Jowett Consulting Limited

Review of Minimum Flows and Water Allocation in Taranaki

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Review of Minimum Flows and Water Allocation in Taranaki

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Prepared for

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Executive Summary

The National Policy Statement for Freshwater Management 2014 (NPSFM) statement requires regional councils to set environmental flows that include an allocation limit and a minimum flow.

The current Taranaki Regional Council Freshwater Plan (2001) sets minimum flows but does not set quantitative allocation volumes, although there are qualitative measures that have to be considered.

In preparing their Draft Freshwater and Land Management Plan (Draft Plan), the Taranaki Regional Council has considered NPSFM requirements and has undertaken targeted consultation. The Draft Plan sets minimum flows and allocation limits and for most catchments specifies minimum flows and allocation limits that are specified as defaults in the *Proposed NES for Ecological Flows*. It also establishes four freshwater management units (FMU). These are for outstanding water bodies, rivers draining from Mt Taranaki (ring plain), eastern hill country rivers, and coastal terrace streams.

Although there are few major catchments in the Taranaki region, there are more than 500 named rivers and streams, which on the volcanic ring plain are generally short, steep and fast flowing. Of the Taranaki rivers, about 17 have water level records with 10 or more years of record and only nine of these have detailed morphological measurements. Seven of these are in the ring plain and two in the eastern hill country. There are two streams in the coastal terrace FMU with water level records, but their length of flow record is too short to determine flow characteristics for the coastal FMU.. Flows in rivers classified as outstanding water bodies have a high level of protection and only allow minimal abstraction.

A common concern of submissions on the flows and allocation in the Draft Plan was how policies 7.7 (allocation) and 7.8 (minimum flow) worked together, both for environmental protection and their effect on reliability of supply.

This report addresses those concerns by discussing:

- the function of the Council in water resource management,
- research that has been carried out into effects of water abstraction and methods of assessing environmental flow requirements,
- principles involved in setting minimum flows and allocation,
- the technical basis for the minimum flows and allocation limits in the Draft Plan
- flow requirements in a sample of Taranaki rivers, and
- minimum flows and allocations[1] that would provide various levels of environmental protection.

The Taranaki Regional Council is responsible for water resource management in their rivers. This involves balancing the two conflicting objectives of safeguarding the ecology of the rivers while managing the efficient allocation and use of water.

The Draft Plan sets objectives for setting minimum flows and allocation. The key objectives are appropriate use and development, ecosystem health and mauri, natural character, and biodiversity.

Balancing water use with the environmental objectives raises the issue of what flow and/or stream characteristic would be used to determine an acceptable level of ecosystem health, mauri and

[1] in terms of percentage of the mean annual low flow

biodiversity. For the purpose of setting flows, ecosystem "health", mauri and biodiversity is indicated by the state of the benthic invertebrate community and fish population.

A basic concept of a minimum flow is that it should provide an acceptable level of protection for the stream. This is known as "standard setting".

Two standard setting methods for minimum flow tend to be used in New Zealand. These are a percentage of a flow statistic (historic flow method) and retaining a percentage of the habitat available at some index flow.

This report is probably the first New Zealand study to examine the combined ecological effects of minimum flow and allocation on ecosystem health, mauri[2] and biodiversity. Minimum flows and allocations are set to achieve target levels of protection for benthic invertebrate community and fish population (i.e., ecosystem health).

Over the last 20 years, New Zealand has been at the forefront of research into the effects of flow change on aquatic ecosystems and there is a considerable amount of information available on environmental flow requirements and the effects of flow changes.

Benthic invertebrates are used internationally and in New Zealand as a measure of ecosystem health. Benthic invertebrates are the food source for both native fish and trout. Trout abundance is directly related to invertebrate density and benthic invertebrates are most abundant in riffles, where native fish are also most abundant. The macro-invertebrate community index (MCI) is commonly regarded as a measure of ecosystem health and has been identified as the one measure that was most closely related to Maori cultural values[3]. Maintaining a high MCI will also lead to high biodiversity and help meet MCI requirements of the National Policy Statement for Freshwater Management (MfE 2015).

Two types of protection level are used in combination:

- to protect the state of the benthic invertebrate community, and
- to protect the fish community.

