**	**22.282**	**1**	**22.282**	**1125.100**	**0.000**
		REGION$	0.042	2	0.021	1.053	0.354
		REGION$*LOG_MALF	0.025	2	0.012	0.630	0.535
		Error	1.644	83	0.020		
	Y-intercept	**LOG_MALF**	**49.184**	**1**	**49.184**	**2505.263**	**0.000**
		REGION$	0.045	2	0.022	1.141	0.324
		Error	1.669	85	0.020		
Fish Class	Slope	**LOG_MALF**	**7.226**	**1**	**7.226**	**407.434**	**0.000**
		NEW_FISH_CLASS$	0.042	4	0.010	0.590	0.672
		NEW_FISH_CLASS$*LOG_MALF	0.026	4	0.006	0.366	0.831
		Error	0.780	44	0.018		
	Y-intercept	**LOG_MALF**	**24.618**	**1**	**24.618**	**1465.535**	**0.000**
		NEW_FISH_CLASS$	**0.266**	**4**	**0.066**	**3.955**	**0.007**

Nominal variable	Testing for	Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
		Error	0.806	48	0.017		
Native:Salmonid	Slope	**LOG_MALF**	**23.654**	**1**	**23.654**	**1502.828**	**0.000**
		NATIVE$	0.029	1	0.029	1.820	0.183
		NATIVE$*LOG_MALF	0.000	1	0.000	0.013	0.910
		Error	0.787	50	0.016		
	Y-intercept	**LOG_MALF**	**25.351**	**1**	**25.351**	**1642.462**	**0.000**
		NATIVE$	**0.285**	**1**	**0.285**	**18.459**	**0.000**
		Error	0.787	51	0.015		

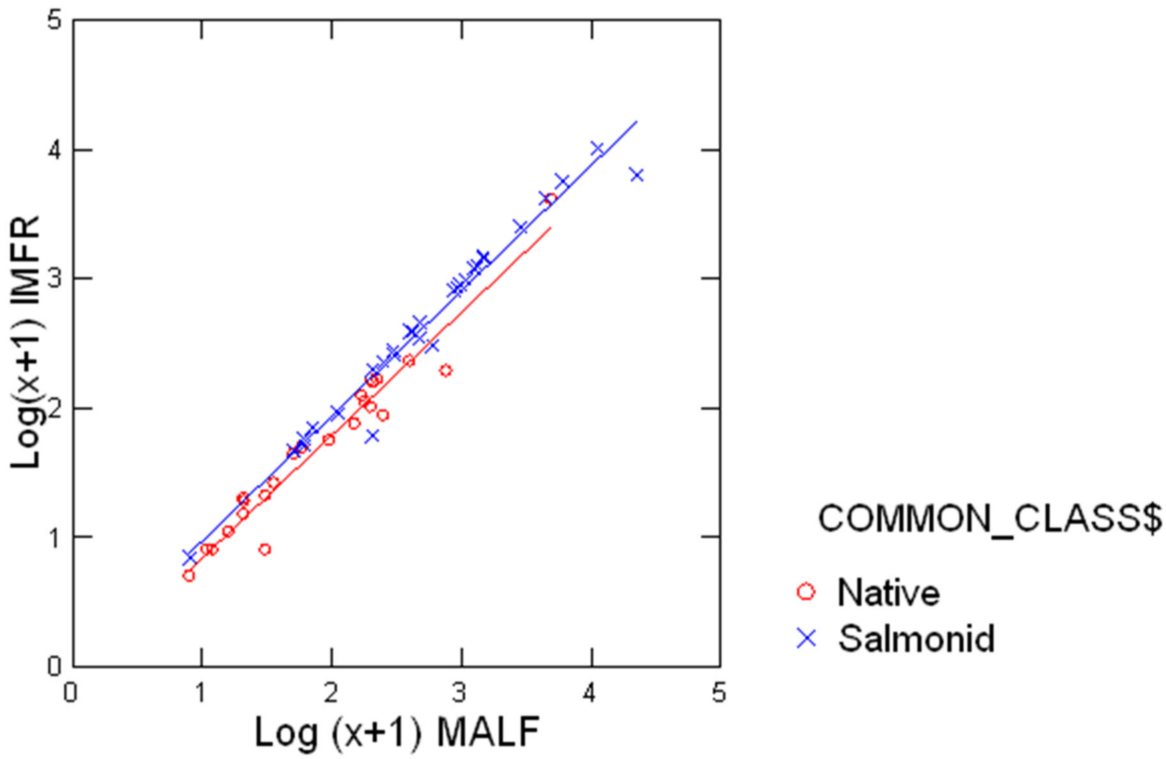
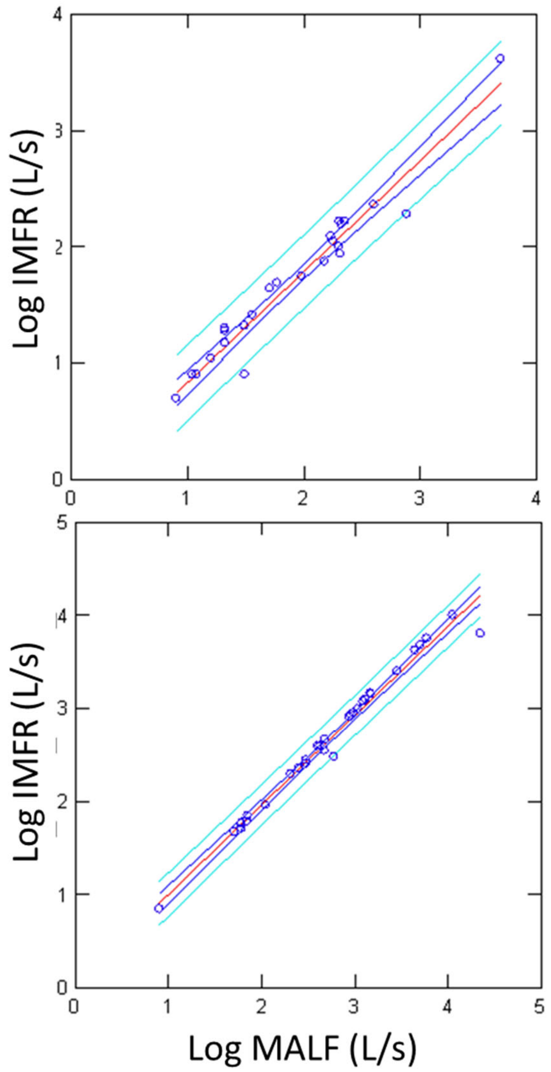


Figure 9 Relationships between the calculated IMFR and a stream's MALF showing how this relationship differed between streams based on whether the target fish species were salmonids or native species.

Given the highly significant differences between the Y-intercept for regressions for native species and salmonids, individual relationships between IMFR and MALF were calculated. Both these regressions explained a very large percentage of total variation (Figure 10). It is suggested that these individual regression lines could be used to calculate the new IMFRs in areas where IFIM surveys have not been undertaken, based on a stream's MALF. The only decision needed for this would be to decide whether a stream should be managed for native fish, or salmonids. This decision could be based either on streams listed in Schedule 1 of the RNRP, or could be based on predictive distributional models for these two fish groups (Leathwick et al 2011). Such predictive models are arguably more powerful that the simple list of streams shown Schedule 1 of the RNRP, as this list shows only named streams. Furthermore, the naming convention of Schedule 1 does adequately consider the fact that fish need access to all lengths of a waterway instead of just the named lengths.



a) Native species

$r^2 = 0.948$, $F = 421.19$, $P < 0.001$

Log IMFR = -0.1112 + (LogMALF x 0.9537)

b) Salmonids

$r^2 = 0.981$, $F = 1502.29$, $P < 0.001$

Log IMFR = 0.0459 + (LogMALF x 0.9593)

Figure 10 Relationships between measured IMFR values and MALF (both log transformed) for a) native fish, and b) salmonids showing the regression line (red) bounded by the 90% confidence intervals (dark blue) and 90% prediction intervals (light blue). These relationships explained a large degree of variability in the data (94.9 and 98.2% respectively for native and salmonids), suggesting that new IMFRs could be calculated at other reaches where MALF is known.

Part 4:
Discussion

This analysis proposes new recommended minimum flows for 56 waterways throughout the region, based on the requirement to retain a specific amount of instream habitat relative to that found at MALF. These 56 catchments cover approximately 40% of the region's land area, and make up nearly 42% of the region's river length, so this information could form part of the flow-setting process that BOPRC is currently undertaking as part of PC12, and further plan changes. Under proposed PC9, minimum flows are set at 90% of a stream's Q_5 7-day flow, and the allocation limit is 10% of the Q_5 7-day flow. This interim approach:

- sets minimum flows independent of stream size, and does not recognise that larger rivers are less susceptible to abstraction pressure than smaller rivers, so effectively more than 10% of the Q_5 7-day flow can be allocated;
- does not consider the different flow requirements of different fish species, and instead assumes a conservative blanket minimum flow of 90% Q_5 7-day flow is adequate for all species.

