

Assessing water quantity limits in the Waihou catchment: A summary & recommendations

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Executive summary

The Waikato Regional Council (WRC) is responsible for managing the status of water resources in the Waikato Region. As part of the scheduled review of water quantity limits in the Waihou catchment, WRC have initiated a range of investigations. The objectives of the studies carried out were to improve the understanding of the dependencies between instream values and flows in the catchment, and hence to inform ongoing management of water quantity in the catchment.

To support the review of water resource use limits in the Waihou catchment, a number of studies have been undertaken including analyses of instream physical habitat, flow variability, dissolved oxygen and flow dynamics. WRC have contracted NIWA to collate and summarise the results of these investigations with respect to the relevant policy and guidance documents in order to inform the limit setting process set out in Section 3.3.3 Policy 1 of the Regional Plan.

The instream physical habitat modelling study indicated that in some areas of the catchment some indicator species may be habitat limited under natural low flow conditions. Consequently, minimum flow limits set below the natural range of low flows are likely to further constrain habitat availability. In other areas of the catchment maximum predicted physical habitat availability occurred at flows well below the natural range of low flows and therefore current minimum flows are not likely to be a bottleneck on physical habitat availability for the indicator species. It was highlighted that a key limitation on the instream physical habitat modelling study was the lack of habitat suitability curves that have been developed in deeper (non-wadeable) streams and rivers, such as the Waihou and some of its main tributaries.

The analyses of flow variability indicated that there were some long-term downward trends in observed summer low flows, particularly at sites in the lower catchment. It is likely that these reflect increasing exploitation of water resources in the catchment over the last 30 years. It was also demonstrated that the flows which maximised instream physical habitat for some of the indicator species fell significantly outside the natural range of low flows that have historically been recorded in the river at some sites. The natural range of flows that have historically occurred set the context for current ecological communities. Significant departure from the natural range of flows experienced in the catchment have a medium to high risk of resulting in significant alterations in aquatic communities in the river.

Analyses of dissolved oxygen conditions at sites across the catchment indicate that in small lowland tributaries and the lower reaches of the main stem of the Waihou River downstream of Paeroa, low dissolved oxygen concentrations may be a constraint on ecological communities. A natural zone of depressed dissolved oxygen occurs in the tidal zone of the lower river between Paeroa and the river mouth. The location and magnitude of the dissolved oxygen minima varies with tide and water temperature. Dissolved oxygen concentrations in this zone fall below recommended protection levels for aquatic fauna during summer low flow conditions and will act as a bottleneck for upstream allocation of water resources. No clear correlation between freshwater flows and dissolved oxygen were identified during monitoring over a narrow range of summer low flow conditions. However, it is considered that there is a medium level risk that significantly reducing summer low flows is likely to exacerbate the dissolved oxygen problem in the lower river.

Spatially defined surface water quantity management units have been proposed, reflecting differences in catchment characteristics and results of the technical assessments. Recommendations for potential revisions to current minimum flow limits are provided. In the Waihou upper zone, it has

been suggested that consideration be given to increasing minimum flow limits due to the sensitivity of spring-fed streams to hydrological alteration and to better protect valued trout and native fish habitats. In the Waihou lower zone, where dissolved oxygen concentrations already fall below the national bottom lines set in the National Objectives Framework during summer low flows, it is recommended that current water quantity limits should remain largely unchanged. However, it was recognised that uncertainty around the sensitivity of dissolved oxygen to freshwater flows in the tidally influenced zone may offer the opportunity to increase primary allocation, but that this should be contingent on tying the management of water takes to continuous monitoring of dissolved oxygen in the worst affected areas. In the Ohinemuri zone, both trout and native fish habitats were identified as being constrained by natural low flows. It was recommended for this sub-catchment that the existing minimum flow limits of 95% of Q_5 be retained for the headwaters. Re-analyses of the habitat outputs to focus on retention of low flow habitat indicated that in the main stem of the river the existing minimum flow limit of 90% of Q_5 provided adequate protection for most target species. However, for reaches known to support trout spawning, it was recommended that the minimum flow be increased to 95% of Q_5 . A large number of reaches in the Kaimai tributaries zone are designated under the Natural State water class in the Waikato regional plan. Consequently, protection levels for these streams should be high. Presently, minimum flow limits are set at 95% of Q_5 and it is recommended that these should be maintained at the very least. In particularly high value tributaries, consideration should be given to increasing the protection level. This could include increasing the minimum flow to 100% of Q_5 or reducing the primary allocation limit to zero, thus ensuring better protection at low flows.

The recommendations made in this report for potential revisions to the current minimum flow and allocation limits in the catchment are based on expert interpretation of the technical assessments within a risk-based framework. WRC must now consider these outcomes in the context of wider catchment issues and management objectives, including providing water for out-of-stream use.

1 Introduction

1.1 Background

The Waikato Regional Council (WRC) is responsible for managing the status of water resources in the Waikato Region. WRC's approach to the protection, allocation and use of water resources is set out in the Waikato Regional Plan (the Plan) (Waikato Regional Council 2007), which became fully operative in 2012. As required by the National Policy Statement for Freshwater Management 2014 (NPSFM; MfE 2014a), the Plan defines minimum flows and allocation limits for all catchments in the region (Table 3-5; Waikato Regional Council 2007). Included within the Plan is a schedule for systematic review of the flow and allocation limits set out in Table 3-5 of the Plan (Table 3-4A; Waikato Regional Council 2007).

As part of the scheduled review of water quantity limits in the Waihou catchment, WRC have initiated a range of investigations. The objectives of the studies undertaken were to improve the understanding of the dependencies between instream values and flows in the catchment, and hence to inform ongoing management of water quantity in the catchment.

1.2 Scope

To support the review of water resource minimum and allocable flow limits in the Waihou catchment, a number of studies have been undertaken including analyses of instream physical habitat (Jowett 2008), flow variability (Franklin and Booker 2009), dissolved oxygen and flow dynamics (Franklin 2010b; Franklin 2010c; Franklin and Smith 2014) and instream ecology (Franklin and Booker 2009; Franklin et al. 2011; Franklin et al. 2013). WRC have contracted NIWA to collate and summarise the results of these studies with respect to relevant policy and guidance documents (e.g., MfE 1998a; Waikato Regional Council 2007; Beca 2008; MfE 2014a) in order to inform the limit setting process set out in Section 3.3.3 Policy 1 of the Plan.

The following report reviews and summarises each study alongside the relevant policy and guidance documents (as identified above). Options for setting minimum flow limits in the Waihou catchment have been identified.

2 Policy context

2.1 National

Resource Management Act 1991

The Resource Management Act (RMA) provides the principal legislative framework for water management in New Zealand (Memon 1997; Pyle et al. 2001). Under the RMA regional councils are delegated primary responsibility for sustainably managing water resources. One of the main mechanisms for achieving this is through the regional planning process. Regional plans can be used to set management objectives and specify regulatory criteria that define how regional water resources can be used. They also define the circumstances in which resource consents to take or use water are required, and the likely conditions that will be imposed on water users (Memon 1997).

National Policy Statement for Freshwater Management 2014

The National Policy Statement for Freshwater Management 2014 (NPSFM, MfE 2014a) came into effect in July 2014. The NPSFM sets out objectives and policies that direct how local government should manage water resources and requires them to set water quality and quantity limits for all water bodies.

Under the NPSFM, freshwater management units (FMU) must be delineated and freshwater objectives defined for all FMUs. Subsequently, limits must be set to ensure that freshwater objectives are fulfilled. Freshwater management units are the “water body, multiple water bodies or any part of a water body determined by the regional council as the appropriate spatial scale for setting freshwater objectives and limits and for freshwater accounting and management purposes” (MfE 2014a). In essence, they are an area within which common freshwater objectives and associated limits are set. Guidance on how FMUs are to be distinguished is expected during 2015 (MfE 2014c). Freshwater objectives describe an intended environmental outcome in a FMU (MfE 2014a). Objectives must be set for all compulsory values as set out in the National Objectives Framework (MfE 2014b). At present this includes ‘Ecosystem health’ and ‘Human health for recreation’ (MfE 2014a). Freshwater objectives may also be set for additional values, for example natural form and character, mahinga kai collection, public water supply or hydro-electric power generation. Once freshwater objectives have been identified, limits must be set which restrict the resource use to ensure that freshwater objectives will be met.

Section B of the NPSFM sets out the requirements for managing water quantity. The objectives with respect to water quantity management are to safeguard the life-supporting capacity, ecosystem processes, indigenous species and associated ecosystems of freshwaters; to avoid over-allocation of freshwater; to improve and maximise the efficient allocation and use of water; and to protect the significant values of wetlands and outstanding freshwater bodies. Policy B1 requires setting environmental flows for all FMUs to give effect to the objectives of the NPSFM. Environmental flows are defined in the NPSFM as “a type of limit which describes the amount of water in a freshwater management unit which is required to meet freshwater objectives. Environmental flows for rivers and streams must include an allocation limit and a minimum flow (or other flow/s)” (MfE 2014a).

The requirements of the NPSFM will be one of the primary policy drivers shaping the future management of water quantity and associated water quantity limits across New Zealand.

Hauraki Gulf Marine Park Act 2000

The Hauraki Gulf Marine Park Act established objectives for the integrated management of the Hauraki Gulf, its islands and catchments. It recognises the interrelationships between the management of catchments and sustaining the life-supporting capacity of the environment of the Gulf. The objectives of the Act are to protect and, where appropriate, enhance the life-supporting capacity of the environment of the Gulf, its islands and catchments. This includes the capacity of the Gulf environment to provide for the social, economic, recreational and cultural wellbeing of people and communities including tangata whenua, and to maintain the water and ecosystems of the Gulf.

Sections seven and eight of the Act have the effect of a National Policy Statement and apply beyond the coastal marine area to include the entire catchment of the Hauraki Gulf. The Waihou is the largest catchment entering the Hauraki Gulf and therefore the objectives of the Act must be taken into consideration when determining water quantity limits for the Waihou catchment.

2.2 Regional

WRC's approach to the protection, allocation and use of water resources is set out in the Waikato Regional Plan (Waikato Regional Council 2007). The Plan implements the directions set out in the Regional Policy Statement (Environment Waikato 2000). The policies and rules set out in the Plan are intended to give effect to WRC's objectives for managing water use and set a framework for how water quantity limits are to be determined and implemented within the Waikato region.

Section 3.3.3 Policy 1 of the Plan dictates the need to establish and review minimum flow and allocation limits for surface water bodies. It also identifies a range of matters that are to be considered when defining limits including, amongst others:

- Avoiding significant adverse effects on instream ecological values and biodiversity
- having regard for the contaminant assimilative capacity of water bodies
- avoiding further degradation of water quality
- recognising the benefits of flow regime variability
- maintenance and enhancement of tangata whenua uses and values of water
- maintenance of intrinsic values and the natural character of rivers
- the benefits derived from taking and using water, and
- the effects of climate change on surface water resources.

Section 3.3.3 Policy 2 of the Plan defines how the level of minimum flows, and the primary, secondary and water harvesting allocable flows will be determined. In general, minimum flows are to be determined following detailed habitat and river studies, such as those that have been carried out recently in the Waihou catchment. Primary allocable flows are to be set on the basis of the difference between the minimum flow and the one in five year 7-day low flow (Q_5), i.e., if the minimum flow is 90% of Q_5 , then primary allocation will be 10% of Q_5 . The secondary allocable flow is set at the portion of the flow between the primary allocable flow and 30% of Q_5 , unless otherwise specified in Table 3-5 of the Plan. For example, if the primary allocation is 10% of Q_5 , then secondary allocation will generally be 20% of Q_5 . In addition to the primary and secondary allocable flows, surface water

harvesting of up to 10% of the river's flow is provided for at times when the river flow is greater than the median flow.

WRC have defined 'Surface Water Allocation Catchments' (SWACs) for the specific purpose of managing water quantity. The limits that apply in different SWACs are defined in Table 3-5 of the Plan. Method 3.3.4.9 of the Plan provides for review of these limits if, among other reasons, the matters listed in Section 3.3.3 Policy 1 are not being provided for, actual or potential adverse effects are occurring within a catchment due to high water demand, investigations indicate that climate change is affecting surface water flows, or the catchment investigation date listed in Table 3-4A of the Plan occurs. The limits defined in the Plan are used to manage water resource use and allocation within the SWACs. It is therefore important to ensure that both minimum flow and allocation limits are transparent, robust, justifiable and based on best available scientific information (Snelder et al. 2014b).

More broadly, the Plan also defines water management classes intended to help direct management objectives associated with different values (Section 3.2.3). Of particular relevance to setting water quantity limits in the Waihou catchment are the Natural State Water Class (Section 3.2.3 Policy 5) and the Fishery Class (Section 3.2.3 Policy 7). The natural state water class recognises water bodies that are considered outstanding because they are unmodified or substantially unmodified by human intervention (Waikato Regional Council 2007). The purpose of this class is to protect the flow regime, water quality, and riparian and aquatic habitat for indigenous species in order to maintain the aesthetic and intrinsic values derived from the unmodified or largely unmodified nature of the catchment. The purpose of the fishery class is to maintain or enhance existing water quality and aquatic habitat in water bodies that currently support a diverse range of fish species and fish habitats with significant conservation values, or which support significant recreational, traditional or commercial fisheries. It is intended that for these fisheries, trout or indigenous fish can complete their life cycles and/or maintain self-sustaining populations, and managed trout and indigenous fisheries can be sustained (Waikato Regional Council 2007).

The approach to setting water quantity limits currently taken by WRC appears to be largely consistent with the main requirements of the NPSFM. However, it is likely that some modifications to WRC's operative Plan will be required as the NPSFM is implemented in full. For example, at present it is unclear how the SWACs may be translated into FMUs and subsequently linked to freshwater objectives. It will also be necessary to clarify how 'over-allocation' as defined in the NPSFM is interpreted with respect to WRC's policy and rule structures. The Proposed Regional Policy Statement (Waikato Regional Council 2013), that is currently under appeal, sets the broad context for implementation of the NPSFM in the Waikato Region. Policy 8.1 outlines the approach to managing fresh water bodies and states that WRC will "Establish measureable limits and targets for each fresh water body to manage the adverse effects on them" (Waikato Regional Council 2013). This will include setting minimum and allocable flow limits in the regional plan (Implementation method 8.1.2) in order to achieve Objective 3.13 which is to recognise and provide for the mauri and health of fresh water bodies. This includes maintaining:

- natural character and function, including flow regime variability
- health and functioning of indigenous biodiversity, ecosystems and habitats, and
- human relationships with fresh water.

It will also be achieved by improving the life supporting capacity of fresh water bodies where they have been degraded as a result of human activities; ensuring high value fresh water bodies are protected; managing adverse cumulative effects of land use activities on fresh water bodies; and enabling people and communities to provide for their social, economic and cultural wellbeing.

Any future potential co-management agreement with Hauraki iwi for the Waihou catchment may also impact on priorities for management of water quantity. However, for the purpose of the current report, any potential future adaptations to the management of water quantity in the region due to the implementation of the NPSFM and other policies will not be considered. Consequently, the results of investigations will be interpreted in the context of WRC's currently operative Plan.