The overall effect of the minimum flow and allocation on the state of the benthic invertebrate community is assessed using the benthic production model. This model predicts an index of benthic invertebrate density for selected species with and without abstraction so that the minimum flow and allocation can be based on an appropriate level of retention. The protection level is the predicted benthic invertebrate density with abstractions as a percentage of the benthic invertebrate density with natural flows. The approach taken here is a risk based approach whereby the minimum flow and allocation should not cause unacceptable environmental degradation.

Native fish and trout can be affected by low flows through a reduction in the amount of suitable habitat if the flows are low for a sufficiently long period. At low flows, the amount of habitat suitable for fish with high flow requirements, such as torrentfish, koaro and adult trout, declines linearly as flows reduce towards zero, so that any reduction in long duration low flow has the potential to affect the fish population proportionally. To maintain populations of these fish species with high

[2] Taranaki iwi will be consulted with separately with regards to local meaning and application during stakeholder workshops.

[3] Tipa & Teirney 2003

flow requirement, low flows over a 30 day period (as indicated by the 30-day MALF[4]) should be maintained at an adequate level. Because trout, koaro and torrentfish have the highest flow requirements of any fish species, flows that maintain adequate habitat for them will be more than adequate for other fish species, such as eels and inanga. In some streams, there may be no fish access to the sea because of cliffs and waterfalls. If this were the case the fish protection level could be relaxed.

The key to setting minimum flows and allocations that meet community expectations for environmental objectives (i.e., the state of the benthic invertebrate community and fish populations) is to set appropriate protection levels and then to calculate the minimum flow and allocation that would achieve them. The setting of minimum flows and allocation limits is a process that involves the Regional Council and community in order to achieve the best water management outcomes for the region taking into account environmental, cultural and economic considerations.

Various combinations of minimum flow and allocation levels were applied to a representative sample of nine Taranaki rivers to determine the effect on ecosystem health, as measured by the two types of protection level. Minimum flows varying from 50% to 90% of the MALF were tested. A minimum of 66% of the MALF is the existing minimum flow requirement and 90% can be regarded as a level at which there would be no measurable effect. Allocations of 0 to 50% of the MALF were tested. Currently, there is no allocation limit, although 33% of MALF has been inferred by Council staff. The range of minimum flows and allocation limits presented in this report are broadly based on limits that have been used by regional councils and in the MfE (2008) discussion document.

The Draft Plan sets different minimum flow and allocation limits for flows less than and greater than 5 m^3/s based on recommendations in the *Proposed NES for Ecological Flows*. Of the nine Taranaki rivers modelled, seven had mean flows less than 5 m^3/s and two were slightly higher than 5 m^3/s. Two of the sample rivers were in the eastern hill country (FMU D) and the other seven were ring plain rivers (FMU B). The hydrology, water quality, and benthic invertebrate communities in both FMUs were similar except for slightly lower runoff and greater turbidity in the eastern hill rivers. Thus, there does not appear to be any ecological reason for setting different flows and allocations in these two areas.

Table 1 below shows minimum flow and allocation options based on average benthic and fish protection levels for Taranaki waterways. The options include protection levels achievable under the current Freshwater Plan (*status quo*), those proposed under the Draft Plan, and two alternatives. The alternative choices provide a fish protection level of 80% and above on the basis that a 20% reduction in fish population is probably not detectable and that the reduction would only occur if the fish population were habitat limited. Similarly, a reduction of 10% in the state of the benthic invertebrate community is small and probably not detectable. For example, a fish protection level of 83% and a benthic protection level of 91% would reduce the number of large (> 40 cm) trout from 7.4 per kilometre to 5.9 per kilometre.

Actual effects on the benthic invertebrate community are probably less than would be indicated by the protection levels because the effects were calculated assuming that the maximum allowable allocation was abstracted all through the year and this would rarely be the case.

[4] MALF is the average annual minimum flow calculated as a running mean over a period of days (e.g., 7 day or 30 days)

Table 1: Possible choices of minimum flows and allocation and the protection levels that they provide. Protection levels are percentages of benthic invertebrate production or fish habitat relative to invertebrate production and fish habitat at MALF

Description	Minimum flow as % MALF	Allocation volume as % MALF	Benthic invertebrate protection level	Fish habitat protection level	Days of partial restriction per year
Current Plan	66	33[5]	87	77	18
Draft Plan	90	30	93	86	42
Alternative 1	85	40	90	81	46
Alternative 2	80	30	91	83	30

The minimum flow and allocation has a relatively large effect on the number of days that there would be partial restrictions in a fully allocated catchment, with the number of days of restriction more than doubling in the Draft Plan and Alternative 1. The differences in protection level for the options look relatively small but the potential reduction in benthic production varies between 13% for the Current Plan and 7% for the Draft Plan. Similarly, the potential effect on torrentfish could be a reduction in numbers of 23% for the Current Plan to 14% for the Draft Plan. Trout numbers would also reduce by more than 20%.