Calculated values of Q_{min} were less than the 90% Q_5 7-day flow in 18 of the 50 sites where this flow statistic was known. Most of these sites (16) had Q_{min} set to protect the hydraulic habitat of native fish, many of which have relatively low flow requirements when compared to trout. That these sites had calculated values of Q_{min} below the hydrologically-based regional default highlights the advantages of catchment specific limits that includes considerations of habitat for fish species (and potentially other values) and flow rate, as envisaged by PC9. These values of the Q_{min} were calculated on the basis of maintaining specified degree of hydraulic habitat (i.e. ΔH) for selected fish species – in this case mostly native fish. Given the close links between these two variables and those describing out of stream uses (e.g. reliability of supply (R) and volume of water allocated (ΔQ)), using the regional default value would have likely provided more protection to in-stream ecological values, and more constraints on abstraction than was necessary to protect ecological values. This is consistent with the intent of PC9 to set a conservative interim limit that "holds the line" on allocation until more detailed local limits can be determined. The default PC 9 rules may thus be providing a more conservative allocation limit (10% of the Q5 7-day flow) than that recommended by the NES (30% of MALF for streams with a mean flow of less than 5 m^3s^{-1}, or 50% of MALF for streams with a mean flow of greater than than 5 m^3s^{-}[100]. However, the default rules under PC9 do not always provide as conservative a minimum flow limit when compared to the NES, which suggests a minimum flow of only 80% of MALF for large streams.

PC9 requires Council to review and potentially replace the default hydrological limits for each WMA using more refined approaches to setting in-stream minimum flows. It is recommended that these approaches include both IFIM, as well as tools such as EFSAP and the regression approach described above to calculate an IMFR based on a stream's MALF. Each of these methods has a number of advantages and disadvantages (Table 8). More quantitative approaches like IFIM are very useful, as they are based on measured changes in hydraulic habitat and are designed to protect a known amount of instream habitat for target fish species.

Table 8 Comparison of three common methods to assess and set Q_{min} in streams in the Bay of Plenty region.

Feature	**Regional defaults (PC9)**	**EFSAP**	**IFIM**	**Using regression equations to estimate IMFR where there are no IFIM studies**
Spatial scale.	Regional.	Regional or WMA.	Reach.	Reach.
Target fish species to model.	None.	Specified by choice.	Specified by occurrence (surveys or NZFFDB).	Select either native or salmonids.
Accuracy.	Not specified. Unlikely to reflect specific instream habitat requirements.	Limited by models – habitat suitability, hydraulic, and flow duration curves.	Limited by habitat suitability models.	Limited by habitat suitability models and based on empirical relationships between IMFR and MALF.
Minimum flow (Q_{min})	Set as 90% of Q5.	Can be determined from decision support diagrams to meet pre-specified habitat protection objectives and reliability objectives.	IMFRs calculated based on reach specific measurements to meet pre-specified habitat protection objectives. Q_{min} is calculated from the IMFR.	Used in streams with no IFIM study to calculate the IMFR, which is used to calculate the Q_{min}.
Determining habitat protection (ΔH).	Not considered.	Can be varied in decision support diagrams to meet objectives.	ΔH formerly specified in regional plan as percentage of habitat protection required.	IMFRs were based on a specified level of ΔH as recommended by Jowett (2012)
Allocation limit (ΔQ).	Set as 10% of Q5.	Can be determined from decision support diagrams.	Not delivered by IFIM but calculated IMFRs can be used in EFSAP to consider allocation limits and reliability.	Not delivered, but calculated IMFRs can be used in EFSAP to consider allocation limits and reliability.
Reliability of supply (R).	Not calculated (but can be assessed using hydrological models).	Can be determined from decision support diagrams.	Not delivered by IFIM. Can be assessed using hydrological models, including EFSAP.	Not delivered. Can be assessed using hydrological models, including EFSAP.

Feature	**Regional defaults (PC9)**	**EFSAP**	**IFIM**	**Using regression equations to estimate IMFR where there are no IFIM studies**
Complexity.	Simple.	More complex, relies on understanding of the steps behind EFSAP. Challenge to determine suitable set of combinations of minimum flow, Allocation and reliability.	Complex field work required. Develop reach-specific IFMRs. May be able to transfer these to other catchments based on regressions.	Relatively simple empirical relationship based on observed relationships between MALF and IMFR.
Based on.	Hydrological limits.	Ecological limits, based on modelled changes in fish habitat suitability with flow.	Ecological limits, based on measured changes in fish habitat suitability with flow.	Regression equations, based in part on measured changes in fish habitat suitability with flow.
Other values (e.g. cultural, recreational, aesthetic).	Does not consider.	Does not consider.	Does not consider (but similar approach can be used).	Does not consider.

Consideration of out of stream values

Although the IFIM and regression approaches are arguably robust ways of determining an IMFR for a particular reach, and thus a Q_{min} for a given level of ΔH, they are both silent on setting other important attributes such as the amount of water that can be allocated (ΔQ), as well the reliability of supply (R). Moreover, like any of the ecological flow setting methods, these methods do not address cultural, economic or recreational values (Table 8). There may thus be cases where the ecologically defined IMFR is not a used to set minimum flows in a river where other values would be adversely affected by implementation of ecologically derived minimum flows. An example of this was the setting of a minimum flow in the lower Rangitāiki of 32 m^3/s at Te Teko. According to IFIM assessments of habitat suitability in the lower Rangitāiki, the calculated IMFR for the Rangitāiki River was only 16.2 m^3/s (Jowett, 2013). However, such a low flow would have resulted in a significant ingress of salt water at high tide in the lower river which would have, amongst other things, affected the ability of abstractors to take water.

Notwithstanding this, the principles behind the basic IFIM methodology could possibly be used for other values, such as cultural or recreation. For example, if the relationships between flow and the value of interest can be described, and the proportion of the value found at flows such as MALF determined, then the effect of reducing flows below MALF could be determined, to see whether any subsequent loss of the ability of the stream to support that value occurs.

While IFIM assessments will provide arguably the most robust estimates of the IMFR to meet desired ecological objectives, EFSAP can be used to assess the options and implications of those minimum flows for ΔQ and R. Following calculation of the IMFR, the Q_{min} is calculated (as a % of MALF). EFSAP can then be used to explore potential implications of setting different Q_{min} values for different habitat protection (ΔH) values for selected fish in cases where there is greater pressure on out-of-stream uses. Gee and Dietrich (2018) provide examples where EFSAP is used to show the consequences of different limits (ΔQ and Q_{min}) on ΔH for selected fish species (such as trout and torrentfish) and R for out-of-stream users. It recognises that these three elements are closely linked. For example, the higher a minimum flow is in a stream, the less water can be abstracted at a given level of reliability. The advantage of the EFSAP tool is that it allows us to visualise the implications of these competing elements, and select the minimum flow (or combination of minimum flow and total allocation) that maximises both habitat protection and reliability of supply. Arguably, this is a far more powerful tool than the reach-specific IFIM process. EFSAP could therefore be run on all NZReaches above each IFIM site to examine the consequences on allocation and reliability of supply within each of these specific catchments for a given minimum flow.

Of interest were the strong relationships observed between calculated IMFRs and MALF. These strong relationships were found both within the Bay of Plenty, and also within Canterbury and greater Wellington. Furthermore, results of the ANCOVA showed no difference in the regression lines within each of these regions. This was a surprising result given the fact that a wide range of methods were used to develop the calculated IMFRs in each region, as well as a wide range of different ecological objectives. The high linearity and high explanatory power of the regression models may simply be a reflection that bigger rivers have higher IMFRs than smaller rivers. Furthermore, there was an extremely wide range of both MALF and IMFR both within the Bay of Plenty only data (7 L/s to 22,550 L/s for MALF, and 4 L/s to 10,050 L/s for the IMFR), and within the combined regional data (7 L/s to 87,000 L/s for MALF, and 7 L/s to 124,000 L/s for the IMFR). Such a large range of river sizes means that any subtle differences between IMFRs calculated using different methods or different target fish species becomes inconsequential to the dominant driver of a stream's IMFR, which is stream size.