3 Approaches to determining water quantity limits

A significant technical challenge for setting regional water resource use limits is providing and using appropriate scientific information on which to base the decision-making process (Snelder et al. 2014b). In New Zealand, the legislative framework is inherently risk-based and requires that assessments of environmental effects be scaled according to the environmental risk (Rouse and Norton 2010). As such, scientific methods for the determination of instream flow requirements should be selected according to an analysis of the significance of the environmental values and the degree of hydrological alteration (e.g., Beca 2008). For example, in low-risk situations, i.e., both the consequence and likelihood of adverse effects are low, the use of reconnaissance-level methods for setting minimum flows is justified. In situations where the risk is greater, a more resource-intensive and spatially specific assessment of environmental flow requirements may be necessary.

A variety of approaches and frameworks exist for assessing instream flow requirements (Tharme 2003; Acreman and Dunbar 2004). The majority of methodologies can be classified into four groups: (i) hydrological; (ii) hydraulic; (iii) habitat; and (iv) holistic. Hydrological methods are typically used for broad-scale planning and are based on hydrological indices (e.g., Tennant 1976). Hydraulic methods involve establishing functional relationships between simple hydraulic variables (e.g., wetted width; Booker 2010) and flow as a guide for establishing minimum flow requirements. Habitat modelling methodologies attempt to assess ecological flow requirements based on the quantity and suitability of physical habitat available to a target species under different flow regimes (e.g., PHABSIM; Bovee 1982). Holistic methods are more closely aligned to the 'natural flow paradigm' (Poff et al. 1997) and are based on the premise that the natural flow regime has intrinsic value or important ecological function that will be maintained by retaining key elements of the natural flow regime (e.g., Richter et al. 1996). Typically, holistic approaches build on the understanding of functional links between different components of the flow regime and ecology, geomorphology, water quality, social, recreational or other objectives of river management (Poff et al. 2010). Hydrologic, hydraulic and habitat approaches can all be components of a holistic assessment (Acreman and Dunbar 2004).

Discussion of the different approaches which can be used for environmental flow setting in a New Zealand context is provided in MfE (1998a), MfE (1998b), Jowett and Biggs (2008), Jowett et al. (2008) and Beca (2008). The most recent guidance on the selection of technical methods for evaluating ecological flow requirements was provided in Beca (2008), in association with the proposed National Environmental Standard on ecological flows and water levels (MfE 2008). This advocated a risk-based approach to selecting the most appropriate scientific method for use in the decision-making process whereby the more significant the instream values, and the greater the degree of hydrological alteration, the more comprehensive and detailed the assessment method(s) that are required (Figure 3-1). This strategy is largely in line with the approach advocated in the original Flow Guidelines for Instream Values (MfE 1998a), which is used by WRC to help guide their strategy to developing and establishing water quantity limits (Method 3.3.4.6, Waikato Regional Council 2007). For the Waihou catchment many of the investigations undertaken and discussed here are focussed on site specific analyses and models as referred to in Figure 3-1.

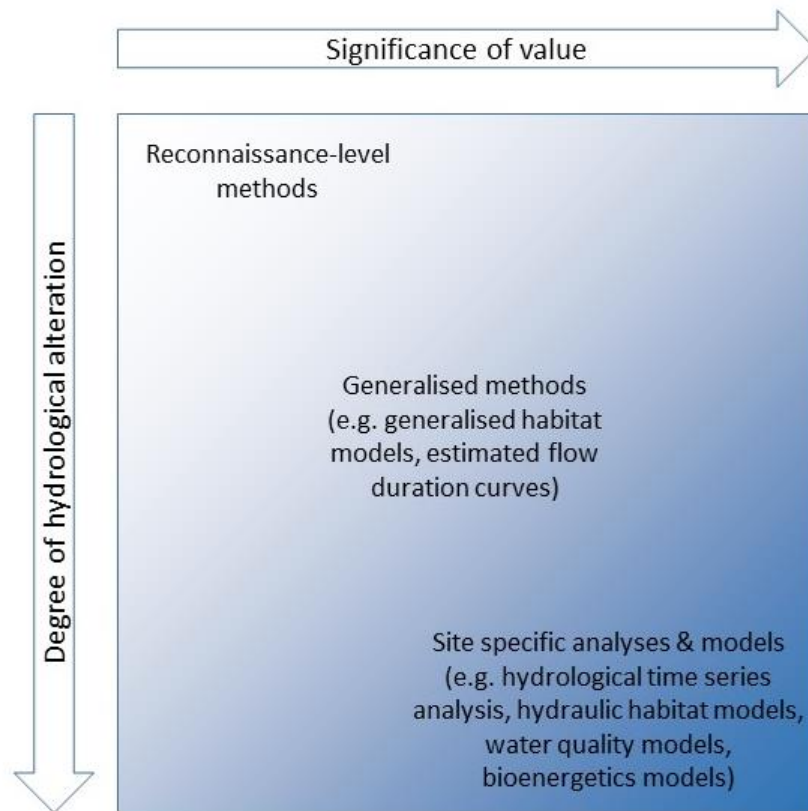


Figure 3-1: Example of a risk-based framework for selecting methods used in the assessment of ecological flow limits. Adapted from Beca (2008).

4 Water quantity limits in the Waihou catchment

4.1 Existing limits

At present, the Waihou catchment is not specifically identified in Table 3-5 of the Plan (Waikato Regional Council 2007). Consequently, the default limits specified for “All other catchments (excluding Coromandel Peninsula)” apply. This states that where mean flow is greater than $5 \text{ m}^3 \text{ s}^{-1}$, the minimum flow is 90% of Q_5 , with a corresponding primary allocation of 10% of Q_5 and secondary allocation of 20% of Q_5 . Where mean flow is less than $5 \text{ m}^3 \text{ s}^{-1}$, the minimum flow is 95% of Q_5 , with a corresponding primary allocation of 5% of Q_5 and secondary allocation of 25% of Q_5 (Figure 4-1).

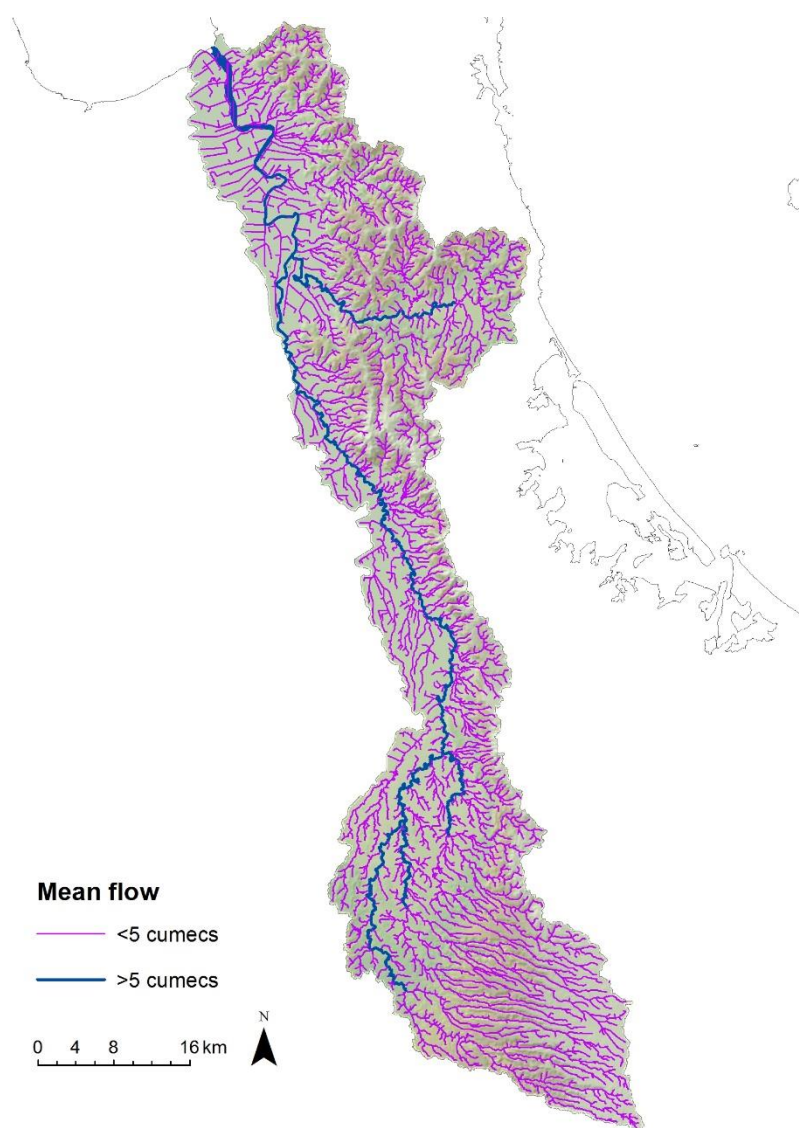


Figure 4-1: Map showing where in the Waihou catchment different water quantity limits currently apply. Where mean flow is $<5 \text{ m}^3 \text{ s}^{-1}$ (pink) the minimum flow is 95% of Q_5 . Where mean flow is $>5 \text{ m}^3 \text{ s}^{-1}$ (blue) the minimum flow is 90% of Q_5 .

4.2 Waihou minimum flow review

A review of water quantity limits in the Waihou catchment was initiated by WRC as scheduled in Table 3.4A of the Plan. The work that has been undertaken during this review process is summarised and evaluated below. Investigations have focused on three primary themes: i. instream habitat for fish; ii. natural character and flow variability; and iii. water quality and contaminant assimilative capacity.

4.2.1 Instream habitat for fish

The interaction between flow and channel morphology determines water depth and velocity in a river and in turn provides physical habitat for plants, invertebrates and fish (Booker and Acreman 2007). The direct relationship between physical habitat and flow provides a means for assessing the ecological impact of changing the flow regime of a river. Assessment of river management options often involves evaluating scenarios that fall outside the range of observed conditions and thus predictive models are required. The Physical Habitat Simulation (PHABSIM) system (Bovee 1982) was the first systematic physical habitat modelling framework to be developed and many models based on a similar concept have been produced including CASIMIR in Germany, EVHA in France and RHYHABSIM in New Zealand. Essentially these models quantify the relationship between physical habitat, defined in terms of the combination of water depth, velocity and substrate, and various flows (Jowett 1997; Tharme 2003). Criticisms of this approach include lack of biological realism (Orth 1987; Hudson et al. 2003) and mechanism (Mathur et al. 1985). Nevertheless, the models have been applied widely throughout the world, primarily to assess the impacts of abstraction or river impoundment (Dunbar and Acreman 2001). In New Zealand, RHYHABSIM has been applied to many rivers for the purpose of assessing instream flow requirements (Lamouroux and Jowett 2005). Jowett and Biggs (2006) reviewed the results from six rivers in which habitat-based methods had been applied to setting flow limits. They found that in five of these cases the biological response and the retention of desired instream values was achieved.

The approach adopted in many physical habitat studies is described by Clausen et al. (2004) and Jowett (1997). This includes: identification of river sectors and species of interest; identification of habitats that exist within the sectors of interest; selection of cross-sections which represent replicates of each habitat type; and the collection of model calibration data (water surface elevation, depth and velocity). The calibration data are used to determine the spatial distribution of depths and velocities across each cross-section and the relationship between water levels at each cross-section and the quantity of water flowing in the river.

The Waihou River and its larger tributaries support valued trout fisheries (Figure 4-2) and much of the main stem of the river is also designated as important native fish habitat in the Plan (Figure 4-3). An assessment of the flow requirements to sustain instream habitat for fish was therefore identified by WRC as being an integral component of evaluating instream flow requirements for the catchment. An instream habitat modelling study has therefore been carried out using the River Hydraulic Habitat Simulator (RHYHABSIM) in the Ohinemuri River, the Waihou River, the Oraka Stream, the Mangawhero Stream, the Waiomou Stream and the Waimakariri Stream (Jowett 2008) (Figure 4-4). The purpose of the study was to investigate the flows required to maintain acceptable physical habitat for native fish and trout in the selected streams.

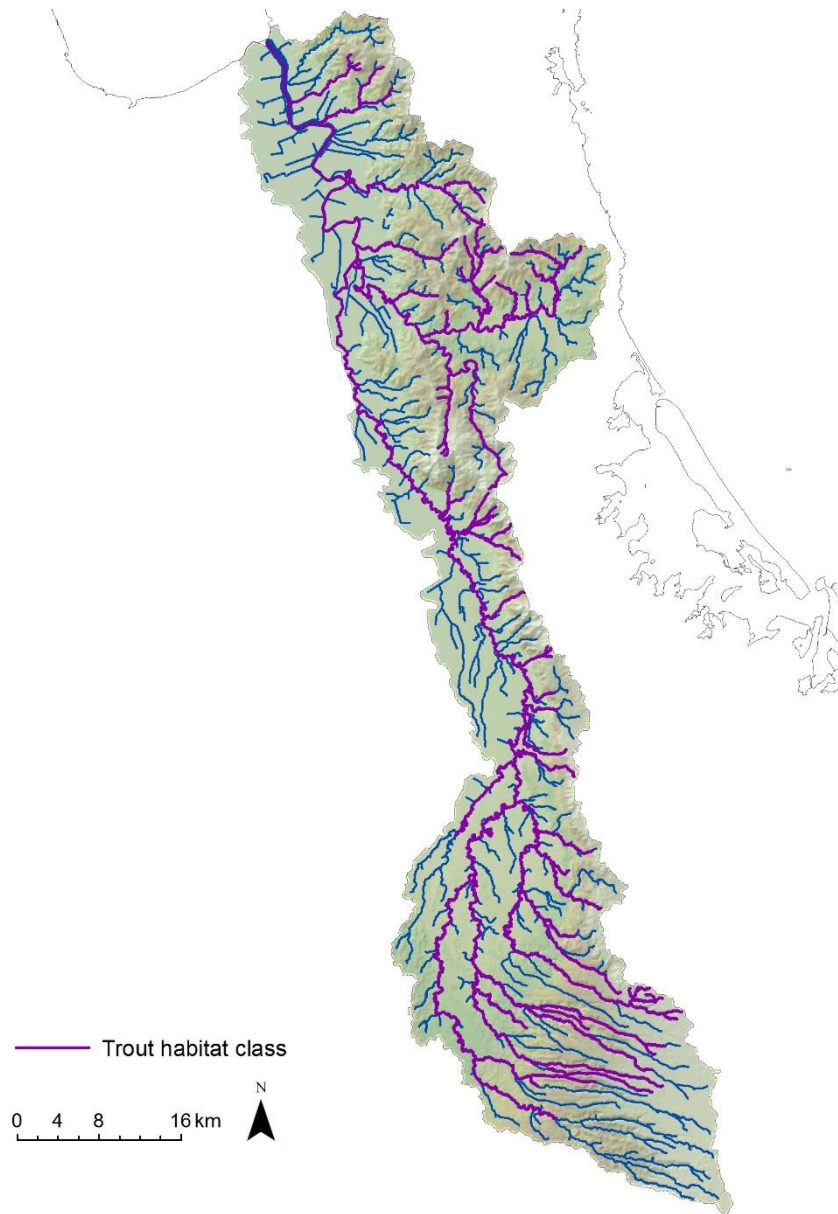


Figure 4-2: Map of river reaches designated in the Waikato Regional Plan as important trout habitat in the Waihou catchment.