There are 45 Taranaki rivers or catchments with consents to abstract water. In these, the total amount of water allocated in the consents is more than 30% of MALF in 36% of the rivers, more than 33% in 27% of rivers and more than 40% of MALF in 24% of rivers. The median amount of water allocated in the consents for Taranaki rivers or catchments is 19% of MALF.

The large abstractions were often from lakes or reservoirs, from streams where there is no access to the sea, or for public water supplies. Although allocation limits of 30-40% of MALF would mean that the limit would be exceeded in some rivers, this does not necessarily mean that there will be a discernible environment effect.

Riparian management can also affect benthic invertebrates and fish communities by increasing shade to reduce water temperatures and creating cover and habitat diversity for fish. Riparian planting has been used to offset the effects of abstraction.

In conclusion, the levels of protection proposed in the Draft Plan and other alternatives proposed in this report represent an increase level of protection from the *status quo* but conversely would represent increased restrictions on consented water users. Accordingly, stakeholder involvement is very important in determining the community’s preferred option and a series of workshops will be held to discuss the methods and choices provided in this report, particularly the levels of protection, minimum flows and allocation limits. The Taranaki Regional Council intends to use this report to inform these community discussions from a technical perspective.

[5] Inferred allocation limit as no limits are specified in the existing plan

1 Introduction

Minimum flows in the current Taranaki Regional Council Freshwater Plan (2001) are based on a report by Jowett (1993) which suggested several methods by which minimum flows could be set. The Regional Council decided on a method where the minimum flow retained 66% of the habitat available for adult brown trout and food production available at mean annual low flow (MALF). No quantitative allocation volumes are established in the plan, although there are qualitative measures that have to be considered.

As part of the review of the Freshwater Plan, the Taranaki Regional Council (the Council) has prepared and undertaken targeted consultation on a draft Freshwater and Land Management Plan (Draft Plan) that takes into account the National Policy Statement for Freshwater Management 2014 (NPSFM). The policy in the statement requires regional councils to set environmental flows that include an allocation limit and a minimum flow.

The Draft Plan establishes four freshwater management units (Fig. 1) and sets minimum flows and allocation limits that take into account current water allocations and uses. Supplementary water takes of up to 10% of the flow are also allowed when the river flow is above the median flow. Supplementary takes are not considered further in this report because they are considered to have a minimal effect on river ecology.

Flows in rivers classified as outstanding water bodies (FMU A) are given a high level of protection in the Draft Plan and only allow minimal abstraction.

The Taranaki ring plain (FMU B), centred around Mount Taranaki, is the most populated part of the region and has fertile and free-draining volcanic soils that are well suited to pastoral farming. Dairying is the most common land use and is more intensive on the flatter lands of southern Taranaki. Two ring plain rivers (Hangatahua or Stony and Maketawa) are considered outstanding freshwater bodies and along with the Lake Rotokaire Scenic Reserve form FMU A.

The coastal terraces along the north and south Taranaki coast (FMU C) also have versatile and productive soils. However, the combination of light, sandy soils and strong winds in some localities (e.g. coastal sand country) make them susceptible to wind erosion if vegetation cover is lost.

The hill country, inland of the ring plain and coastal terraces, consists of older rock - siltstone, mudstone and sandstone, known locally as papa. This country is steep, and prone to soil erosion. A large part of the hill country is in public ownership and vegetated in indigenous forest. In other parts, the hill country supports both pastoral farming and commercial forestry.

Annual rainfall varies markedly throughout the region, ranging from less than 1,400 mm in coastal areas, to in excess of 8,000 mm at the summit of Mount Taranaki.

Taranaki has more than 500 named rivers and streams. Over 300 rivers and streams flow from the flanks of Mount Taranaki in a distinctive radial pattern across the ring plain. Typically ring plain rivers are short, small and fast-flowing.

By contrast, the eastern hill country (FMU D) displays a branch-like (dendritic) pattern of drainage. The rivers of the hill country are generally longer than ring plain rivers and are contained by narrow valleys that carry relatively high sediment loads as a result of hill country erosion.