Despite the fact that larger rivers generally have higher IMFRs, the ANCOVA clearly showed that, within the Bay of Plenty streams at least, salmonids appeared to have a higher IMFR for a given MALF than native fish. This finding suggests that IMFRs could be calculated from the regression equations between IMFR and MALF based on either "native" species, or "salmonids". These regressions could be particularly useful to calculate the IMFR (and then Q_{min}) at sites where the MALF is known (or modelled), but where IFIM surveys have not been done. These values of Q_{min} were based on the requirement to meet specified habitat protection levels (ΔH), meaning that two of the four variables used by EFSAP are already known. EFSAP could therefore be used to identify the implications of these variables on ΔQ and R.

Discussions with the community groups need to emphasise that there are different techniques to set a streams IMFR, and Q_{min} (as well as allocation limits and reliability of supply measures: Table 8). While some methods such as IFIM provide very robust assessments of a stream's minimum flow, they do not enable any comments to be made as to the effect of setting such a minimum flow on reliability of supply. Other more general methods such as EFSAP provide this information, but at a possible loss of accuracy when compared to the more bespoke IFIM method. The final choice of methods to set water allocation is likely to involve a combination of different approaches, all of which are regarded as more robust and transparent than the current default hydrological methods.

Finally, although the above analyses will support decision-making regarding instream minimum flow and total allocation limit (both of which are required under the NPS FM), it will not assist us to assess the impacts of individual water takes on both upstream availability, and downstream environmental effects. To do this, NIWA has developed a new hydrological model called the Cumulative Hydrological Effects Simulator (CHES) and there may be other similar models. This is designed to estimate net changes to flow regimes throughout a catchment due to multiple individual water takes, and quantifies the consequences for both availability and reliability of supply of the resource, as well as the residual flows below the water take that determine the instream environmental effects. As with EFSAP, CHES is based on TopNet modelled flows, meaning that both models are utilising the same hydrological data. EFSAP can therefore be used to help explore the consequences of different IMFRs, allocation limits, and reliability of supply, while CHES enables a more nuanced view of changes to flow regimes throughout a catchment as a result of individual or multiple water takes which is particularly useful for accounting and resource consenting. By working with both models (EFSAP and CHES or similar), BOPRC can help set water use limits to balance both in-stream and out of stream needs, and account for spatial variability at multiple scales. This will help achieve the objectives of the NPSFM for better water quantity management throughout the region.

4.1 Recommendations

Based on the above analysis, a decision support diagram has been developed to help explain links between the different tools (regional default, IFIM methodology, and EFSAP) that are currently available to BOPRC to determine the appropriate allocation regimes in streams (Figure 11). This diagram follows a set of four clearly defined questions that need to be asked by the consent and policy team. These are outlined below, and are shown on Figure 11 in circles.

1 The need to set ecological flows needs to be established. The IFIM methodology has been used mostly for setting minimum flows for fish species with relatively good success (e.g. Jowett and Biggs 2006). However, as discussed above, ecological values are only one of many values to consider, and it may be more appropriate to set minimum flows to protect other values deemed more important to the community.

2 IFIM surveys have already been done in 56 rivers throughout the region, making up approximately 40% of the land area or length of all NZReaches. If any waterways are above the location of these IFIM surveys (i.e. yes to Question 2), then EFSAP can be used to assess the implications of different water allocation scenarios on R and ΔQ, given that Q_{min} and ΔH have been determined from the IFIM analysis (Figure 11). EFSAP results in the creation of Decision Support Systems (DSS) that illustrate the consequences of different allocation scenarios. These DSS diagrams are used to find acceptable outcomes of allocation scenarios. If waterways are not above the current IFIM surveys (i.e. No to Question 2), then the following methods can be used to help determine Q_{min} over and above the current regional default limits.

3 The choice of the most applicable method to determine Q_{min} at these sites should follow the proposed NES methodology. Thus, for streams with only a low degree of hydrological alteration, a low to medium in-stream value, or streams that are not over-allocated, Q_{min} could simply be calculated from the regressions of IMFR against the stream's current MALF. Before this is done, the decision needs to be made as to whether the regressions derived for trout, or native fish should be used (Question 4 in Figure 11). Once this is done, EFSAP can be used to determine an appropriate allocation regime (Figure 11).

4 In streams where there is potentially a large degree of hydrological alteration, where instream values are high, or where the stream is in an catchment with high water use demand (i.e. yes to Question 2), it may be preferable to undertake a new IFIM survey in order to more robustly determine Q_{min} for a given level of ΔH. Choice of target fish species can be determined from either field observations of what fish are at that site or from predictive models. Once Q_{min} has been established, then EFSAP can be used to assess the implications of different water allocation scenarios on R and ΔQ.

By following these steps, it is hoped that a series of transparent and robust steps can be taken to help determine an appropriate allocation regime in the region's waterways.

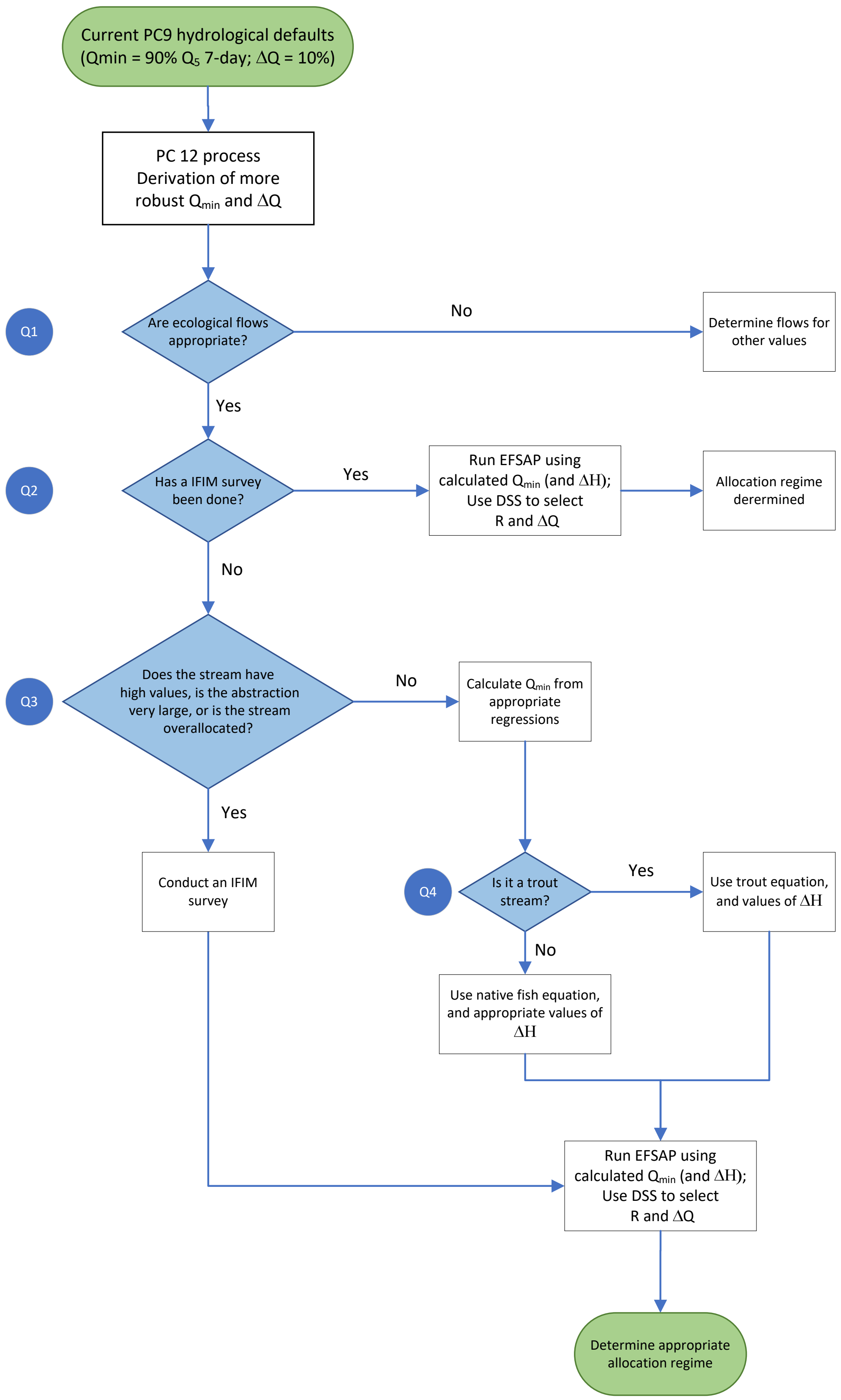


Figure 11 Decision support diagram showing potential steps that can be taken as part of the PC12 process that helps set new allocation regimes in waterways throughout the Bay of Plenty region, using a mixture of IFIM, EFSAP, and regressions derived from the IFIM work currently done in the region.