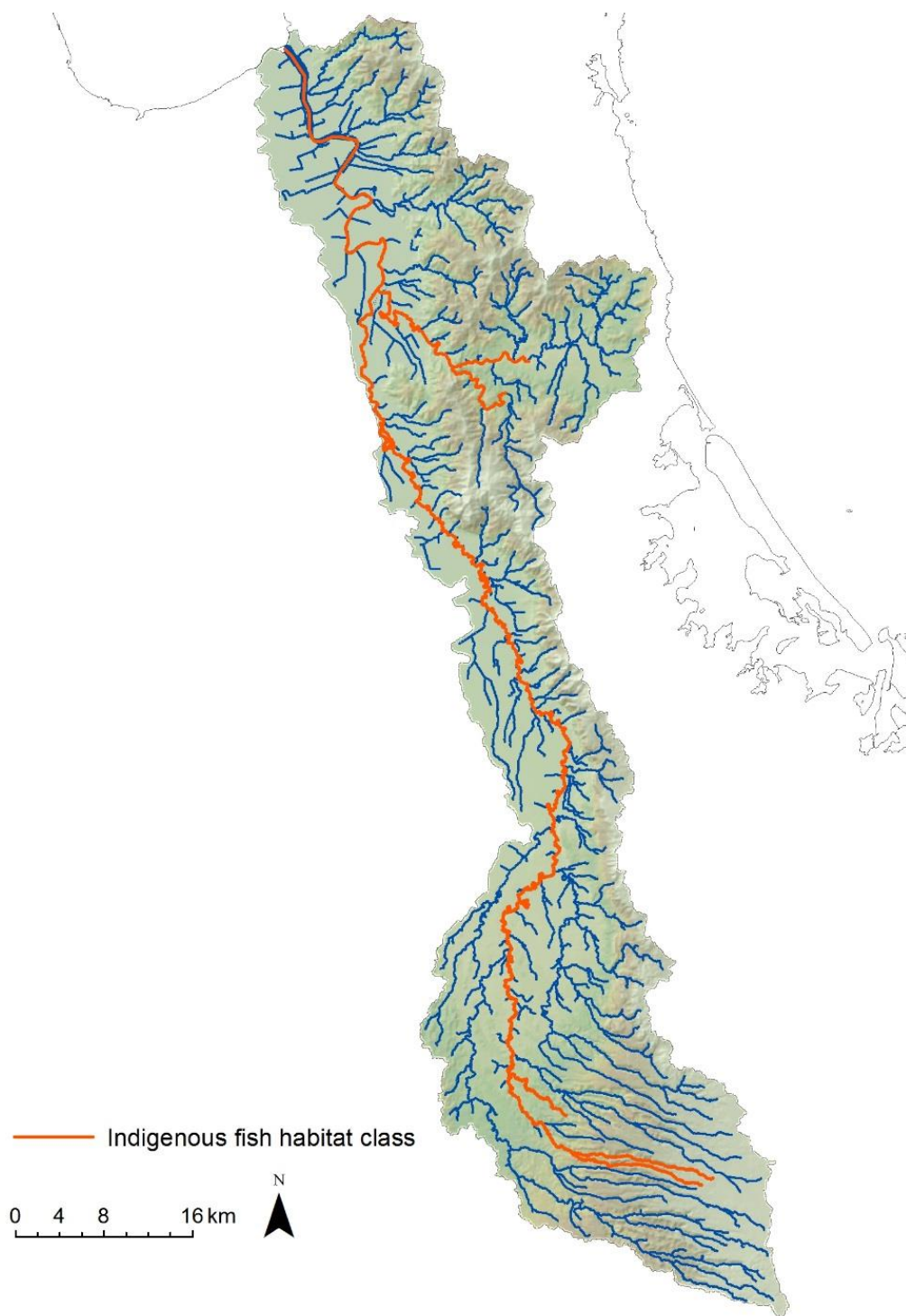


Figure 4-3: Map of river reaches designated in the Waikato Regional Plan as important indigenous fish habitat in the Waihou catchment.

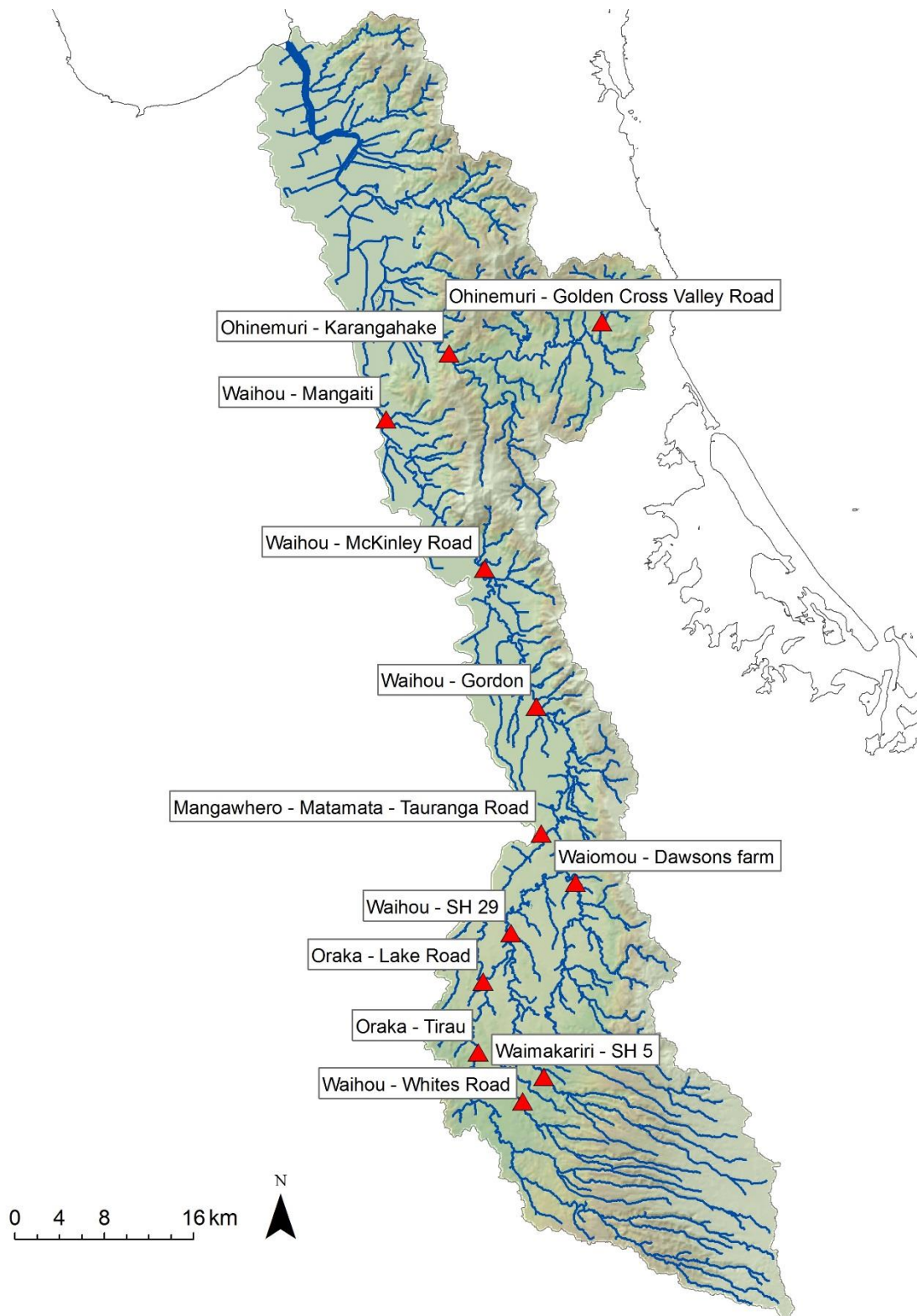


Figure 4-4: Map identifying the location of the RHYHABSIM study sites used by Jowett Jowett (2008).

Instream physical habitat surveys were carried out in each river and flow requirements for the resident species were assessed by examining the relationships between flow and suitable physical habitat using instream physical habitat modelling. Habitat suitability was determined from habitat suitability curves developed from studies in other rivers (Thomas and Bovee 1993; Jowett and Richardson 1995; Jowett 2002). For each target fish species at each site the optimum flow (i.e., the flow that provides maximum habitat), flows that provide 90%, 80% and 70% of the optimum habitat and the flow below which habitat declines sharply were identified (Figure 4-5; see Table 5.1 in Jowett (2008) for values).

Maximum habitat was predicted to occur at flows less than Q_5 at the majority of sites for most species (Figure 4-5; habitat curves to the left of the vertical dashed line). This was particularly the case for the sites on the main stem of the Waihou River downstream of State Highway 29 (Gordon, McKinley Road, Mangaiti; Figure 4-4). The main exceptions to this pattern were the sites on the Ohinemuri Stream where maximum habitat occurred at flows greater than Q_5 for the majority of species. Adult rainbow trout were the most 'flow demanding' species at all sites in that maximum predicted habitat occurred at a higher flow than other species. In many cases, the flow below which predicted habitat declines sharply occurred at somewhere between the flows that provided 90% and 100% of the maximum habitat.

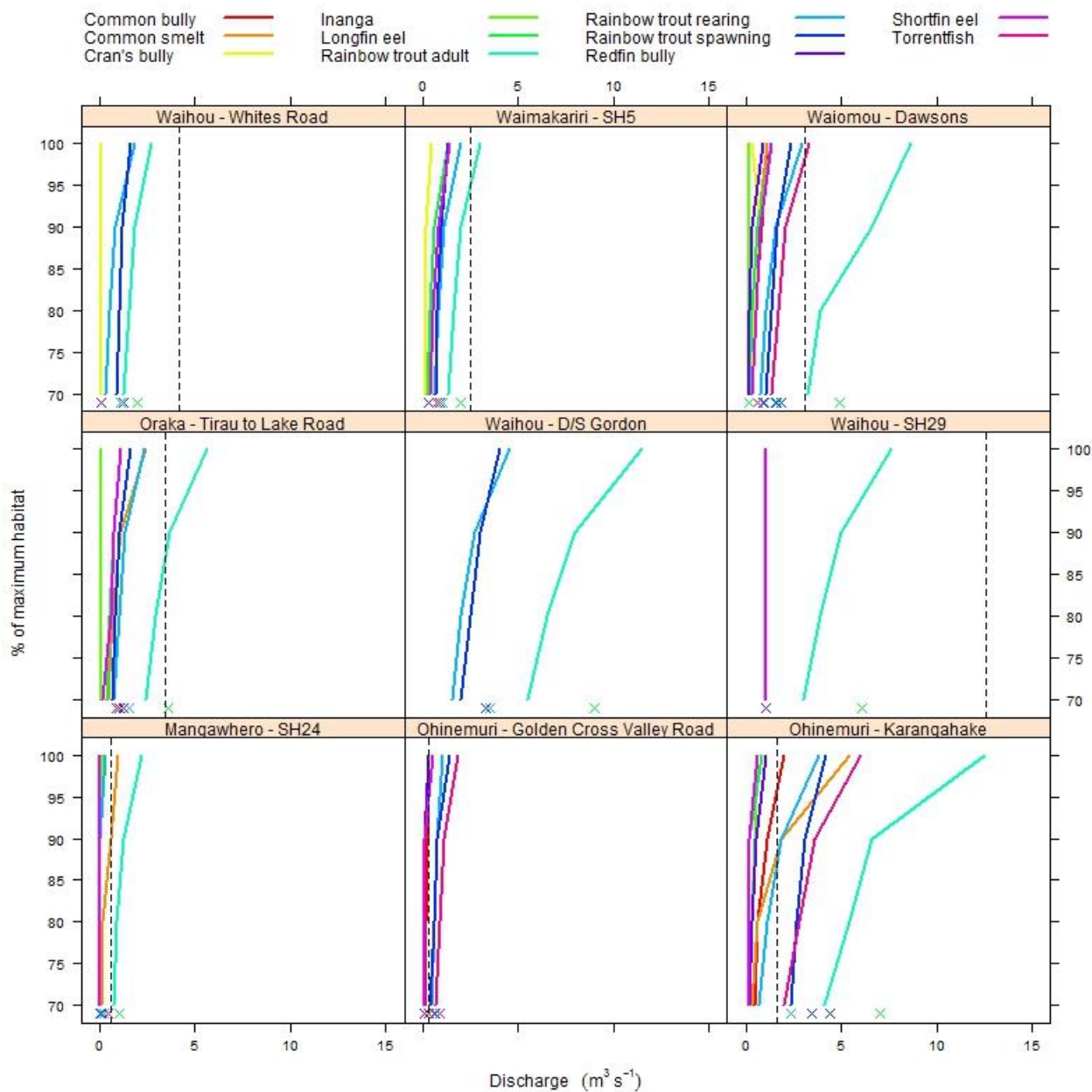


Figure 4-5: Summary of flows providing for 70%, 80%, 90% and 100% of maximum predicted habitat compared to the 1 in 5 year 7-day low flow (Q_5) at different sites. Black vertical dashed line represents Q_5 (no line is shown for Waihou - D/S Gordon as Q_5 ($23 \text{ m}^3 \text{ s}^{-1}$) is greater than the limit of the x axis). Crosses give an indication of the breakpoint where habitat rapidly declines as flow decreases (colours correspond with species).

Selecting appropriate physical habitat protection levels for different species and therefore setting corresponding minimum flow limits is challenging, particularly when seeking to protect multi-species assemblages. The process is generally subjective and dependent on having clearly defined objectives for different values. Where the objective is to optimise conditions to support a trout fishery, selecting a flow which corresponds with the maximum predicted instream physical habitat may be an appropriate target. However, where the objective is to maintain natural native fish communities, selecting flows based on optimising maximum predicted habitat may not be appropriate. Firstly, maximum habitat for multiple species rarely occurs at a single flow, and therefore making the selection of one flow to maximise all species is essentially impossible. Secondly, the natural flow paradigm (Poff et al. 1997) would suggest that the ecological communities present in a stream are adapted to the natural flow regime. Annual low flows will vary between years within a certain range and therefore favour different species in different years, resulting in the mixed assemblage present at a site. For example, in wet years when low flows are higher, species favouring higher flows will be more successful. However, in drought years when low flows are lower than average, the species more able to tolerate these conditions will have a better year. Consequently, selecting habitat protection levels based on safeguarding a certain proportion of the habitat available under natural low flow conditions may be a more appropriate approach for this objective.

WRC have set objectives for different water classes in the Plan and these may help to guide definition of appropriate protection levels and therefore flow limits in certain parts of the catchment. For example, in the natural state class the objective may be to minimise changes in the flow regime and to try and maintain the diversity and abundance of natural native fish communities. However, in the trout fishery class, the objective may be to optimise the quantity of habitat available for the different life stages of trout in order to support a healthy and self-sustaining trout population.