The Waitara River is the largest river in the region a mean flow of 58 m^3/s at Bertrand Road. The Patea (mean flow 29 m^3/s at McColls Bridge) and Waiotara are two other rivers that could be considered large (mean flow > 10 m^3/s).

Figure 1: Proposed Freshwater Management Units for Taranaki

Of the Taranaki rivers, about 17 have water level records with 10 or more years of record and only nine of these have detailed morphological measurements. There are only two streams in the coastal terrace FMU with water level records. One, the Kaikura Stream, is in the southern coastal terrace and has been operating since 2014, and the other is in the northern coastal terrace and has been operating for 8 months. There is no morphological data for these streams and their records are not sufficiently long to determine flow characteristics of coastal terrace streams.

The flow regime of Taranaki rivers is dominated by frequent storms from the west and north and these usually affect ring plain, coastal and eastern hill country river. Consequently runoff from rivers exposed to the north-west is higher than those in the south and east although the general pattern of flows is similar. For example, the Waiwhakaiho River is a high runoff ring plain river draining the north-west of Mt Taranaki and the Kaupokonui is a ring plain stream draining the south of Mt Taranaki. The Mangaehu Stream is a tributary of the Patea River draining the eastern hill country river to the east of Mt Taranaki. 2013 was a relatively dry year and the pattern of flows is similar in all rivers (Fig. 2) although runoff (L/s/km^2) is higher and freshes more frequent in the Waiwhakaiho than in the other two rivers. The Pearson correlation between the eastern hill country river (Mangaehu) and southern ring plain river (Kaupokonui) is higher (0.74) than the correlation between the Mangaehu and Waiwhakaiho (0.54).