Part 5:
References

Arthington, A. H., Bunn, S. E., Poff, N. L., and Naiman, R. J. (2006). The challenge of providing environmental flow rules to sustain river ecosystems. *Ecological Applications* 16, 1311–1318.

Bloxham, M. (2005). Minimum flow report for the Rotorua area. Environment Bay of Plenty environmental publication 2005/01. 50p.

Bloxham, M. (2008). Minimum flow report for Whakatane, Opotiki and East Cape area. Environment Bay of Plenty Environmental Publication 2008/06. 62p.

Booker, D.; Dietrich, J.; Franklin, P. (2014). Options for default minimum flow and allocation limits in the Bay of Plenty. NIWA client report CH C 2014 – 068. 62p.

Booker, D. (2015). Generalised physical habitat models. Development and testing for the Bay of Plenty region. NIWA client report CH C 2015 – 087. 63p.

Collier, K.J. (1993). Flow preferences of aquatic invertebrates in the Tongariro River. Department of Conservation Science and Research Series 60. Department of Conservation, Wellington. 65p.

Davies, P.M.; Naiman, R.J.; Warfe, D.M.; Pettit, N.E.; Arthington, A.H.; Bunn, S.E. (2013). Flow–ecology relationships: closing the loop on effective environmental flows. *Marine and Freshwater Research* 65(2) 133-141 https://doi.org/10.1071/MF13110.

Gee, E. and Diettrich, J (2018). Water Allocation Limits for the Rangitaiki and Kaituna-Pongakawa-Waitahanui Water Management Areas. NIWA Client Report 201806CH. 77p.

Jowett, I., Biggs, B.J.F. (2006). Flow regime requirements and the biological effectiveness of habitat-based minimum flow assessments for six rivers. International Journal of River Basin Management 4: 179-189.

Jowett, I. (2010). RHYHABSIM River hydraulics and habitat simulation. Software manual version 5.0. 108p.

Jowett, I. (2012). Methods for setting ecological flow requirements in the Bay of Plenty Regional Water and Land Plan. Jowett consulting Ltd Client Report IJ 1202. 22p.

Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., Sparks, R. E., and Stromberg, J. C. (1997). The natural flow regime: A paradigm for river conservation and restoration. *Bioscience* 47, 769–784.

Poff, N. L., Richter, B., Arthington, A. H., Bunn, S. E., Naiman, R. J., Apse, C., Kendy, E., Warner, A. T., Tharme, R., Bledsoe, B. P., Merritt, D., Jacobson, R. B., Freeman, M., Rogers, K., Henriksen, J., Olden, J., O'Keeffe, J., and Acreman, M. (2010). The ecological limits of hydrologic alteration: A framework for developing regional environmental flow standards. *Freshwater Biology* 55, 147–170.

Snelder, T.H., Rouse, H.L. Franklin, P.A., Booker, D.J., Norton, N., Diettrich, J. (2013). The role of science in setting water resource use limits: case studies from New Zealand. Hydrological Sciences Journal 59: 1-16.

Snelder, T.; Fraser, C.; Suren, A. (2016). Defining a biophysical framework for freshwater management units for the Bay of Plenty region. L WP client report 2016 – 001. 70p.

Suren, A.M., Biggs, B. J. F., Duncan, M. J., Bergey, L. (2003) Benthic community dynamics during summer low flows in streams with contrasting enrichment: II) Invertebrates. *New Zealand journal of marine and freshwater research 37: 71-84.*

Suren, A.M., Riis, T (2010). The effects of plant growth on stream invertebrate communities during low flow: a conceptual model. *Journal of the North American Benthological Society* 29:711-724.

Wilding, T. K. (2002a). Minimum flow report for streams of the Kaimai area. Environment Bay of Plenty Environmental Report 2002/05. 46p.

Wilding, T. K. (2002b). Minimum flow report for the Haumea Stream. Environment Bay of Plenty Environmental Report 2002/07. 36p.

Wilding, T. K. (2002c). Minimum flow report for the Waitahanui stream. Environment Bay of Plenty environmental report 2002/25. 38p.

Wilding, T. K. (2003). Minimum flow report for the Tauranga area. NIWA Client Report HAM2003 – 043. 81p.

Wilding, T. K. (2004). Minimum flows for the Whirinaki River and upper Rangitaiki River. NIWA Client Report HAM2004 – 159. 36.

Appendix 1:

Glossary of terms

EFSAP: Environmental Flow Strategic Allocation Platform - A generalised habitat modelling tool designed to enable planners and water allocation decision-makers to simulate and compare spatially explicit water management scenarios at catchment, regional and national scales.

IFIM (Instream Flow Incremental Methodology): IFIM is based on showing how hydraulic habitat quality changes with incremental changes in water flow. It assumes that available habitat is based on the quality of microhabitat variables (water velocity, water depth, substrate and cover) and macrohabitat variables (water temperature, dissolved oxygen, and other water quality variables), depending on an individual organism's preference for these variables.

IMFR: The empirically derived instream minimum flow from detailed IFIM studies. The IFIM method selects the most flow hungry species and calculates the flow below MALF where a specified percentage of the instream hydraulic habitat for the target fish is protected. The IMFR is specific to the reach where the IFIM study was conducted, although all takes above this reach need to maintain the IMFR at this location.

MALF: The 7-day mean annual low flow, a hydrological measure of low flow.

Management flow: The sum of the minimum flow limit and total allocation, i.e. the flow at which restrictions on water abstraction start to apply.

Physical habitat change, ΔH: The change in weighted useable area (WUA) due to the allocation scenario. This is determined relative to MALF, i.e. we calculate WUA at MALF (WUAMALF) using the position of MALF on the natural FDC. We then calculate WUA at the same position on the modified (by abstraction) FDC (WUANEW), and determine the difference.

Qmin: the minimum flow (in L/s) for individual waterways in the region. This is the level below which no more water can be abstracted. For convenience, all Q_{min} values are set to a specific % of a stream's low flow, usually MALF or Q_5 7day. Q_{min} can be calculated by a variety of methods:

1. Based on EFSAP analyses, where any two of the following are known: total allocation (ΔQ), reliability of supply (R), or the amount of physical habitat change (ΔH).
2. Based on the calculated IMFR as defined earlier.
3. Using a set of hydrological "rules". Under PC9, the hydrological "rule" to calculate Q_{min} throughout the Bay of Plenty is based on 10% of the Q_5 7-day flow (this could also be changed to be based on 10% of the streams MALF).

Reach group: A group of stream reaches that may be managed together for the purposes of setting water allocation limits. A reach group is defined as a combination of a catchment and biophysical unit.

REC: The River Environment Classification, a classification system for New Zealand rivers (Snelder and Biggs 2002). BoPRC is currently using the first version of the REC, although a second version with more accurate river lines has also been produced (REC2).

Reliability of supply, R: The percentage of time that an abstraction can be taken. This is divided into the reliability of supply at management flow (the percentage of the time that the ***total allocation*** can be taken without restrictions) and the reliability of supply at minimum flow (the percentage of time that at least some water can be taken).

RHYHABSIM: The River Hydraulic Habitat Simulation program models basic hydraulic parameters and physical habitat as a function of flow in rivers. The program relies on a series of cross-sectional measurements along a reach taken of depth, velocity and substrate nature. These measurements are taken at different flows, so that changes in hydraulic habitat can be modelled with reductions in flow. When linked to habitat preference curves for specific fish species, the RHYHABSIM package allows us to model the effect of flow on instream habitat.

Total abstraction limit/total allocation, ΔQ: The total flow that may be abstracted from a given stream reach, which may result from one or many consented allocations.