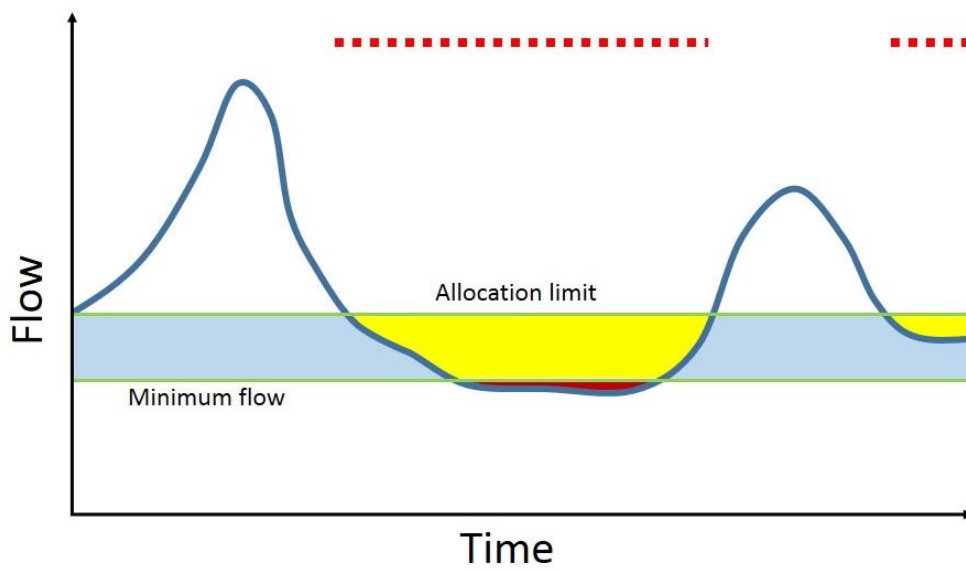
In any case, the results of an instream physical habitat modelling study should be interpreted with an awareness of the assumptions and limitations of the model. The main assumptions and limitations of the instream physical habitat modelling approach are widely described in the literature (e.g., Bovee 1982; Nestler et al. 1989; Elliott et al. 1996; Jowett 1996; Milhous 1999; Hudson et al. 2003) and will not be repeated here. However, there are a number of considerations that are particularly pertinent to this application in the Waihou catchment and they will therefore be discussed.

As highlighted in Jowett (2008), many of the stream and river reaches evaluated in the Waihou catchment were relatively deep and fast flowing (Jowett 2008). However, the habitat suitability curves that were used for native fish species were developed from data collected in locations primarily <0.4 m deep and with a water velocity of <0.4 m s⁻¹ (Jowett and Richardson 1995). The use of habitat suitability curves that have not been developed in an equivalent stream type and that do not capture the full range of conditions present in the study streams will bias results towards predicting optimal habitat at lower flows, where water depths and velocities are reduced to below 0.4 m and 0.4 m s⁻¹ respectively. The habitat suitability curves for spawning rainbow trout were developed in the Tongariro River and those for the other life stages of trout were developed in a river in Colorado, USA (Thomas and Bovee 1993). In both cases the rivers in which the habitat suitability curves were developed are both morphologically and hydrologically different to the predominantly spring fed streams of the Waihou catchment. The appropriateness of transferring these habitat suitability curves to the Waihou may be open to question, but was not addressed in the original report. Interpretation of the results for rainbow trout should therefore be considered in the context that the curves may not be appropriate, particularly in the main stem of the lower Waihou.

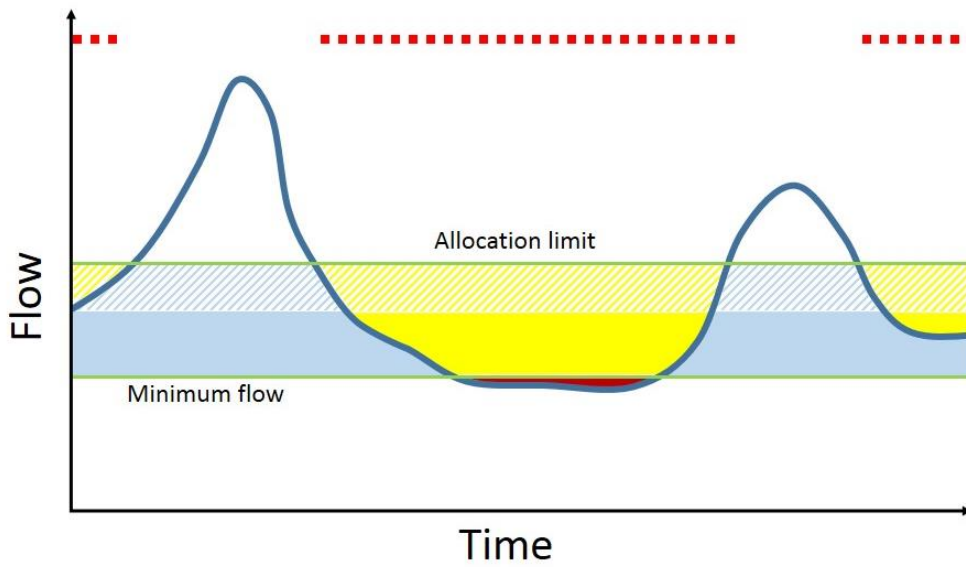
A challenge in any instream physical habitat assessment is in selecting sites for assessment and then scaling the results from the assessment reaches to the broader catchment. This is usually achieved either through identifying critical reaches that are thought to be the most sensitive to changes in flow and therefore act as a 'bottleneck' for setting water quantity limits, or by identifying reaches that are considered representative of broader sections of river. Jowett (2008) took a representative reach approach for the Waihou physical habitat assessment, but the report does not make it clear which river sections the study reaches were chosen to represent. It is recommended that WRC give careful consideration to the spatial variability between river sections before transferring the results to other parts of the stream/river. It should also be noted that all study reaches were located on the main stem of the Waihou and its major tributaries, as this is where WRC identified the main allocation pressures to be. However, smaller tributaries are likely to respond differently to the main stem of the river and may be important habitats, particularly for some native fish species and for juvenile trout. WRC should therefore consider the relevance of transferring the results of the instream habitat modelling work for contributing directly towards setting minimum flow limits in the smaller tributaries.

In interpreting the results of the instream physical habitat analyses, consideration should be given to the effects of temporal variations in flow (and hence habitat) (e.g., Capra et al. 1995) and the interacting influence of the allocation limit in determining the resultant impact on instream physical habitat availability (Snelder et al. 2014b). Temporal variations in habitat availability for different species may be important in balancing community composition and/or may act as a limit or bottleneck to the maintenance of sustainable populations if critical habitats are constrained at certain times of the year. Species may be able to adapt to small changes in the timing, duration, and magnitude of habitat availability, but the larger the changes become, the greater the likelihood of impacting on instream ecological community structure and functioning. Altering minimum flow limits can impact on the timing, duration and frequency of potentially limiting habitat conditions. It may also be appropriate to consider different minimum flow limits at different times of the year to reflect seasonal variations in habitat requirements or interactions with other stressors.

The degree of hydrological alteration and hence impact on habitat availability is also affected by the allocation limit. For a given minimum flow limit, the greater the allocation limit, the larger the quantity of water available for abstraction (light blue shaded areas in Figure 4-6), but the lower the reliability of that water (yellow shaded areas in Figure 4-6) and the greater the duration the river will be at the minimum flow (red dotted line in Figure 4-6). Increasing the duration of 'flat-lining' at the minimum flow, also results in a 'flat-lining' of the habitat, which has the potential to impact on space, competition, food supply and predation, for example, over time. Unfortunately, relatively little is known about the impacts of these factors for native fish species meaning that there is no clear guidance on how this might be implemented in a limit setting scenario. However, as a rule of thumb it has been suggested that the duration of 'flat-lining' should generally not be increased by more than 30 days and ideally should be kept less than this (Beca 2008).



A.



B.

Figure 4-6: Demonstration of how different allocation limits affect the quantity and reliability of water available and hence instream physical habitat availability. A. Lower allocation limit. B. Higher allocation limit. Dark blue line = river flow; Light blue shading = water available for takes; Yellow shading = restrictions on water takes required; Red shading = no water available; Red dotted line = period river is 'flat lined'. Striped shading in B indicates the difference between the low and high allocation limit.

4.2.2 Natural character and flow variability

Increasingly it has also been recognised that physical habitat approaches tend to focus on one or a few species, and that setting a single minimum flow fails to recognize that what is good for individual species may not be of benefit to the ecosystem, and what is good for the ecosystem may not consistently benefit individual species (Poff et al. 1997; Arthington et al. 2006). Subsequently, more holistic approaches targeting preservation of aquatic species at the community level and recognising the importance of flow variability have been developed (Richter et al. 1996; Acreman and Dunbar 2004; Arthington et al. 2006; Poff et al. 2010).

The flow regime of a river has been called a master variable that limits the distribution and abundance of riverine species and regulates the ecological integrity of flowing water systems (Poff et al. 1997). Numerous flow characteristics are presumed to be important for the maintenance and regeneration of riverine habitats and hence for biological diversity (Poff and Ward 1989; Richter et al. 1997; Bunn and Arthington 2002; Poff et al. 2010). These characteristics can be defined by five critical components: magnitude, frequency, duration, timing and rate of change of hydrologic conditions (Richter et al. 1996; Poff et al. 1997). Although possible functions of different flow regime components have been identified, the degree to which the frequency and duration of these events affects biota is not well understood and there is currently no quantitative method of assigning acceptable frequencies and durations, other than to mimic nature. The natural flow paradigm suggests that the full range of natural intra- and inter-annual variation in flow characteristics is critical in sustaining the full native biodiversity and integrity of aquatic ecosystems (Poff et al. 1997; Richter et al. 1997). This is because native riverine species develop life history traits that enable individuals to survive and reproduce within a certain range (i.e., the natural range) of environmental variation (Townsend and Hildrew 1994; Stanford et al. 1996) and departure from this can result in community change and a loss of biodiversity.

A number of holistic flow assessment frameworks aligned with the natural flow paradigm have subsequently emerged (Tharme 2003). The range of variability approach (RVA), and the associated indicators of hydrological alteration (IHA), characterises the 'natural' flow regime using a set of hydrological parameters which identifies the natural range of hydrological variability that exists (Richter et al. 1997). The implicit assumption of this method is that the natural flow regime has intrinsic value or important ecological functions that will be maintained by retaining the key elements of the natural flow regime. Flow guidelines are then designed on the basis of allowing an appropriate degree of alteration relative to the natural range of variation. A further development of this principle are approaches such as the building block method (BBM) (King et al. 2008), the flow events method (FEM) (Stewardson and Gippel 2003) and the Ecological Limits of Hydrological Alteration (ELOHA) method (Poff et al. 2010). These approaches are based on the concept that some flows within the complete hydrological regime are more important than others for the maintenance of the river ecosystem, and that these flows can be identified and characterised in terms of their magnitude, duration, timing and frequency. They take a prescriptive approach, identifying key components of the flow regime for protection and designing a flow limits to maintain a river in a particular condition. However, the amount of hydrological variation required to maintain a healthy ecosystem is poorly understood and the complexity of natural systems makes it difficult to define thresholds at which the flow regime will maintain a desired river condition (Acreman and Dunbar 2004; Beca 2008). Consequently, a cautious approach to setting flows is required that builds buffers for risk and unknown outcomes.

Although tools such as RVA have not routinely been applied in New Zealand, they were included in the proposed National Environmental Standards (NES) schedule of methods for rivers with a high significance of instream values (Beca 2008). The draft guidelines stated that “while analysis of hydrological variation will not by itself allow the setting of ecological flows, it will act as a ‘flag’ to other methods to illustrate the extent of hydrological change, and how these hydrological parameters may be affected by the ecological flow decision” (Beca 2008). In essence, a set of statistical parameters are used to characterise hydrological conditions in each year of a flow time-series. These parameters provide information designed to describe the natural flow regime, including those components that are considered ecologically relevant (Table 4-1). Statistical measures of spread are then used to quantify the variation in these parameters between years. These characteristics are then used to provide a natural context to inform management activities and setting water quantity limits.

Table 4-1: Summary of hydrologic parameters and their ecosystem influences. Adapted from IHA user's manual (The Nature Conservancy 2007).

IHA parameter group	Hydrologic parameters	Ecosystem influences
1. Magnitude of monthly water conditions	Mean/median flow for each month	<ul style="list-style-type: none"> ▪ Habitat availability for aquatic organisms ▪ Water quality ▪ Connectivity between habitats ▪ Reliability of water supply for terrestrial flora & fauna
2. Magnitude and duration of annual extreme water conditions	<p>Annual 1-day mean minima & maxima</p> <p>Annual 3-day mean minima & maxima</p> <p>Annual 7-day mean minima & maxima</p> <p>Annual 30-day mean minima & maxima</p> <p>Annual 90-day mean minima & maxima</p> <p>Number of zero-flow days</p> <p>Base flow index (BFI)</p>	<ul style="list-style-type: none"> ▪ Balance of competitive, ruderal & stress-tolerant species ▪ Structure of river channel morphology & physical habitat ▪ Nutrient exchange between river & floodplain ▪ Duration of stressful conditions ▪ Sediment dynamics ▪ Connectivity between river & floodplain habitats
3. Timing of annual extreme water conditions	Julian date of each annual 1-day minimum and maximum flow	<ul style="list-style-type: none"> ▪ Predictability of disturbance/stress ▪ Compatibility with life cycles of organisms ▪ Spawning cues for migratory fish ▪ Evolution of life-history strategies & behavioural mechanisms
4. Frequency and duration of high and low pulses	<p>Number of low & high flow pulses in each water year</p> <p>Mean/median duration of low & high pulses</p>	<ul style="list-style-type: none"> ▪ Frequency & duration of stress ▪ Availability of & access to habitats ▪ Nutrient & organic matter exchange ▪ Sediment dynamics
5. Rate and frequency of water condition changes	<p>Rise rates: Mean/median of all positive differences between consecutive daily values</p> <p>Rise rates: Mean/median of all negative differences between consecutive daily values</p> <p>Number of hydrologic reversals</p>	<ul style="list-style-type: none"> ▪ Stranding/entrapment of organisms ▪ Desiccation stress on low-mobility stream edge organisms

The RVA was applied to a selection of sites across the Waihou catchment with appropriate hydrological records with the aim of characterising the flow regime in the catchment (Franklin and Booker 2009). The purpose was to provide a more holistic framework for setting flow benchmarks and defining flow requirements to protect instream ecological communities in the catchment. The analysis of flow regimes focussed on the hydrological gauging sites in the catchment with the longest records (Table 4-2).

Table 4-2: Location of flow gauging sites used for flow analysis.

Flow gauge number	River	Location	Easting	Northing	Record length (Years)
1122.34	Waihou	Te Aroha	2749400	6402600	42
1122.38	Waihou	Tirohia	2743700	6414800	41
619.16	Ohinemuri	Karangahake	2750600	6417200	40
669.13	Oraka	Pinedale	2756300	6344600	28
1122.18	Waihou	Okauia	2760200	6375600	25
619.19	Ohinemuri	Queen's Head	2757600	6417000	23

A range of hydrologic parameters representing different components of the flow regime were calculated from available hydrologic data, providing information on the natural range of flow variability across the catchment. The flow regimes across the catchment are generally flashy throughout the year, and are slightly elevated over the winter period. The sites in the upper catchment have a more stable flow regime consistent with a higher contribution of baseflow. Broadly speaking, the range and variance of flows generally increases with distance downstream (i.e., from Okauia to Tirohia). The inter-quartile range at Okauia is considerably narrower than at the Te Aroha and Tirohia gauging sites indicating a more stable flow regime. This is consistent with the predominance of groundwater, and hence higher baseflow contribution, in the upper catchment. This pattern is also reflected in the flow summaries for the Oraka Stream. Flows in the Ohinemuri River are characterised by quite low medians relative to the maximums recorded at each site. The mean flow at Karangahake ($12.13 \text{ m}^3 \text{ s}^{-1}$) is approximately double the median flow ($6.37 \text{ m}^3 \text{ s}^{-1}$) suggesting relatively low base flows, but a high frequency of high flow/flooding events. For details of the results, please refer to Franklin and Booker (2009).