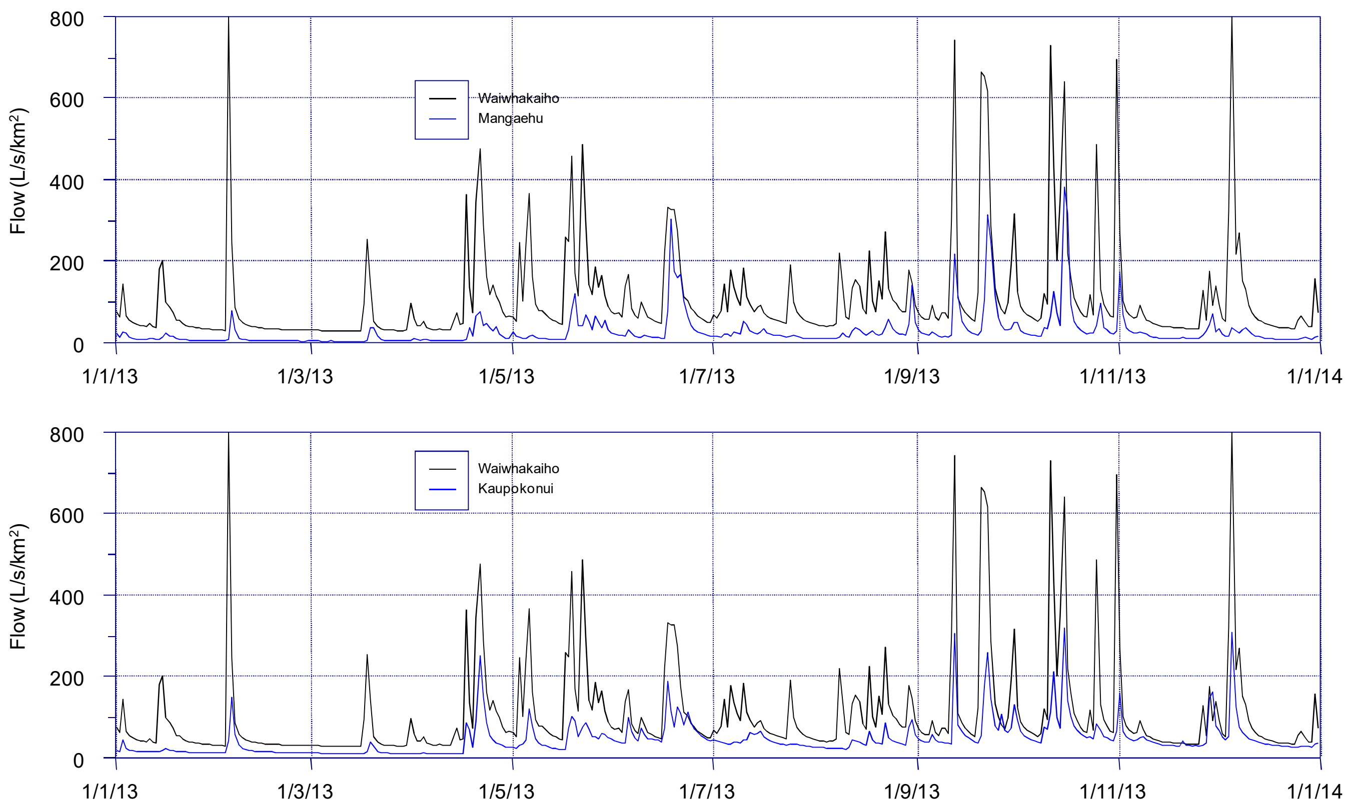

Figure 2: 2013 flows in the Waiwhakaiho River and Mangaehu Stream (above) and Waiwhakaiho and Kaupokonui rivers below.

For most catchments, the Draft Plan specifies minimum flows and allocation limits set as defaults in the Proposed NES for Ecological Flows (MfE 2008). However in some catchments with existing takes and high water use, the Draft Plan set limits reached through the prehearing process with stakeholders associated with resource consents. Almost all these cases have involved nationally or regionally significant water takes, such as urban supply or hydroelectricity generation.

Some submissions to the Draft Plan have questioned or requested more information on the methods used to determine the minimum flows and allocation limits.

In order to provide more information for submitters and to inform the plan and section 32 review this report describes the:

- function of the Council in water resource management,
- research that has been carried out into effects of water abstraction and methods of assessing environmental flow requirements,
- present method of minimum flow assessment and some principles involved in setting minimum flows and allocation,
- the technical basis for the minimum flows and allocation limits in the Draft Plan, and finally
- it examines flow requirements in a sample of Taranaki rivers and determines minimum flows and allocations that would provide various levels of environmental protection.

2 Planning framework

Amongst their many responsibilities, the Taranaki Regional Council is responsible for water resource management in their streams and rivers.

The Resource Management Act (RMA) and National Policy Statement for Freshwater Management (NPSFM) give some guidance with broad objectives to:

- safeguard the life-supporting capacity, ecosystem processes and indigenous species including their associated ecosystems of fresh water, in sustainably managing the taking, using, damming, or diverting of fresh water, and
- improve and maximise the efficient allocation and efficient use of water.

The NPSFM (MfE 2017a) sets compulsory values of ecosystem health and human health for recreation. The attributes of ecosystem health given in the report are periphyton and water quality (nitrate, ammonia, dissolved oxygen and E. coli).

Flow related attributes receive little mention in the NPSFM although the macroinvertebrate index[6] (MCI) is included in monitoring. Regional council monitoring methods must include the MCI. Low scores or declining trends would indicate that ecosystem health is not being provided for. The report considered that it was not possible to define a nationally applicable attribute state for MCI because it varies significantly depending on local conditions (MfE 2017b). A similar comment could be made for fish and other aquatic biota that are likely to be affected by flow changes.

In practically all cases, abstraction of water from a river will have some detrimental effect on the aquatic ecosystem, although often the effect will be small and not measurable. The Council is required to find a balance between water use and environmental protection of the rivers and lakes. The “balance” is not determined by any cost-benefit study but rather by setting an appropriate level of environmental protection. Ideally, this level of protection is set by the Council in consultation with its stakeholders. In this process, the Council should not be an advocate for either water users or protection and as such is likely to be criticised by both sides of the debate.

[6] The MCI was originally developed by Dr John Stark when he was working with the TRC and there is much data available.

The Resource Management Act is “effects based” and resource consents are required to consider the effects of their activity. Similarly, Council decisions on minimum flows and allocation should consider actual and potential effects on the environment.

The minimum flows in the present Freshwater Plan were developed in 1993, and methods for assessing minimum flows and their associated standard of protection have developed since then. A series of reports have been produced beginning with the flow guidelines in 1998 (MfE 1998) and followed by a review of methods for setting minimum flows for the Southland Regional Council (Jowett & Hayes 2004), supporting technical reports for Horizon’s One Plan (Hay & Hayes 2007) and the proposed National Environmental Standard (NES) for ecological flows (MfE 2008) and its associated technical report (BECA 2008).