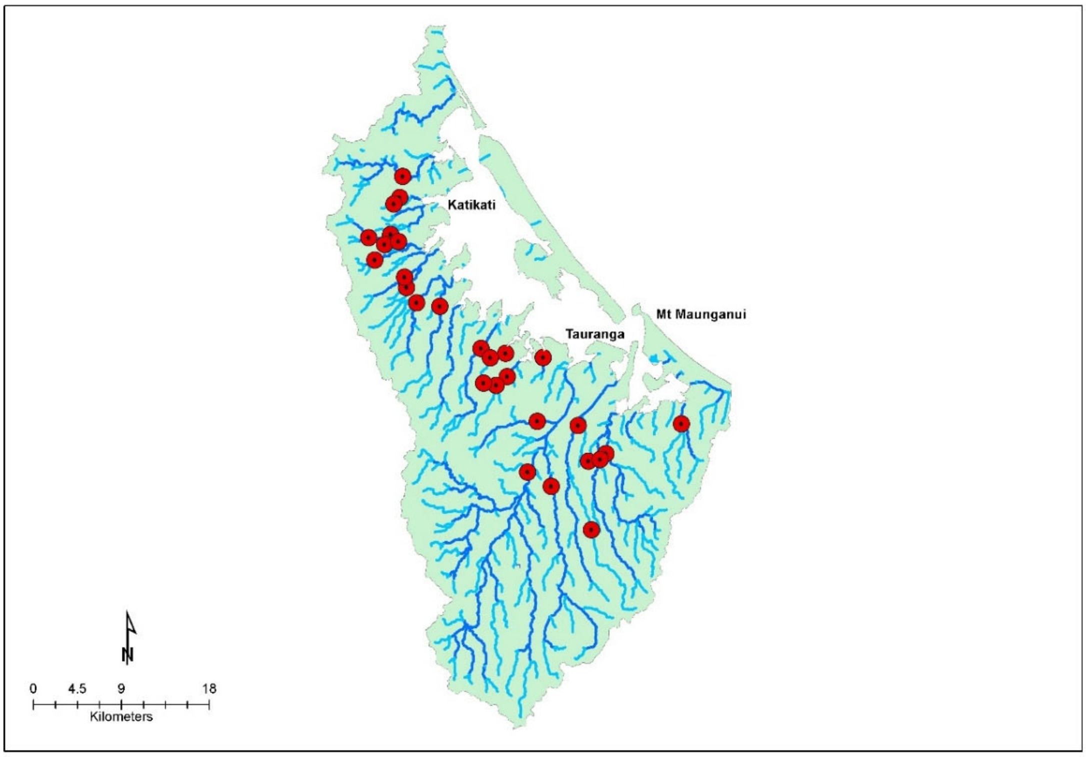
Weighted useable area, WUA: A measure of the available suitable physical habitat in m^2 per 1,000 m of river channel.

Appendix 2:

Location of IFIM sites

Maps showing the location of the different IFIM reaches in each of the 10 WMAs throughout the region, as well as information on the NZReach at each site, its biophysical classification, and the values of MALF (L/s) as given in the original IFIM reports. Also shown are the new calculated values of the IMFR (L/s) as well as the target fish species selected for each IMFR.

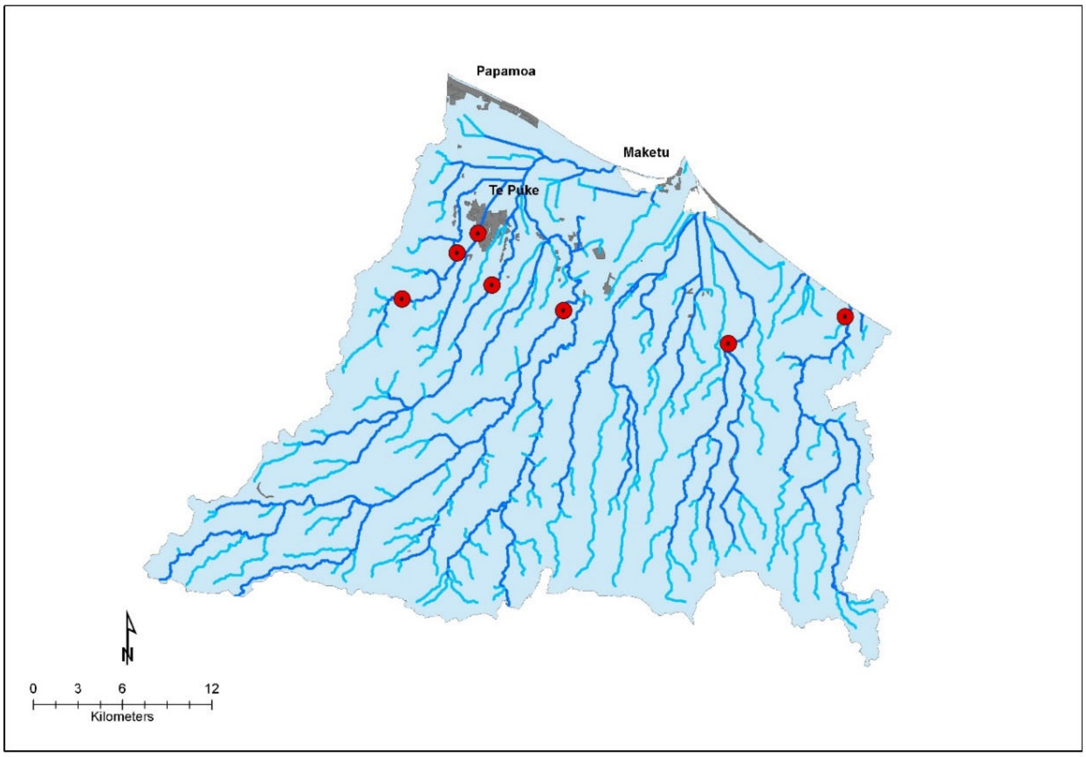
Tauranga



River	NZReach	BPU	MALF (L/s)	New IMFR (L/s)	Target Fish species
Aongatete	4000573	Volcanic+Hill+ Small	225	165	Common bully.
Boyd Tributary	4000379	Volcanic+Low+ Small	20	18	Banded kōkopu.
Kopurereroa	4001670	Volcanic+Low+ Small	1,490	1,420	Rainbow trout adult (Tongariro).
Mangawhai	4000893	Volcanic+Low+ Small	10	7	Redfin bully.
Ngututuru	4000405	Volcanic+Hill+ Small	20	14	Inanga.
Ohourere	4001622	Volcanic+Low+ Small	250	225	Rainbow trout adult (Bovee, 1978).
Omanawa	4002698	Volcanic+Low+ Small	1,075	980	Rainbow trout adult (Bovee 1978).
Oturu	4000905	Volcanic+Low+ Small	20	19	Banded kōkopu.
Tahawai L/B	4000290	Volcanic+Hill+ Small	35	25	Torrentfish.
Tahawai R/B	4000295	Volcanic+Hill+ Small	15	10	Redfin bully.

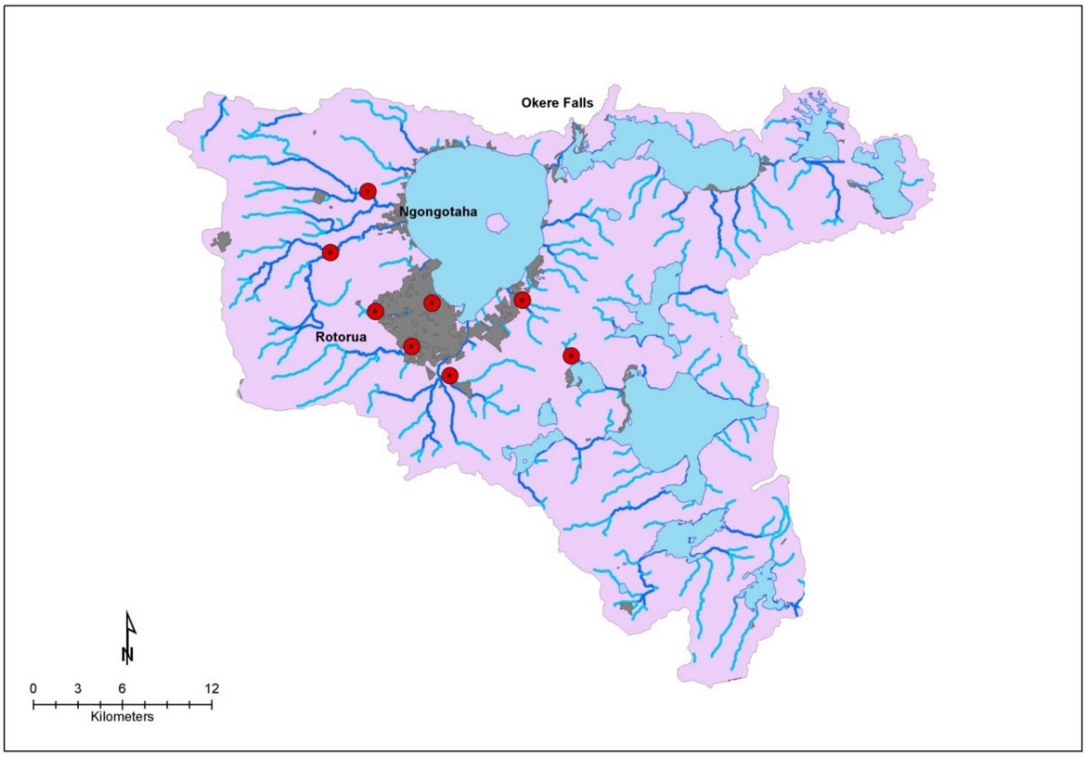
River	NZReach	BPU	MALF (L/s)	New IMFR (L/s)	Target Fish species
Tautau	4003439	Volcanic+Low+ Small			
Te Puna at rapids	4001150	Volcanic+Low+ Small	150	74	Redfin bully.
Te Puna Tributary	4001172	Volcanic+Low+ Small	11	7	Redfin bully.
Te Rereatukahia	4000421	Volcanic+Hill+ Small	95	55	Redfin bully.
Tuapiro	4000229	Volcanic+Hill+ Small	400	390	Rainbow trout – feeding.
Tuapo	4000517	Volcanic+Low+ Small	50	43	Smelt.
Uretara at Rea	4000392	Volcanic+Hill+ Small	210	155	Smelt.
Uretara at Wharawhara	4000392	Volcanic+Hill+ Small	200	100	Torrentfish.
Waimapu at Joyce	4001922	Volcanic+Low+ Small	30	7	Banded kkōkopu.
Waimapu at McCarrols farm			769	190	Banded kkōkopu.
Waiorohi	4002438	Volcanic+Low+ Small			
Waipapa Tributary at Jeffco farm	4001183	Volcanic+Low+ Small	7	4	Banded kkōkopu.
Waipapa Tributary at Plumer Road	4000966	Volcanic+Low+ Small	30	20	Redfin bully.
Wairoa	4002453	Volcanic+Low+ Large	425	390	Rainbow trout adult (Tongariro).
Waitao	4001643	Volcanic+Hill+ Small	170	122	Common bully.
Waitekohe					
Whatakao	4000599	Volcanic+Low+ Small	180	110	Redfin bully.