Whilst calculation of the hydrological parameters is relatively straightforward, evaluating their precise ecological significance and translating them into water quantity limits is more challenging. Jowett and Biggs (2008) suggested that whilst flow regimes in New Zealand differ according to climate and river type, the aquatic communities are broadly similar across these regimes. They argued that the high proportion of diadromous fish in New Zealand reduces the long-term susceptibility of fish communities to inter-annual variations in flow because recruitment is external to the catchment. This means that the effect of a large disturbance is buffered in the long-term by annual re-colonisation from outside of the affected catchment. However, the converse to this is that non-diadromous fish species may have a greater sensitivity to the effects of flow variability, which was supported by the analyses of Leathwick et al. (2008) and Crow et al. (2013). Furthermore, Jowett and Biggs (2008) did not discuss the important functional role that elevated flows play in the reproduction of some of New Zealand's native fish species. For example, the five galaxiid species

which make up the whitebait catch are all dependent on elevated flows for spawning and hatching of larvae (e.g., Charteris et al. 2003) and in the absence of these flows, recruitment may fail.

Successful colonisation of macrophytes is controlled by flood frequency because macrophyte immigration and growth rates are relatively slow, and thus prolonged periods of hydrological stability are required for macrophyte propagules to arrive and develop to substantial levels of cover (Biggs 1996; Riis and Biggs 2003). Riis and Biggs (2003) showed that vegetation abundance and species diversity within stream reaches in New Zealand were negatively correlated with flood frequency. They proposed that significant macrophyte development was restricted to streams which experienced an average of less than 13 flood events per year (where a flood event is defined as when flow exceeded 7 times the median flow). Biggs and Close (1989) and Snelder et al. (2014a) have shown that hydrological factors may be as equally important as nutrients in determining periphyton biomass. Flood events which cause elevated velocities, substratum disturbance and suspended solids abrasion can cause significant loss of periphyton biomass, depending on the magnitude of the event. Biggs (2000) suggests that flood events with a 0.5-1 year return period generally result in considerable loss of periphyton biomass. This was in part reflected in the results of the Waihou ecological surveys which found macrophyte abundance highest in the lower gradient, lowland streams with more stable flows and a lack of significant macrophyte growth in the more flashy streams draining the Coromandel Ranges, although it is acknowledged that other factors such as shading also contribute to the presence of macrophytes.

Macroinvertebrate communities are also known to display responses to changes in flow conditions. Townsend et al. (1997) found evidence to support the intermediate disturbance hypothesis, with taxon richness maximised in habitats subject to an intermediate level of disturbance. Susceptibility to disturbance was related to substrate size and hydrological variability. Suren and Jowett (2006) showed that invertebrate communities changed more after floods and the degree of change was proportional to flood magnitude. They also observed that community similarity increased with increasing time since the last disturbance, suggesting that the longer stable flows lasted, the less the community would change. However, it has also been recognised that the response of different species to changes in both high and low flows varies (Dewson et al. 2007; James et al. 2009). Overall it has been suggested that alterations to hydrological regimes that change flood frequency will affect aquatic invertebrate diversity, abundance and community composition in many rivers (Greenwood and Booker 2014).

The amount of hydrological variation required to maintain a healthy ecosystem is poorly understood and the complexity of natural systems makes it difficult to define quantitative thresholds at which the flow regime will maintain a desired river condition. However, it is becoming increasingly clear that modification of the hydrological regime alters the dynamics of aquatic ecosystems. Ideally the RVA is employed in a comparative framework, whereby alternative managed flow regimes are compared to natural conditions and the risk of ecological impacts evaluated based on the degree of deviation from the natural flow regime. However, the approach that has been taken for the Waihou study is to characterise the current flow regime, establishing a baseline against which future annual flow records and alternative flow management regimes can be compared.

The RVA results can provide valuable context for the results of other components of the instream flow assessment and limit setting procedure. Franklin and Booker (2009) illustrated this by comparing some of the results from the Waihou instream physical habitat modelling study of Jowett (2008) to the natural range of low flows that occur in different parts of the river. That example is reproduced here as this is considered a valuable demonstration of the complementary way in which

different components of the flow assessment process can be combined to inform flow management decision making.

The minimum flow requirements determined for adult trout were compared to the natural range of variability in 7-day low flows calculated using the RVA approach for two sites. The first example was taken from the Karangahake site on the Ohinemuri River (Figure 4-7). The minimum flows proposed for the preservation of adult trout habitat at this site all fall above the natural range of 7-day low flows. This could be interpreted to mean that adult trout populations are naturally restricted by low flows in this part of the catchment. Consequently, any further reduction in low flows will result in a reduction of suitable habitat and potentially a reduction in trout. If the trout fishery is highly valued then this may be an undesirable outcome and low flows should be protected from exploitation. However, trout are only one component of the fish community and it may be that the natural restriction in their optimum habitat will result in benefits for native fish species by reducing competition. If the success of native fish populations was valued more highly than trout, and optimum flows for native fish were lower than the natural range of low flows, then some exploitation of water may be encouraged to support this value.

The second example is representative of the Waihou River downstream of Gordon (Figure 4-8). It can be seen that in this case the optimum flows for maintaining suitable trout habitat were considerably lower than the natural range of 7-day low flows. If the trout fishery was highly valued, it could be argued that a significant proportion of river flow could be allocated to consumptive uses and this may enhance trout habitat. However, it could also be argued that such use would result in flows significantly outside of the natural range of variability and consequently outside of the range of flows to which the aquatic ecosystem is adapted. Flora and fauna other than trout, along with important physico-chemical processes (e.g., changes in water temperature, dissolved oxygen or sedimentation), may be adversely affected by reductions in flow outside of the natural range of variability, with a subsequent degradation in the river.

It is suggested that a similar approach to utilising the RVA results to that described above and in Franklin and Booker (2009) would be a sensible strategy for integrating this part of the overall instream flow assessment into the water quantity limit setting process. The first step should be to identify the instream values and objectives for particular parts of the catchment. The aspects of the flow regime most relevant to supporting each value can then be identified and used to inform the limit setting process. For example, for the natural state waterway class there is an objective to limit the degree of flow regime alteration. In this case, all aspects of the flow regime are important to maintain and it might be appropriate for the degree of alteration from the natural state to be relatively small. An alternative objective may be to limit the proliferation of periphyton, in which case setting limits which restrict changes in the magnitude of low flows and frequency of floods are of most relevance (Snelder et al. 2014a).

In common with the instream habitat study, one of the limitations with the RVA assessment is that it is constrained to sites where suitable hydrological data are available. This presents a challenge when seeking to set limits for river reaches or sub-catchments where data are not available. In the case of the Waihou catchment, analyses were also carried out on observed flows rather than naturalised flow records. This means that human induced changes in flows caused by increasing water use over the duration of the flow record are integrated within the flow statistics. This is thought to be the main cause of long-term negative trends in median flows at a number of the sites where flows were assessed. This should be considered when utilising the RVA results in the water quantity limit setting process.

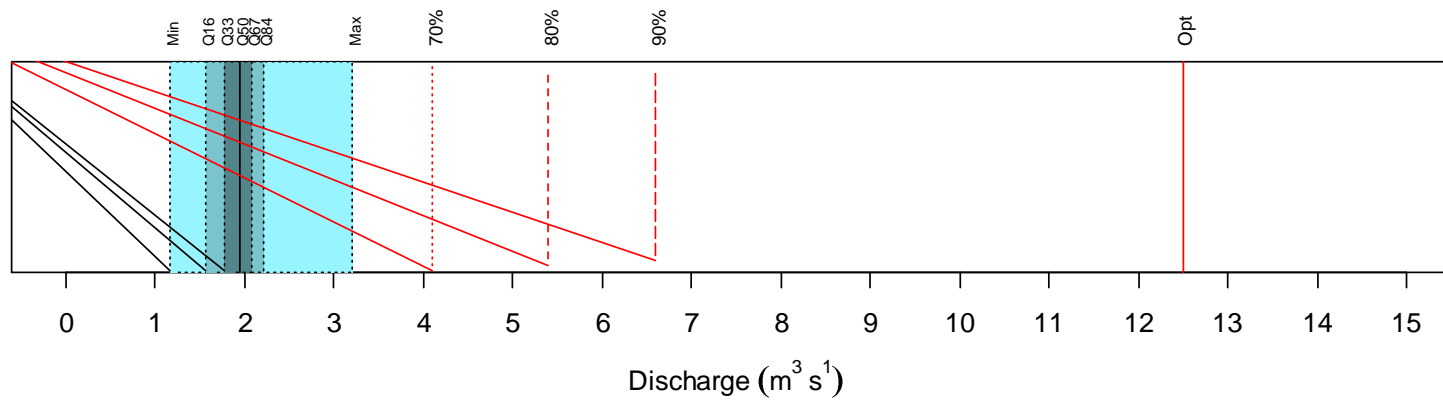


Figure 4-7: Natural range of variability in 7-day flow minimum compared to minimum flow requirements for adult trout for the Ohinemuri River at Karangahake. Red lines represent flows offering differing levels of habitat protection for adult trout (Opt=Optimum; 70%=70% of optimum). The ranges in 7-day low flows between minimum and maximum, 16th and 84th percentiles and 33rd and 67th percentiles are shown by the blue shaded areas and the median flow (Q50) by the solid black line.

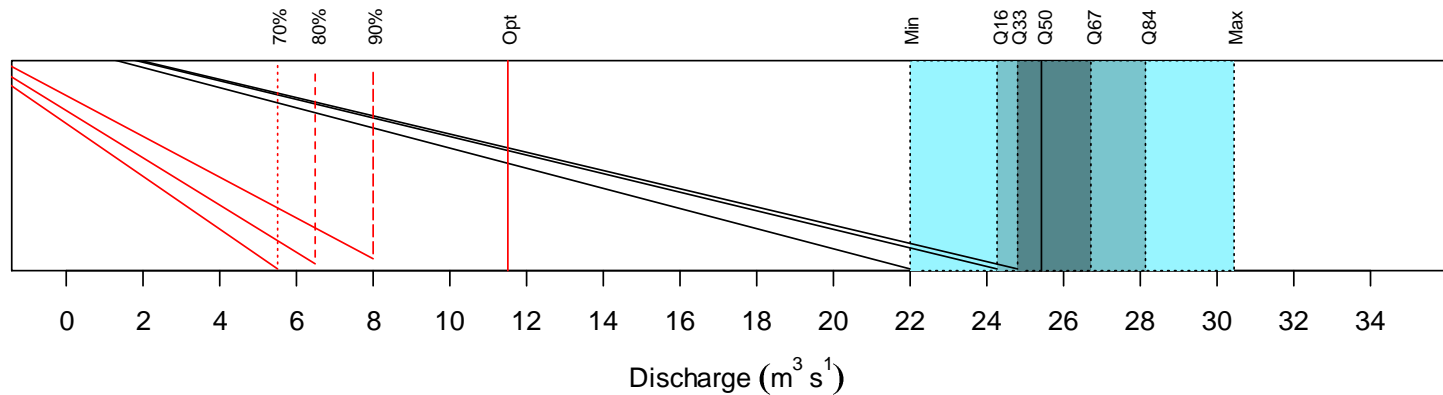


Figure 4-8: Natural range of variability in 7-day flow minimum compared to minimum flow requirements for adult trout for the Waihou River downstream of Gordon. Flow statistics are calculated for the Te Aroha gauging site. Red lines represent flows offering differing levels of habitat protection for adult trout (Opt=Optimum; 70%=70% of optimum). The ranges in 7-day low flows between minimum and maximum, 16th and 84th percentiles and 33rd and 67th percentiles are shown by the blue shaded areas and the median flow (Q50) by the solid black line.

4.2.3 Water quality and contaminant assimilative capacity

A water body has a natural ability to assimilate and process some contaminants. Processing can occur in a variety of ways including dilution, sedimentation, chemical transformation or re-aeration. The rate at which these processes occur will be dependent on factors such as temperature, light availability, mixing and water velocity. However, if the load of a contaminant is too high, the capacity of a water body to assimilate and process the contaminant may be exceeded. This can result in a degradation of water quality and, if effect thresholds are exceeded, adverse effects on flora and fauna, amenity values, human health and downstream receiving environments such as lakes and estuaries.

One factor that controls the assimilative capacity of a stream or river is flow, through effects on processes such as dilution, residence time, re-aeration and settling rates. For example, for a given contaminant load, as river flow increases, dilution increases and the concentration of a contaminant in the river decreases, thus reducing the likelihood of exceeding thresholds causing adverse effects. Conversely, increased flows may also reduce residence time (the amount of time a given body of water remains within a river reach/lake), and reduce settling rates, which could retard the processing of some contaminants. This could increase the likelihood of adverse effects if the increase in dilution is not sufficient to compensate. The net effect will be dependent on the nature and load of the contaminants, their delivery pathways (how they get into the river), processing mechanisms, background water quality and the magnitude of flow. Management of flow can therefore be important in managing water quality and this is recognised in the Plan (Section 3.3.3 Policy 1b).

Jowett (2008) noted the potential for impaired water quality, particularly low dissolved oxygen, in some of the low gradient tributaries of the Waihou and the need for this to be accounted for in the water quantity limit setting process. Subsequently, WRC initiated a study to investigate dissolved oxygen dynamics at selected sites in the Waihou catchment (Franklin 2010b). The objective was to explore the prevalence of impaired dissolved oxygen conditions and therefore establish whether there was a need to further assess the relationships between flow and assimilative capacity in the Waihou as component of the water quantity limit review.

Dissolved oxygen loggers were deployed at six lowland stream sites in the Waihou catchment between February and April 2009. Dissolved oxygen minima below 3 mg l⁻¹ occurred at four of the six sites during summer low flow conditions (Franklin 2010b). These concentrations are below the recommended dissolved oxygen protection limits for fish (Instantaneous minimum = 3.5 mg L⁻¹; Franklin 2013) and thus were identified as presenting a potential problem for fish and other aquatic organisms. At one site, daily mean dissolved oxygen remained below 3 mg L⁻¹ for the entire monitoring period and on one occasion was below 1 mg L⁻¹ for over two days. This is likely to cause severe impairment to fish and invertebrate communities in the stream. Subsequently, it was recommended that further investigations of dissolved oxygen dynamics in the Waihou and its tributaries be carried out as part of the review of water quantity limits in the catchment (Franklin 2010b).

An empirical approach to investigating flow-dissolved oxygen relationships in the Waihou was utilised due to the uncertainty in existing modelling approaches for rivers like the Waihou (Franklin 2010a). Two studies were carried out focusing on the middle (Franklin 2010c) and lower (Franklin and Smith 2014) reaches of the river (Figure 4-9).

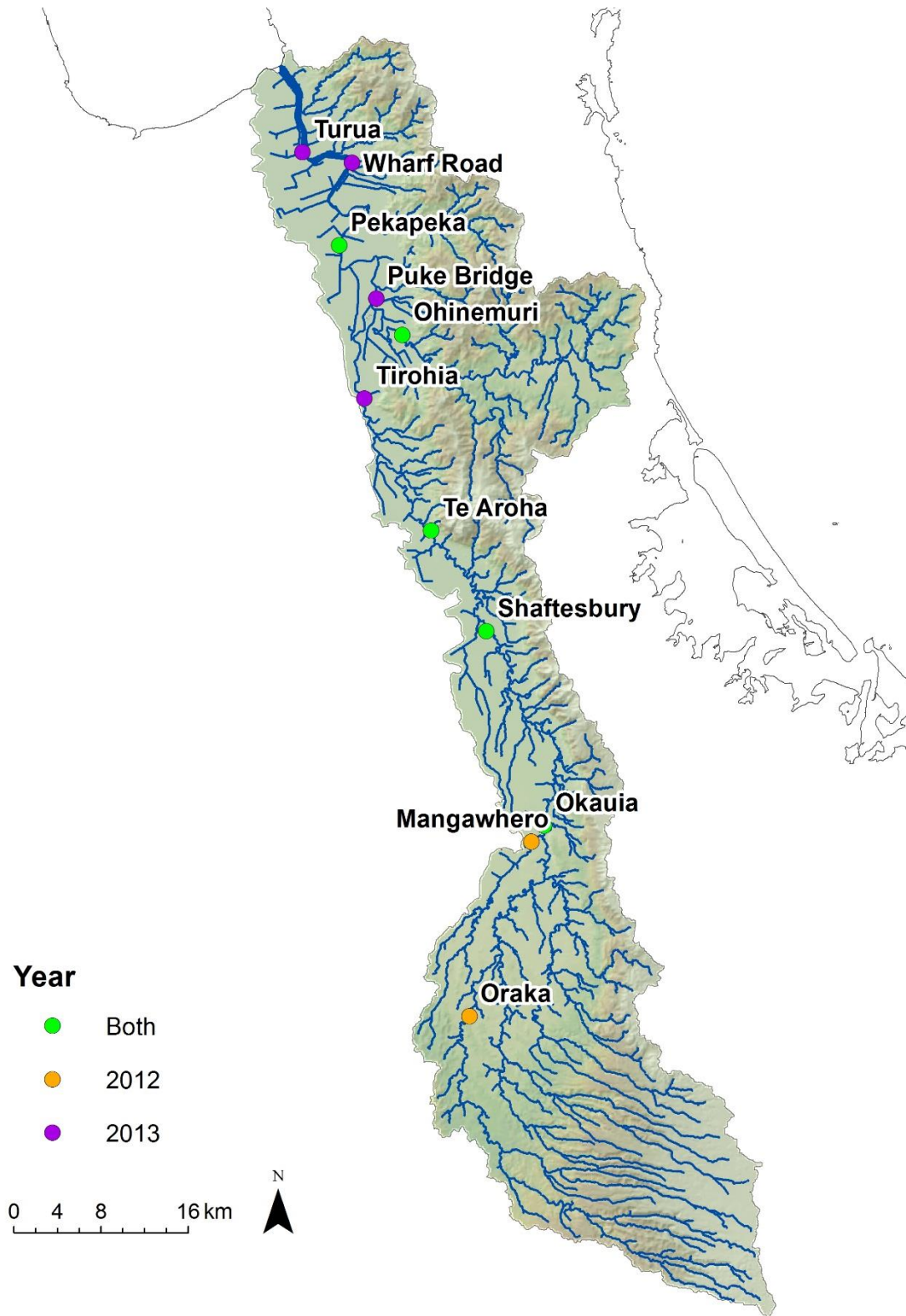


Figure 4-9: Location of dissolved oxygen temporal monitoring sites in 2012 and 2013.

Analysis of long-term dissolved oxygen monitoring data indicated that, in general, dissolved oxygen is not likely to be a limiting factor for aquatic ecology in larger tributaries and the main Waihou River. However, in some of the small lowland tributaries continuous monitoring of dissolved oxygen during summer indicated that dissolved oxygen concentrations regularly fell below the recommended protection levels for freshwater fish (Franklin 2010c).

During the study of Franklin (2010c), no generalised correlation was identified between daily dissolved oxygen minima and mean daily flow across the limited range of summer low flows experienced at the sites. Other components of the flow regime which were not investigated as part of the Franklin (2010c) study could, however, interact with dissolved oxygen levels. In the main stem of the river upstream of Te Aroha, where dissolved oxygen does not appear to be limiting for ecological communities, if the degree of hydrological alteration is expected to be low, there may be little need to consider dissolved oxygen dynamics in the flow allocation process at the catchment scale. However, in the smaller tributaries where the aquatic communities are impacted by low dissolved oxygen concentrations it was recommended to take dissolved oxygen into account when making flow allocation decisions (Franklin 2010c).

Dissolved oxygen time series data collected at a range of sites in the lower Waihou catchment during the summers of 2012 and 2013 showed that generally the majority of sites met the recommended thresholds for ecosystem protection (Franklin and Smith 2014). The main exceptions were the sites in the lower, tidal part of the river at Turua and Wharf Road where the recommended 7-day mean daily limit of 7.0 mg L^{-1} (Franklin 2013) was not met. There was little evidence to suggest that there was any significant relationship between dissolved oxygen and flow over the relatively limited range of summer low flows that occurred during the monitoring period. A possible exception was the Ohinemuri River where some association between low flows and low dissolved oxygen was recognised, but the failure of the logger at this site in 2013 mean this was not confirmed. The time series data showed that dissolved oxygen is depleted in the main stem of the Waihou River during summer flushing flow events. This is most likely a consequence of the mobilisation of decaying organic matter with a high biochemical oxygen demand.

In the lower river, downstream of Paeroa, the presence of a dissolved oxygen sag first identified in a WRC study (Vant 2011) was confirmed (Franklin and Smith 2014). During summer low flows, the location of the dissolved oxygen minima varied from the mouth of the river at Thames at low tide, to nearly 20 km inland at high tide and coincided with the limit of the saline wedge and a peak in turbidity (Franklin and Smith 2014). The magnitude of the dissolved oxygen sag was strongly correlated with mean water temperature, with the dissolved oxygen minima at the time of the surveys (mid-morning) varying from 4.4 mg L^{-1} (14 Jan 2013) to 7.5 mg L^{-1} (12 April 2013) (Franklin and Smith 2014). Freshwater inflows were not identified as having a significant control on the location or magnitude of the dissolved oxygen minima, but this is likely to be a result of the relatively small range of freshwater flows ($23\text{-}27 \text{ m}^3 \text{ s}^{-1}$ at Te Aroha) over which observations occurred in 2013 (Franklin and Smith 2014).

This estuarine turbidity maxima occurs when catchment-derived particles are carried downriver in the light, fresh surface waters until decreasing water velocities and saline-induced flocculation near the head of the estuary cause them to settle into the denser, more saline, bottom waters (i.e., the salt wedge). These bottom waters then carry the particles back upstream. Suspended solids are thus recycled and concentrated in a conspicuous zone of turbidity near the head of the estuary (Vant 2013). It is the processing of organic matter trapped within these sediments suspended in the water column that most likely drives the drop in dissolved oxygen concentrations. In a similar case in

the upper Humber estuary in the UK, where observations were made over a greater range of freshwater inflows, flow was found to be an important driver of both the location and magnitude of the dissolved oxygen minima (Mitchell et al. 1999). In that case, suspended sediment, and the oxygen demand associated with that sediment in the water column, were identified as being the main cause of the drop in dissolved oxygen. However, it was the interaction between tide height and freshwater inflows that determined the location and concentration of the suspended sediment maxima and hence dissolved oxygen minima (Mitchell et al. 1999).

It is highly likely that the same functional processes are driving the dissolved oxygen dynamics in the water column of the lower Waihou and therefore that freshwater inflows (over a broader range than those measured) will have an important functional role in controlling the location and magnitude of the observed dissolved oxygen sag. It is also likely that high flow flood events will be important for periodically flushing sediment from the lower Waihou into the Firth of Thames. Consequently, the low dissolved oxygen conditions in the lower river were identified as potentially being the main bottleneck for setting upstream minimum flow and allocation limits (Franklin and Smith 2014). It was concluded that there was a reasonable risk that decreased magnitude and increased duration of summer low flows could lower the dissolved oxygen minima in the lower river. Lower minimum flows would also increase the probability of the dissolved oxygen minima, and associated saline wedge and turbidity maxima, penetrating further inland at high tide. While the depressed dissolved oxygen concentrations in the lower river are likely a natural phenomenon, it is also likely that they are exacerbated by changes in land use that increase sediment load and water temperatures, and reduce flows. It was therefore recommended that a precautionary approach be taken to setting minimum flows for that part of the river due to existing conditions in the river already exceeding recommended protection levels for aquatic ecosystems (Franklin and Smith 2014).

4.3 Recommendations

Policy 1 (Section 3.3.3) of the Plan sets the criteria for determining appropriate water quantity limits in the Waikato Region. The investigations summarised above are focused on addressing Policy 1c, d, f and g, which broadly covers maintaining and improving water quality (including accounting for contaminant assimilative capacity), and avoiding significant adverse effects on instream ecological values, biodiversity and habitats of indigenous fauna. These factors were identified by WRC as being the most likely constraints on determining instream flow requirements in the Waihou catchment, but will be balanced against the requirements of the other values, including out-of-stream water needs, in making a final determination on water quantity limits for the catchment. It is beyond the scope of this report to consider these other values and thus the remainder of the report will focus only on flow requirements for maintaining water quality and ecological communities as addressed by the technical assessments summarised above.

4.3.1 Accounting for spatial variability

It is apparent from the technical assessments that the main constraints on water allocation vary spatially within the catchment. For example, in the lower catchment the main constraint is likely to be the zone of low dissolved oxygen, whereas in the Ohinemuri sub-catchment fish habitat is likely to be the primary factor influencing water quantity limits. It is therefore suggested that WRC should seek to develop surface water quantity management zones within the catchment that reflect differences in river type and expected responses to hydrological alteration. A possible option for this is proposed in Table 4-3 based on broad scale differences in hydrology, geomorphology, instream

values and controls on surface water allocation identified in the technical investigations. The approximate boundaries are also illustrated in Figure 4-10.

Table 4-3: Potential surface water quantity management zones for the Waihou catchment.

	Zone name	Zone delineation	Reason for zonation
1	Waihou upper	All waterways upstream of the Okauia hydrological gauging station.	Baseflow dominated flow regime, regionally important trout fishery and important native fish habitats.
2	Waihou lower	The main stem of the Waihou River downstream of Okauia and tributaries draining from the true left (west).	River size and importance of assimilative capacity.
3	Ohinemuri	All waterways upstream of the Ohinemuri's confluence with the Waihou River at Paeroa.	Surface water dominated hydrology, steeper gradient and significance for trout and native fish.
4	Kaimai tributaries	All tributaries joining the Waihou from the true right (east) downstream of the Okauia gauging station (excluding the Ohinemuri).	Surface water dominated hydrology, steeper gradient, important habitats for native fish and a high proportion of reaches in natural state water class.

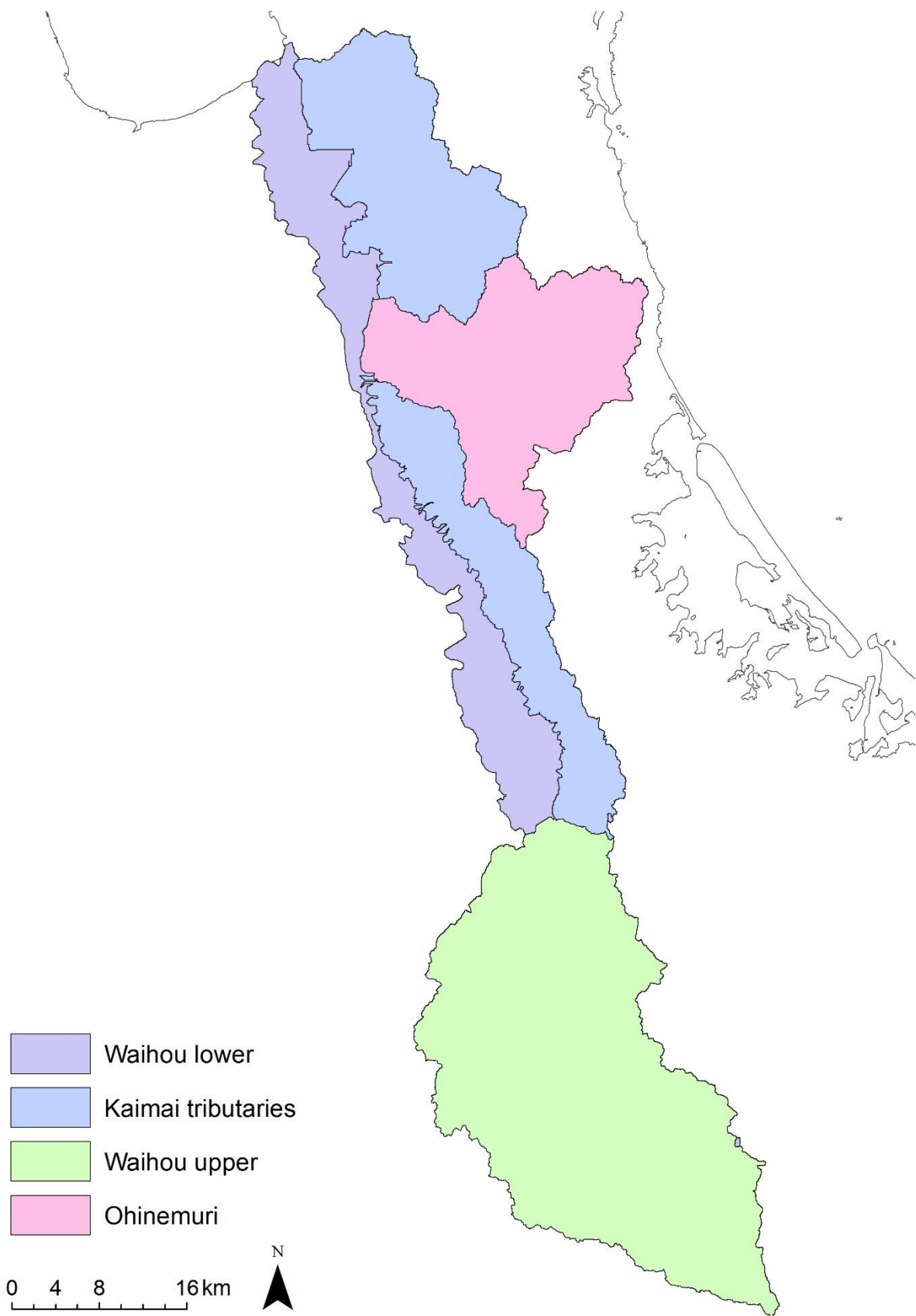


Figure 4-10: Approximate boundaries of proposed water quantity management zones in the Waihou catchment.