Kaituna, Maketu, Pongakawa and Waitahanui



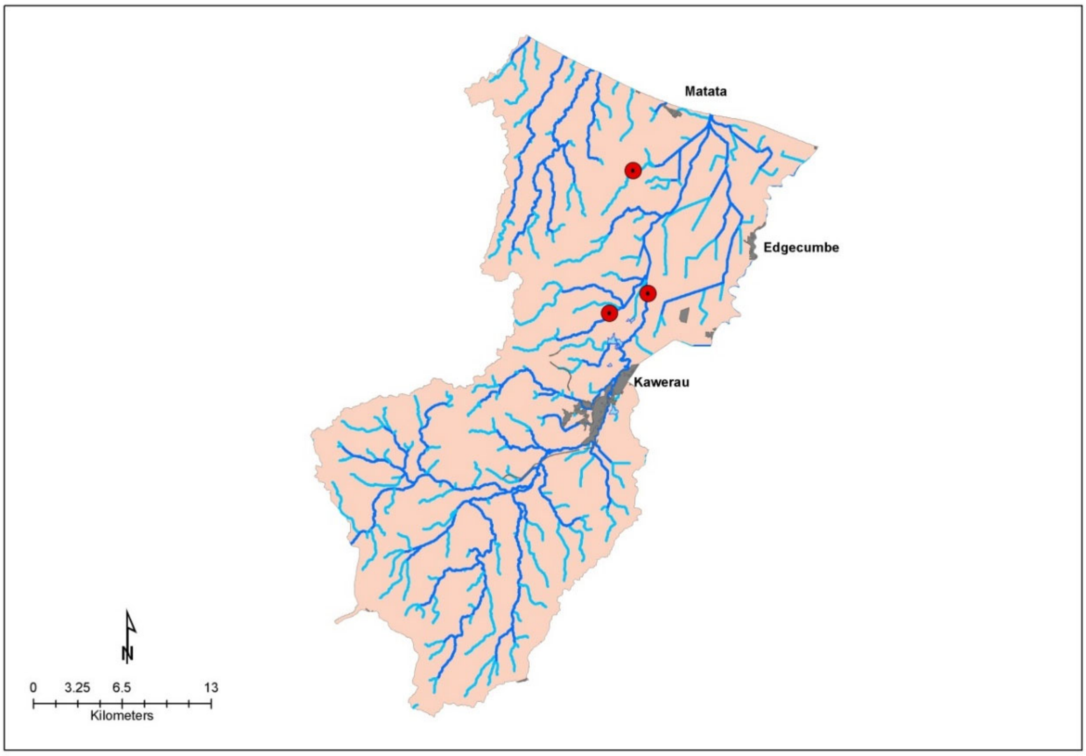
River	NZReach	BPU	MALF (L/s)	New IMFR (L/s)	Target Fish species
Mangorewa	4003688	Volcanic+Low+ Large	6,000	5,630	Rainbow adult Tongariro.
Ohinieangaanga	4002382	Volcanic+Low+ Small	250	86	Torrentfish.
Pongakawa	4004139	Volcanic+Low+ Small	4,450	4,200	Rainbow trout.
Raparapahoe No. 4	4002970	Volcanic+Hill+ Small	600	300	Rainbow adult feeding.
Raparapahoe No. 3	4003612	Volcanic+Hill+ Small	300	253	Rainbow trout - adult feeding.
Waiari	4003416	Volcanic+Low+ Small	3,448		Juvenile Rainbow trout feeding (Cheeseman Bovee).
Waitahanui	4003723	Volcanic+Hill+ Small	4,950	4,100	Inanga.

Rotorua



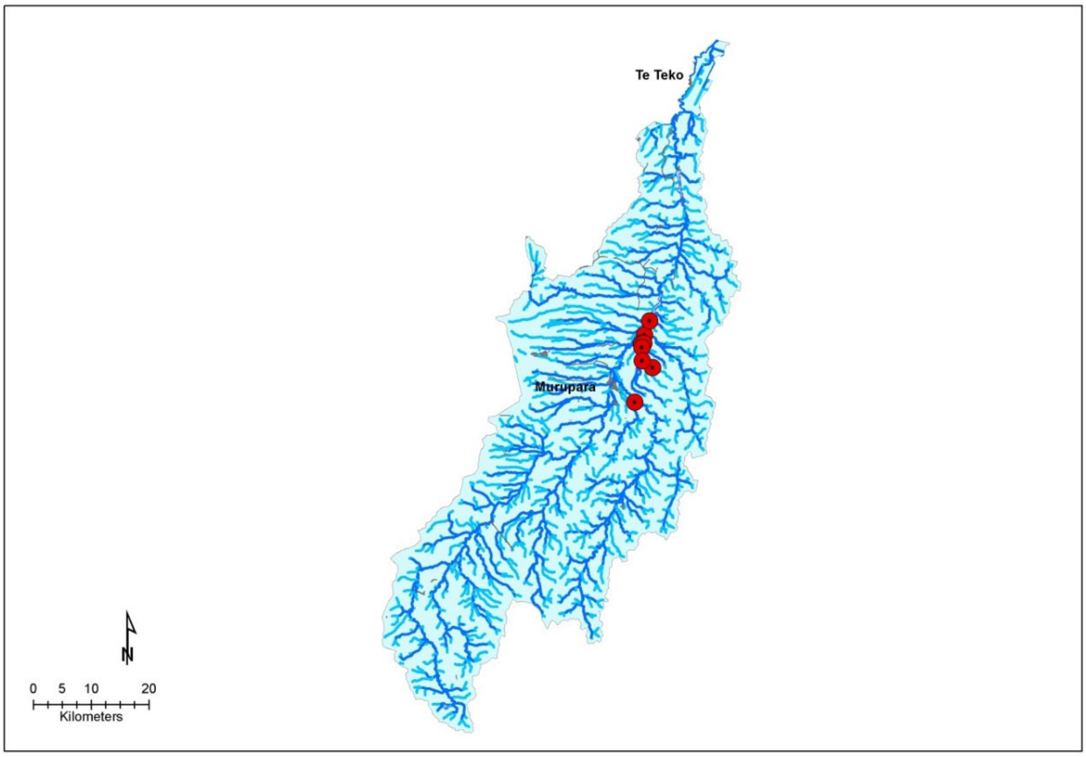
River	NZReach	BPU	MALF (L/s)	New IMFR (L/s)	Target Fish species
Mangakakahi	4012259	Volcanic+Hill+ Small	205	60	Brown trout adult (Hayes & Jowett).
Miller Road	4013463	Volcanic+Hill+ Small	7	6	Brown and Rainbow trout.
Ngongotaha	4010956	Volcanic+Low+ Small	1,235	1,190	Brown trout fry to 15 cm (Raleigh et al.).
Utuhina downstream	4012158	Volcanic+Low+ Small	1,315	1,250	Juvenile Rainbow trout feeding (Cheeseman Bovee).
Utuhina upstream	4013175	Volcanic+Low+ Small	970	890	Rainbow trout feeding (30-40 cm Cheeseman Bovee).
Waingaehe	4011992	Volcanic+Low+ Small	205	195	Brown trout adult (Hayes & Jowett).
Waipa	4013953	Volcanic+Low+ Small	480	460	Brown trout adult (Hayes & Jowett).
Waitetī	4009645	Volcanic+Low+ Small	880	810	Brown trout yearling (Raleigh et al.).