4.3.2 Waihou upper zone

The upper Waihou catchment is characterised by its stable, baseflow dominated flow regimes. The ecology of these spring-fed streams is strongly influenced by the stable flow regime and is therefore considered sensitive to hydrological alteration. The upper Waihou and its main tributaries, including the Waimakariri, Waiomou and Oraka, are some of the most popular trout fisheries in the Waikato region, and therefore managing flows to support this value is likely to be a priority. The upper Waihou in the vicinity of the Blue Springs is also home to the northernmost (nationally) and only known population of dwarf galaxias (*Galaxias divergens*) in the Waikato region. This non-diadromous galaxiid species is classified as At Risk – Declining (Goodman et al. 2014) and is known to be susceptible to predation by trout and habitat loss (Department of Conservation 2004). At a regional level this population is of high biodiversity value and therefore ensuring its preservation should be a priority.

Based on the results of the instream physical habitat modelling (Figure 4-5), optimum trout habitat generally occurs at flows above Q_5 at the study reaches in the upper catchment, meaning that the current minimum flow limits (either 90% or 95% of Q_5 depending on whether mean flow is greater or less than $5 \text{ m}^3 \text{ s}^{-1}$ respectively) are sub-optimal for maintaining adult trout. The exception is the site on the Waihou at Whites Road, where optimum adult trout habitat occurs at a flow of 64% of Q_5 . However, this is also the reach where the population of dwarf galaxias exists and therefore it is recommended to avoid improving the suitability of the reach for supporting trout in order to avoid increasing predation. Consequently, it is recommended that current minimum flow limits in the Waihou upper zone are not reduced. If sustaining or improving the trout fishery is a priority value, habitat availability would be increased by raising the minimum flow limits to 100% of Q_5 .

A further factor that may become relevant in evaluating the need to revise minimum flow limits is the programme of mature willow and poplar removal that is currently underway in the upper Waihou catchment (focusing on the Waiomou and Oraka Streams) (Waikato Regional Council 2014). This large scale removal (32 km of waterway) of mature trees is likely to alter instream physical habitat availability, reduce shading and increase water temperatures. There is also evidence to indicate that, following willow removal, increased light availability has led to the proliferation and encroachment of aquatic macrophytes at some sites which is beginning to reduce channel conveyance (Rien van de Weteringh, WRC, pers. com.). Due to these additional stressors there may be a need for more conservative minimum flow requirements in order to reduce the risk of elevated water temperatures and also to maintain water velocities at a level that will minimise the encroachment of macrophytes into the channel. Further analysis would be required to understand appropriate limits for managing this stressor, but water velocities of $\geq 1 \text{ m s}^{-1}$ are generally considered sufficient to avoid establishment of most aquatic macrophytes (Franklin et al. 2008).

4.3.3 Waihou lower zone

The Waihou lower zone primarily constitutes the main stem of the Waihou River downstream of Okauia. The technical assessments suggest that the main constraint on allocating water in this reach of the river is likely to be the zone of low dissolved oxygen in the lower river downstream of Paeroa. The dissolved oxygen minima in this zone are lowest under summer low flow conditions and the affected reach extends at least 20 km from the mouth of the river upstream. The technical assessments also showed that dissolved oxygen minima in this reach regularly fall below the recommended protection levels for freshwater fish (Franklin 2013) under current minimum flow and allocation limits. At the Turua monitoring site, the 7-day mean daily minimum dissolved oxygen was

below the 5.0 mg L⁻¹ 'bottom line' set in the NPSFM National Objectives Framework for several weeks during the 2013 summer low flow period.

The lower river is an important transitional habitat for species migrating between the sea and freshwater. Furthermore, it is also likely to support resident populations of both freshwater and marine species, including sensitive species such as smelt (*Retropinna retropinna*) and inanga (*Galaxias maculatus*). It is therefore important to ensure that conditions within this reach are maintained at a level that will avoid any significant adverse effects on these species. An additional consideration is that water quality in the lower Waihou will impact on water quality dynamics in the Firth of Thames and is therefore subject to the provisions of the Hauraki Gulf Marine Park Act.

The technical assessments failed to identify a clear correlation between freshwater flows in the lower Waihou River and the location and magnitude of the dissolved oxygen minima (Franklin and Smith 2014). However, it was highlighted that monitoring of dissolved oxygen conditions only covered a relatively narrow range of flows (23-27 m³ s⁻¹ measured at Te Aroha), albeit at the low end of the natural range of low flow conditions for the river (Figure 4-8). The current minimum flow limit for this section of the river is 90% of Q_s, which equates to a flow of 22.1 m³ s⁻¹ at Te Aroha. This is just below the range of flows captured during the dissolved oxygen monitoring. The lack of sensitivity in the magnitude of the dissolved oxygen to changes in flow over the 23-27 m³ s⁻¹ range suggests that the current minimum flow is likely to be sufficient to avoid significant further reductions in the dissolved oxygen minima below those observed in the lower river during the technical assessments by Franklin and Smith (2014). However, it is noted that the dissolved oxygen values are already falling below the national 'bottom lines' set in the NPSFM National Objectives Framework for dissolved oxygen and therefore it is not recommended that the minimum flow be reduced without detailed monitoring over a broader range of flows, including flows close to the proposed minimum flow.

Whilst the depressed dissolved oxygen concentrations in the lower river are likely a natural phenomenon and therefore may be subject to exception in the National Objectives Framework, this threshold is considered a suitable target for avoiding significant adverse ecological effects and therefore WRC may wish to consider using dissolved oxygen concentrations in the lower river as a trigger for managing upstream water use. For example, takes could be restricted when the 7-day mean daily minimum dissolved oxygen concentration (determined through continuous monitoring) in the vicinity of Turua falls below the 5.0 mg L⁻¹ threshold or the 1-day minimum falls below 4.0 mg L⁻¹ (i.e., the NPSFM 'national bottom line' for dissolved oxygen, or higher if the target attribute state for the Waihou is A or B).

An alternative to reducing the minimum flow could be to increase the primary allocation limit by 5% in the lower Waihou zone. This would have the effect of increasing the availability of more reliable water for out-of-stream use, but also has the potential to increase the duration of low flows if fully exploited. The effect of low flow duration on dissolved oxygen dynamics is poorly understood, but there was some evidence in the technical assessments to suggest that over prolonged periods of stable low flows, the dissolved oxygen minima progressively declined at Turua. This trend was not observed, however, at any of the upstream sites. This strategy would therefore complement the use of a dissolved oxygen trigger level in the lower Waihou River to manage upstream takes, in combination with the more typical constraints based on river flow.

The above suggestions with regards to future minimum flow and allocation limits in the lower Waihou zone could be interpreted as being reasonably precautionary. However, the lower river is subject to the cumulative effects of all upstream catchment development and water resource use.

Ultimately it is the aggregate effect of these multiple stressors, such as increased water temperature, greater sediment load, and reduced water quality, in addition to reduced flows, that determine the outcomes for instream values. The synergistic dynamics of these multiple pressures are poorly understood, but it is the author's opinion that there is a medium level risk that reducing flows significantly below the natural range of low flows in the river will exacerbate the currently degraded conditions in the lower river and compromise ecosystem health. Given this, and the fact that current guidelines for the protection of ecosystem health are already exceeded, it is advised that any revision of the current water quantity limits should be contingent on gaining a better understanding of the ecosystem dynamics of the lower river and linked to continuous monitoring of key water quality parameters such as dissolved oxygen. Furthermore, consideration should be given to potential future impacts of climate change which will likely result in increased water temperatures, reduced freshwater flows and increased sea levels (and therefore greater tidal incursion).

4.3.4 Ohinemuri zone

The hydrology of the Ohinemuri sub-catchment is rainfall driven resulting in a much more flashy flow regime than that of the main stem of the Waihou River. Channel morphology is also significantly different reflecting the geology and a steeper gradient. These differences are reflected in the outcomes of the technical assessments and prompt the recommendation for treating this area as a separate zone for setting water quantity limits.

The Ohinemuri is identified in the Plan as an important habitat for both trout and native fish (Figure 4-2 and Figure 4-3). The habitat assessments (Figure 4-5) indicate that at both sites assessed in the Ohinemuri catchment, optimum habitat for both trout and many of the native fish species occurs at flows higher than Q_5 . This suggests that low flows are likely to be a natural limiting factor on instream physical habitat availability in the Ohinemuri. Consequently, setting minimum flows at below Q_5 is likely to further constrain physical habitat availability, especially for trout. Furthermore, there was some indication of a negative relationship between flow and dissolved oxygen during the summer low flow period in the Ohinemuri. However, it was highlighted that due to the failure of monitoring equipment there would be a need to revisit this if dissolved oxygen was considered a constraint for allocation in the catchment. It is the author's opinion that in this case, instream physical habitat at low flows is more likely to be a greater constraint on fish communities than dissolved oxygen. Consequently, it is recommended that the habitat assessments be used as the primary tool for determining the minimum flow limits in these reaches.

At present, the main stem of the Ohinemuri River has a minimum flow limit of 90% of Q_5 . Relative to the flows required to maximise instream physical habitat availability, this is sub-optimal. However, even under natural low flow conditions instream physical habitat is limiting for fish communities and therefore it may be an unrealistic and unnecessary target to try and maximise instream physical habitat availability. It is suggested that a more realistic approach to evaluating suitable limits for protecting instream physical habitat in this case would be reanalyse the outputs of the habitat modelling to look at the deviation in habitat availability relative to that available under natural low flow conditions (i.e., Q_5). A threshold can then be set for what is considered to be an acceptable reduction in habitat availability relative to 'natural' conditions (see Appendix A for updated results).

In the tributaries of the Ohinemuri, the current minimum flow limits are set at 95% of Q_5 . For those with similar morphology to the main stem, it is likely that instream physical habitat will be similarly constrained by natural low flows. In the absence of targeted habitat assessments for these tributaries, the current minimum flow limits are likely sufficient to provide a precautionary level of

protection to instream values. However, it is recommended that if allocation pressure is high or increases, targeted investigations be carried out to evaluate the potential instream impacts and hence establish more targeted limits.

4.3.5 Kaimai tributaries zone

Many of the tributaries draining to the eastern side of the Waihou River have their headwaters in the Kaimai and Coromandel Ranges, which has a significant influence over both their hydrology and geomorphology. Typically, these streams are relatively short, steep and have quite flashy, rainfall driven flow regimes. In many cases, the headwaters drain areas with intact riparian habitat (e.g., native bush) and therefore have significant value as indigenous habitats. This is reflected in the designation of many of these tributaries as belonging to the natural state water class in the Plan.

Many of these streams are poorly surveyed and therefore understanding of their ecology is relatively meagre. However, recent surveys in some of these streams indicate that they may be important habitats for native galaxiid fish species such as banded kokopu (*Galaxias fasciatus*) and koaro (*G. brevipinnis*) (e.g., Franklin and Hodges 2012; Franklin et al. 2014). Their designation in the natural state water class sets objectives for protecting the flow regime, water quality, indigenous habitats and biodiversity. In the absence of targeted technical assessments for these streams, it is recommended that at the very least, minimum flows in these streams (currently set at 95% of Q_5) should be maintained at their current levels. However, depending on interpretation of the Plan rules on the protection of waterways designated in the natural state water class, consideration could be given to increasing minimum flows to 100% of Q_5 to enhance the level of protection for these valued waterways or reducing total allocation. Another further possibility would be to reduce the primary allocation limit to zero, hence providing greater protection at low flows due to the greater restrictions on secondary allocation, or reduce the allocation limit overall. One possible benefit of taking the step to increase the minimum flow or reduce the allocation limit in these streams may be the opportunity to increase the level of allocation in the main stem of the Waihou River. This is because water quality from those tributaries with intact native headwater catchments is likely to be better than that in the main stem of the Waihou River and therefore may help to counteract the impact of multiple stressors in the lower river.

4.3.6 Limitations

Translating the outputs of technical assessments into practical water quantity limits is a significant challenge for water resource managers. Difficulties include balancing the requirements of multiple, competing values, transferring site based assessments to multiple reaches, understanding and accounting for uncertainty in technical assessments and fulfilling legislative requirements. A critical step in developing effective limits is ensuring that the assumptions, limitations and uncertainties associated with scientific methods and their use in setting limits are acknowledged and accounted for.

In general, the main assumptions and limitations underlying specific technical assessments are outlined and accounted for in the respective reports describing the results (e.g., Jowett 2008; Franklin and Booker 2009; Franklin and Smith 2014). Some of the most critical limitations to these assessments and their specific relevance to the limit setting process have been highlighted in the summary of the technical assessments included in this report (i.e., Section 4.2). However, in addition to these method specific limitations, there is a need to consider the constraints associated with translating the results of the targeted technical assessments into catchment wide limits.

The focus of this report has been on delivering recommendations for setting minimum flow limits in the Waihou catchment that provide for particular instream values (primarily sustaining aquatic ecological communities). The recommendations in this report are based on the author's interpretation of the available technical assessments against the backdrop of current policy frameworks. The options considered are not exhaustive and do not specifically integrate the competing requirement to balance out-of-stream water needs and other values as this was outside the scope of the current project. In developing these recommendations, a risk-based framework has been adopted that attempts to balance best available scientific knowledge and information with the need for functional limits, whilst acknowledging uncertainties around ecosystem responses and limitations in available data.

A key challenge in the Waihou catchment is accounting for spatial variability in catchment characteristics and the differing impacts of multiple synergistic stressors. Technical assessments are generally constrained to site or reach-specific appraisals, which must then be up-scaled to the broader sub-catchment or catchment level. There is little guidance on how this can be achieved effectively and therefore the process becomes reliant on expert knowledge guided by the use of spatial frameworks (e.g., Frissell et al. 1986; Snelder and Biggs 2002) and balanced with policy derived spatial management units (e.g., the NPSFM freshwater management units). This has been addressed by proposing four spatially discrete surface water quantity management zones.

The Waihou River and its tributaries are also subject to a range of different pressures, the impact of which vary spatially within the catchment. It is important that the interacting effects of these different stressors are taken into account when defining water quantity limits. Whilst all areas of the catchment are subject to multiple impacts, the greatest cumulative effect of these stressors occurs in the lower river. However, the dynamics of how these stressors combine to affect the structure and function of aquatic ecosystems are poorly understood. Consequently, in the absence of robust knowledge on ecological thresholds and potential synergistic effects between stressors, there is a need for a precautionary, but flexible approach to setting limits, particularly in the lower river. It is recommended that one of the most transparent ways of achieving this is to implement ongoing monitoring of key ecosystem attributes (e.g., dissolved oxygen and water temperature) at critical locations in the catchment, and to integrate maintenance of these attributes with the implementation of revised water quantity limits.