Tarawera



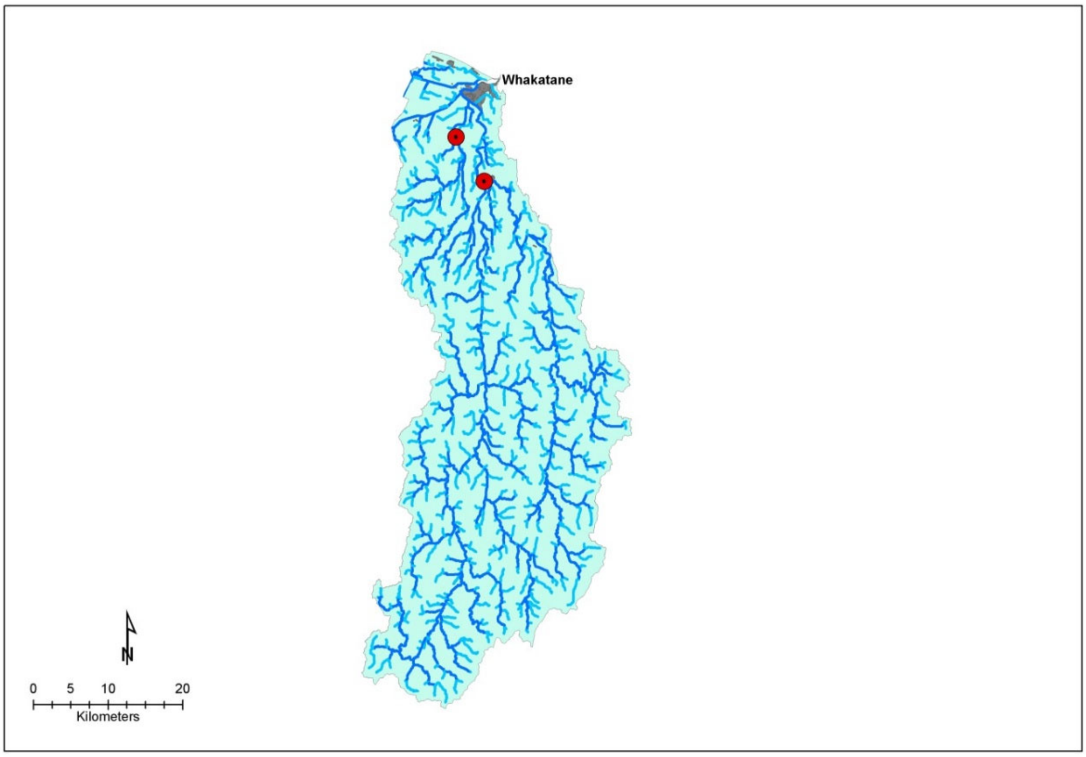
River	NZReach	BPU	MALF (L/s)	New IMFR (L/s)	Target Fish species
Awakaponga	4006018	Volcanic+Hill+ Small	60	57	Brown trout adult (Hayes & Jowett).
Mangaone	4008644	Volcanic+Hill+ Small	1,480	1,450	Brown trout yearling (Raleigh 1986).
Tarawera	4008565	Volcanic+Hill+ Large	22,549	6,370	Rainbow trout feeding (30-40 cm Cheeseman Bovee).

Rangitāiki



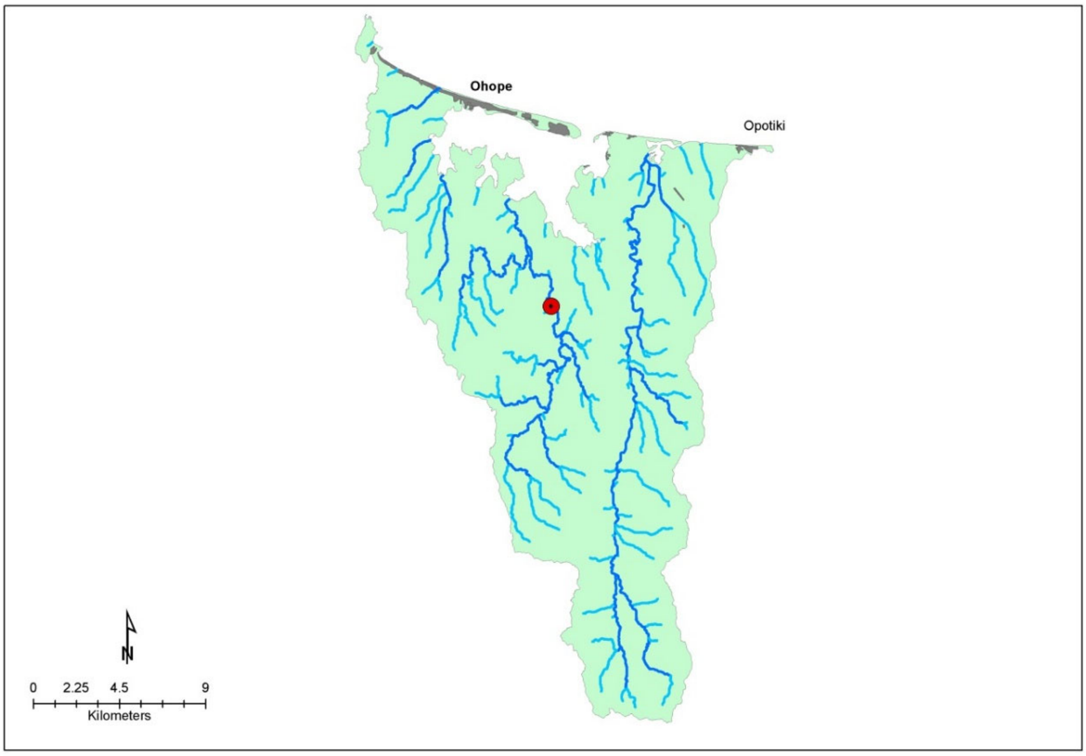
River	NZReach	BPU	MALF (L/s)	New IMFR (L/s)	Target Fish species
Haumea at Galatea	4020602	Volcanic+Hill+ Small	925	850	Rainbow trout adult feeding (Thomas & Bovee (1993)).
Haumea at Magee's	4020893	Volcanic+Hill+ Small	475	350	Rainbow trout adult feeding (Thomas & Bovee (1993)).
Mangakotukutuku	4021228	Volcanic+Low+ Small	110	90	Rainbow trout juvenile feeding (Thomas & Bovee (1993)).
Mangamutu	4021118	Volcanic+Low+ Small	60	50	Rainbow trout juvenile feeding (Thomas & Bovee (1993)).
Ruarepuae at Bannans farm	4021901	Volcanic+Hill+ Small	50	46	Rainbow trout juvenile feeding (Thomas & Bovee (1993)).
Ruarepuae at Waitaruna	4021655	Volcanic+Hill+ Small	300	276	Rainbow trout adult feeding (Thomas & Bovee (1993)).
Upper Rangitaiki at Galatea	4022892	Volcanic+Hill+ Large	20600		
Whirinaki	4019982	Volcanic+Low+ Large	5200		

Whakatane



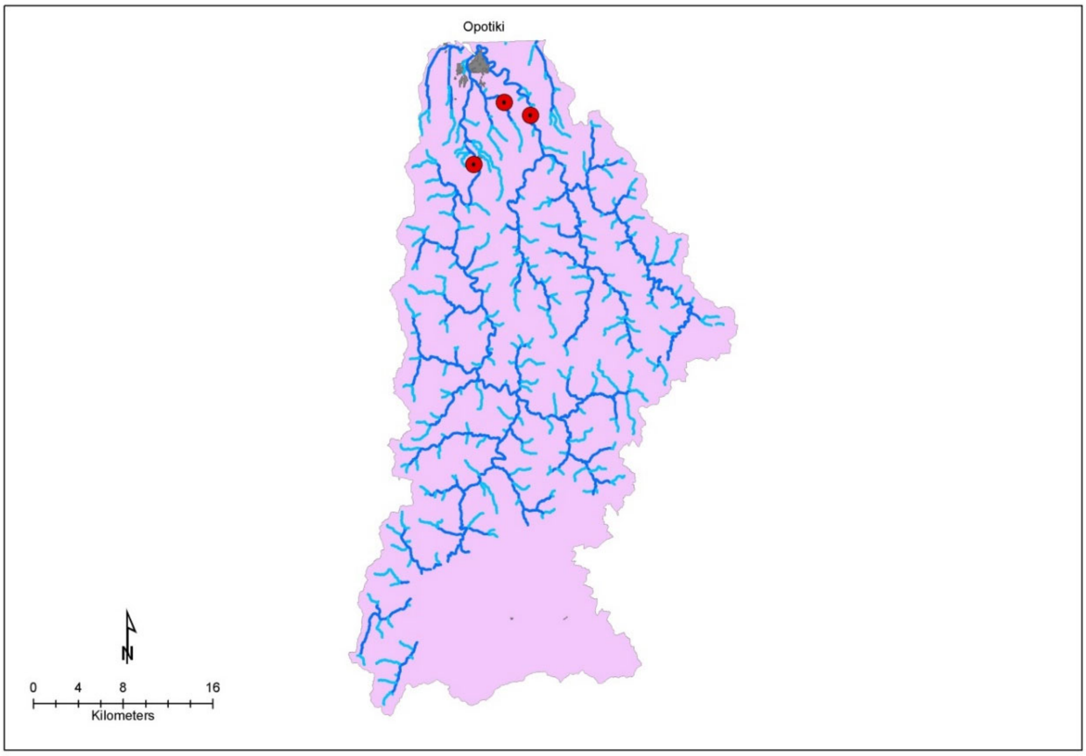
River	NZReach	BPU	MALF (L/s)	New IMFR (L/s)	Target Fish species
Waioho	4008633	Volcanic+Hill+ Small	400	228	Redfin bully.
Whakatāne	4010794	Volcanic+Hill+ Large	11319	10050	Brown trout adult (Hayes & Jowett) OR Rainbow trout feeding (30-40 cm Cheeseman Bovee).