Recent legislative developments, particularly the National Policy Statement on Freshwater Management (MfE 2014a), provide further drivers and challenges for setting limits for surface waters. The implementation of the NPSFM and associated National Objectives Framework by WRC will influence how water quantity limits are set and implemented in the future and therefore should be taken in to consideration when setting new limits for the Waihou catchment. This general direction is signalled in Section 8.1 of the Proposed Regional Policy Statement (Waikato Regional Council 2013). A particular challenge in implementing the NPSFM is likely to be the need to match the spatial and temporal scale of limit setting with multiple (often competing) freshwater values and objectives, in a transparent and accountable way. The way in which limits are defined and implemented can lead to vastly different outcomes for both water users and the downstream flow regime (Booker et al. 2014). Consequently, careful consideration of the methods and scale for implementing water quantity limits and how they match with the requirements of the NPSFM is equally as important as defining the limits themselves.

4.3.7 Summary

The process of identifying and setting water quantity limits is a trade-off between multiple competing values. Limits should be clear, transparently derived and linked to management objectives (Snelder et al. 2014b). The default water quantity limits that currently apply in the Waihou catchment are in need of reviewing in order to ensure that limits in the catchment fulfil the objectives defined in Policy 1 (Section 3.3.3) of the Plan. The technical assessments summarised in this document focus on evaluating the instream flow needs of ecological communities in the catchment. In some parts of the catchment it is likely that aquatic communities are limited by physical habitat availability, whilst in others water quality is likely to be the main constraint. Recommendations have been made for potential revisions to the current minimum flow limits in the catchment based on expert interpretation of the technical assessments within a risk-based framework (Table 4-4). WRC must now consider these outcomes in the context of wider catchment issues and management objectives, including providing water for out-of-stream use.

Table 4-4: Summary of recommended minimum flow limits for the Waihou catchment proposed water quantity management zones.

Water quantity management zone	Current minimum flow limit (%Q ₅)		Recommended minimum flow limit (%Q ₅)	
	Mean Q <5 m ³ s ⁻¹	Mean Q ≥5 m ³ s ⁻¹	Mean Q <5 m ³ s ⁻¹	Mean Q ≥5 m ³ s ⁻¹
Ohinemuri	95	90	90-95 ¹	90-95 ²
Waihou upper	95	90	95-100 ³	95-100 ⁴
Waihou lower	95	90	95	90 ⁵
Kaimai tributaries	95	NA	95-100 ⁶	NA

¹ Main stem 90% of Q₅, except in reaches important for trout spawning where the minimum flow should be 95% of Q₅. Headwater streams should retain a minimum flow limit of 95% of Q₅.

² 90% except in reaches important for trout spawning where the minimum flow should be 95% of Q₅.

³ Depending on weight given to protecting trout habitat. The higher the desired protection level, the higher the recommended minimum flow.

⁴ As above

⁵ Maintain current minimum flow, but place restriction on allocation tied to maintaining minimum dissolved oxygen concentrations in the lower Waihou

⁶ Depending on weight given to protecting natural character and native fish habitats. The higher the desired protection level, the higher the recommended minimum flow.

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Appendix A Ohinemuri RHYHABSIM output updates

Introduction

In Section 4.2.1 it was recognised that for the two sites in the Ohinemuri sub-catchment where RHYHABSIM modelling was undertaken, maximum habitat availability for the majority of species occurs at flows greater than Q_5 . This indicates that low flows may be a natural limiting factor on instream physical habitat availability in the Ohinemuri. Because of this it may be an unrealistic and unnecessary target to try and maximise instream physical habitat availability at these sites. Consequently, it was suggested in Section 4.3.4 that a more realistic approach to evaluating suitable limits for protecting instream physical habitat in these cases would be reanalyse the outputs of the habitat modelling to look at the deviation in habitat availability relative to that available under natural low flow conditions (i.e. relative to habitat available at Q_5). WRC have requested that NIWA undertake these analyses and the results are presented below.

Methods

The archived RHYHABSIM files for the Ohinemuri at Karangahake and Golden Valley Cross Road were used to reproduce the original outputs from Jowett (2008) in RHYHABSIM 5.0. In the original report, the habitat suitability curves used for native fish were taken from Jowett and Richardson (1995). These have subsequently been superseded by those in Jowett and Richardson (2008) and thus both sets of curves were used for the re-analyses of the results.

Weighted Usable Area (WUA) at Q_5 was identified for each indicator species at each site. The proportion of that low flow habitat available at discharges corresponding to 70, 75, 80, 85, 90 and 95% of Q_5 was then calculated for each species.

Results & recommendations

At the Karangahake site inanga, redfin bully and shortfin eel are all predicted to have an increase in WUA as flow is reduced from 100% of Q_5 to 70% of Q_5 (Figure A-1). However, WUA for rainbow trout, torrentfish, smelt and food producing is predicted to reduce. For longfin eel and common bully, the trend varies depending on which habitat suitability curve is used (1995 v. 2008), but the overall change in WUA relative to that available at Q_5 is small (c. 5% with a 30% reduction in flow).

There was no significant difference at this site over the range of flows modelled between the WUA predicted for shortfin eel or redfin bullies using the 1995 and 2008 habitat suitability curves. However, for longfin eels there was a difference of about 10% (+5% versus -5% change in WUA for the 1995 and 2008 curves respectively) at a flow of 70% of Q_5 . A similar difference was observed for common bullies, except that the 1995 curve predicted a decrease in WUA availability relative to Q_5 and the 2008 curve predicted an increase in WUA. The only species with a significant difference in the predicted availability of WUA over the range of modelled flows was torrentfish, with the revised 2008 curve resulting in a significantly greater decrease in WUA being predicted with reduced flow.

Food producing, rainbow trout spawning, smelt and torrentfish (2008) are the most flow sensitive indicators at this site over the range of flows from 70 to 100% of Q_5 . The current minimum flow of 90% of Q_5 at this site corresponds to about an 85% WUA protection level for these species (i.e. habitat is reduced by up to 15% relative to that available at Q_5). For the remaining indicator species, the current minimum flow corresponds to the 95% protection level (i.e. a no greater than 5% reduction in WUA relative to that available at Q_5). Given that the Ohinemuri at this site is designated as an important trout and native fish habitat, it is recommended that minimum flows should not be

reduced beyond the current limit of 90% of Q_5 . For areas known to support trout spawning, consideration should be given to increasing the minimum flow to 95% of Q_5 .

At the Golden Valley Cross Road site, WUA declines relative to that available at Q_5 for all species as flow is reduced from 100% to 70% of Q_5 (Figure A-2). The most flow sensitive indicators are again food producing, rainbow trout spawning and torrentfish (2008) habitat. WUA for rainbow trout adults and juveniles is also predicted to be relatively sensitive to flows being reduced below Q_5 . A significant difference in predicted WUA is again observed between the 1995 and 2008 habitat suitability curves for torrentfish. There is also a reasonable difference in the results for longfin eel, with a 10% greater reduction in WUA predicted at a flow of 70% of Q_5 .

The current minimum flow limit (95% of Q_5) at this site provides a minimum 90% protection level for all indicators. For all reaches where trout spawning is known to occur, it is recommended that this protection level be retained. Where trout spawning is not a critical value, it may be feasible to reduce the minimum flow to 90% of Q_5 , which would provide a greater than 90% habitat protection level for the majority of target species. The only exceptions are torrentfish (which are currently unlikely to be present this high in the catchment due to the presence of a weir downstream) and food producing habitat. The constraint on food producing habitat is potentially of greatest concern and is the reason for not recommending a reduction in the minimum flow beyond 90% of Q_5 .

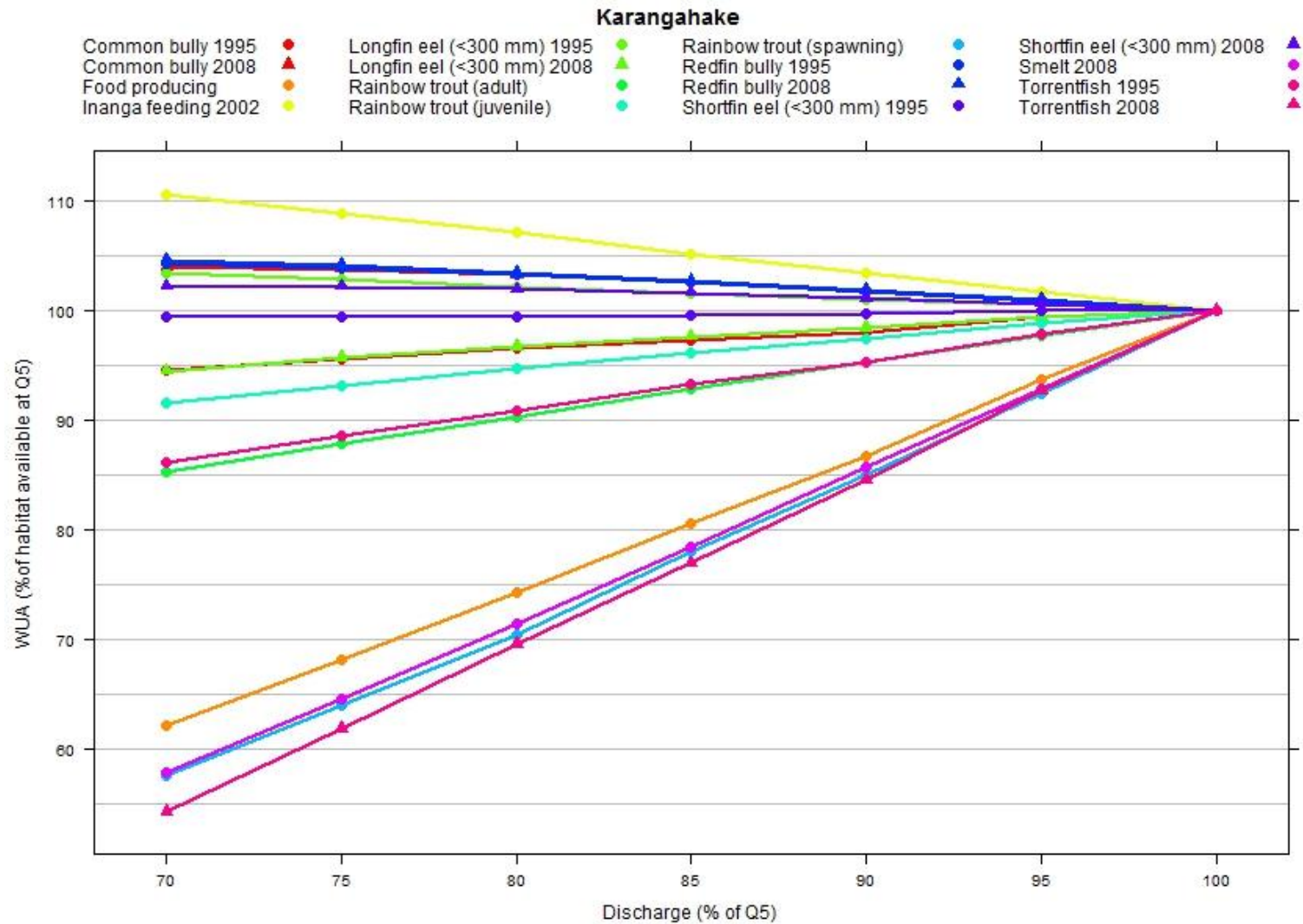


Figure A-1: Change in WUA relative to that available at Q5 at different flows for indicator species at the Karangahake RHYHABSIM site. If WUA > 100%, habitat availability has increased. If WUA < 100%, habitat availability has decreased.

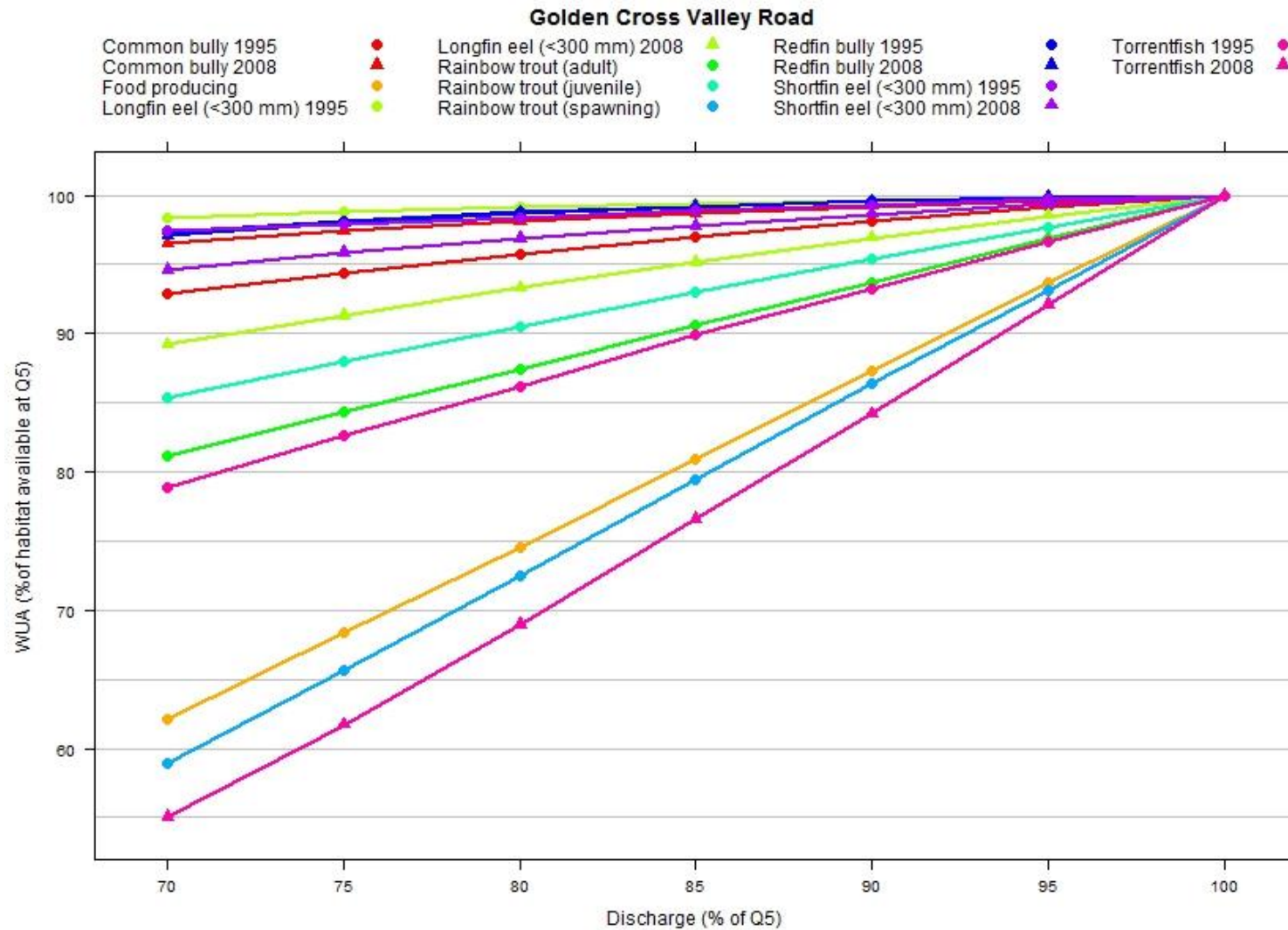


Figure A-2: Change in WUA relative to that available at Q5 at different flows for indicator species at the Golden Vally Cross Road RHYHABSIM site. If WUA > 100%, habitat availability has increased. If WUA < 100%, habitat availability has decreased.