Ohiwa



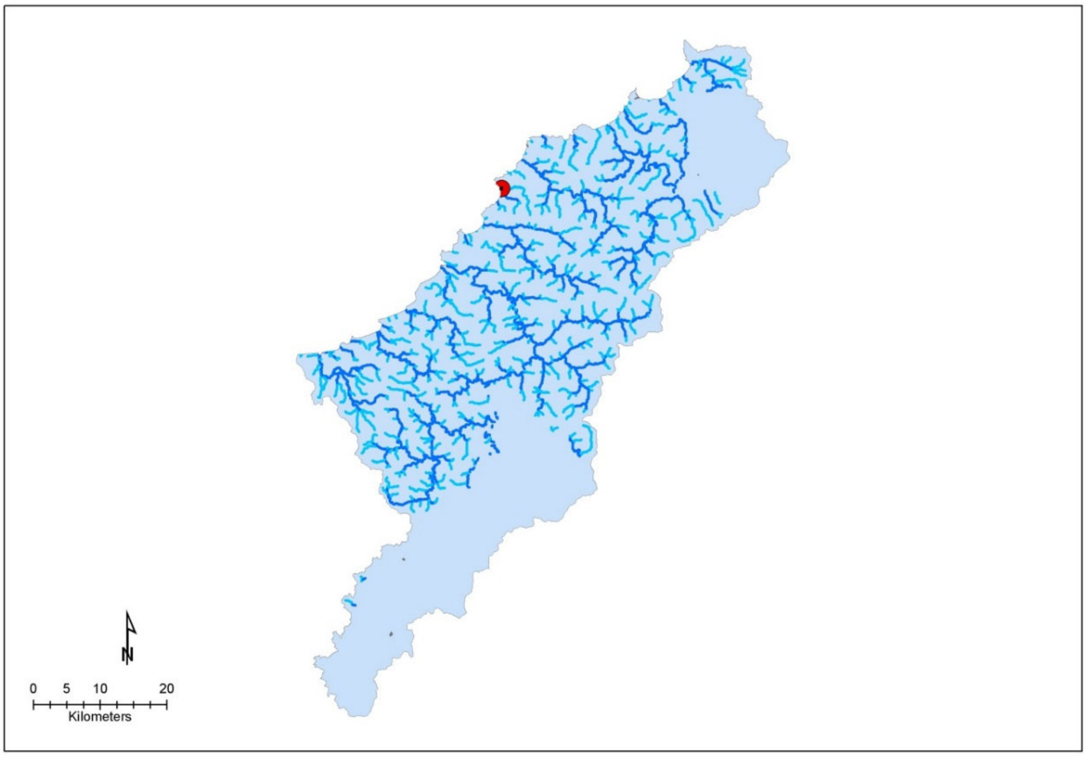
River	NZReach	BPU	MALF (L/s)	New IMFR (L/s)	Target Fish species
Nukuhou			201	165	Torrentfish.

Waioeka and Otara



River	NZReach	BPU	MALF (L/s)	New IMFR (L/s)	Target Fish species
Mill Stream	4010105	Volcanic+Hill+ Small	70	69	Brown trout adult (Hayes & Jowett 1994).
Otara	4010536	Non-Volcanic +Large	2,864	2,510	Rainbow trout spawning (Tongariro).
Waioeka	4011953	Non-Volcanic +Large	5,136	4,800	Rainbow trout spawning (Tongariro).

East Cape



River	NZReach	BPU	MALF (L/s)	New IMFR (L/s)	Target Fish species
Puremutahuri	4002924	Non-Volcanic +Small	58	48	Common bully.

Appendix 3:
Explanation of ANCOVA

Analysis of covariance (ANCOVA) is used when you want to compare two or more regression lines to each other; ANCOVA will tell you whether the regression lines are different from each other in either slope or intercept. In this case, we are interested in comparing the relationship between IMFR and MALF, between the different biophysical units, regions, fish classes, or native:salmonid fish grouping. Regression lines are best described by the formula *Y = ax + b,* where:

- *Y* = dependent variable (the IMFR).
- *X* = independent variable (the MALF).
- *a* = the slope of the regression line.
- *b* = the Y intercept.

In this instance, we have two measurement variables (the MALF and IMFR) and one nominal variable (in this case the different Biophysical Units, regions, fish classes, or native:salmonid fish classes). The nominal variable divides the regressions into two or more sets. ANCOVA compares the *Y* variable (the IMFR) among groups while statistically controlling for variation in *Y* caused by variation in the *X* variable (the river's MALF).

The ANCOVA analysis is run in two steps. Firstly, the model being tested includes the X variable (MALF), the nominal variable, and the interaction term (e.g. MALF x Biophysical Unit). This interaction term tests whether the slopes of the regression lines are significantly different. If the slopes are significantly different (i.e. the MALF x Biophysical Unit interaction term has a p-Value < 0.05), then the test is complete. If the slopes are not significantly different, then a new model is run without the interaction term, as the model assumes that the slopes of the regression lines are equal. Examination of the p-Value for the nominal variable shows whether the Y intercepts are significantly different. If they are, it means that for a given MALF, the IMFR differs between the different nominal groups.

Below is an example of the ANCOVA for the firstly the biophysical units, and secondly the different fish classes. Note how in both examples the slopes of the regression lines with the same between either the biophysical units, or the fish classes, as shown by the non-significant interaction term (highlighted in yellow).

IMFR with respect to biophysical unit

Interaction term to see if slopes are parallel.

Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
LOG_MALF	0.477	1	0.477	25.721	0.000
BPU_VER2$	0.139	4	0.035	1.880	0.131
BPU_VER2$*LOG_MALF	0.140	4	0.035	1.891	0.129
Error	0.816	44	0.019		

The BPU x Log_MALF interaction term is not significant, so the slopes are the same.

Now rerun the model without the interaction term, to assess whether the Y-intercept differs.

Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
LOG_MALF	28.297	1	28.297	1420.265	0.000
BPU_VER2$	0.116	4	0.029	1.452	0.231
Error	0.956	48	0.020		

The BPU term is not significant, so the Y-intercept is the same between the different biophysical units.

The BPU term is not significantly different. Thus the Y-intercept of the different biophysical units are the same. This means that there is no statistical difference in either the slope or the Y intercept between the relationships of IMFR and MALF between the different biophysical classes.

IMFR with respect to fish class

Interaction term to see if slopes are parallel.

Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
LOG_MALF	7.226	1	7.226	407.434	0.000
NEW_FISH_CLASS$	0.042	4	0.010	0.590	0.672
NEW_FISH_CLASS$*LOG_MALF	0.026	4	0.006	0.366	0.831
Error	0.780	44	0.018		

The Fish_Class x Log_MALF interaction term is not significant, so the slopes are the same.

Now rerun the model without the interaction term, to assess whether the Y-intercept differs.

Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
LOG_MALF	24.618	1	24.618	1465.535	0.000
NEW_FISH_CLASS$	0.266	4	0.066	3.955	0.007
Error	0.806	48	0.017		

The Fish_Class term is significantly different. Thus the Y-Intersect of the different fish species are not the same. The graph below shows that both brown and rainbow trout appear to have a higher IMFRs than the other fish species. Their IMFR is thus higher for a given flow.