Most of these reports discuss methods for determining the effects of minimum flows and only the proposed NES for ecological flows specifies actual minimum flows and allocation limits. One reason why technical reports do not specify actual minimum flows is that the selection of an appropriate minimum flow is a process that involves collaboration between the stakeholders which technical experts can assist by providing assessments of the effects of the various alternatives.

Minimum flows are set by rules rather than methods. The well-known Tennant or Montana method sets rules for various levels of protection, such as a minimum flow of 30% of the mean flow to provide near optimum conditions[7]. These rules were based on a method which determined that 30% of the mean flow provided water depths of more than 0.6 m and velocities of more than 0.6 m/s.

What is an environmental flow? In this report, an environmental flow is synonymous with the minimum flow. The minimum flow of a river is the flow at which most consent holders are required to cease abstraction. Naturally occurring low flows can be less than “the” minimum flow. The minimum flow is also used for the flow that is required to be discharged below a diversion - also called the residual flow. An ecological flow is a flow requirement for ecological purposes. An environmental flow regime is the flow regime that is required to maintain the stream environment (Biggs et al. 2008; Jowett & Biggs 2008). It would usually contain a minimum flow requirement as well as requirements that maintain a degree of flow variability including flushing (e.g. fine sediment and periphyton) and channel maintenance flows.

What is an allocation limit? The National Policy Statement for Freshwater Management 2014 requires regional councils to set environmental flows that include an allocation limit and a minimum flow. The reports mentioned above have focussed on minimum flow requirements with very little discussion of the effects of total allocation. The allocation in any consents is usually for the maximum take and the sum of maximum takes for all consents is the total allocation. In practice, most consent holders only abstract at a maximum rate for a short period of time. For example, irrigation takes only take water in the summer and only at peak rates when it is necessary. Actual takes are usually about 50% of the total allocation (MfE 2015). Total allocation, as specified in consents, is almost always higher than actual takes to allow for climatic and other forms of variation such as varying seasonal demands.

[7] Tennant’s winter recommendation. In Montana winter is the season of low flows.

Supplementary allocation is the amount of water than can be taken when river flows are higher than normal[8] and are usually for purposes such as filling storage dams. Supplementary takes are considered to have a minimal effect on river ecology.

3 Methods for determining minimum flow and allocation

3.1 Review of Regional Council minimum flow methods

The first study of minimum flow requirements for the Taranaki region was carried out by Jowett (1993). He prepared a report for the Council outlining methods that could be used to determine minimum flows. Instream habitat surveys[9] were made of 11 rivers[10] which had a good degree of variation in size and gradient. Two methods were suggested both based on adult brown trout habitat at mean annual low flow (MALF) and food producing habitat. These habitat criteria were used because a nationwide study of brown trout abundance (Jowett 1992) had shown that these two factors were very important determinants of trout abundance and were the only factors that could be found that varied with flow. The 1992 study also identified benthic invertebrate density as the single most important factor related to brown trout abundance. At the time of the study habitat criteria were not available for native fish. Some options for determining the measures and levels of protection were presented in the report and the Council decided to use the habitat retention method which limited the amount of change caused by flow abstraction. For habitat retention, Jowett (1993) assumed a level of protection of one-third loss (i.e., retention of two-thirds) compared to MALF for food producing or brown trout habitat at naturally occurring low flows, but noted that there was no way of scientifically selecting a percentage loss of “natural” habitat which would be considered acceptable. The criteria applied to these Taranaki rivers were not solely for trout and the report noted that “consideration of food producing habitat is or should be common to all rivers, whether it is to maintain native fish, brown or rainbow trout or to maintain a “healthy” stream environment”. The adult trout and food producing criteria specify that relatively deep and swift water is the most suitable habitat. When these criteria are applied to small streams and rivers the flow that retains two-thirds of the trout and food producing habitat available at MALF is essentially two-thirds of MALF.

Habitat suitability curves for native fish were developed subsequent to the 1993 study (Jowett & Richardson 1995; Jowett & Richardson 2008) and some Regional Councils began to use these as a means of determining minimum flows. The analyses for these methods are relatively complicated and often required field surveys. For example, the Bay of Plenty Regional Council, specified levels of protection based on the fish species present in the stream and required the minimum flow to retain the maximum level of protection (Wilding 1999). Jowett & Hayes (2004) suggested a similar method for the Southland Regional Council but based their levels of protection on categories based on instream values, essentially the “target” fish species and their perceived value. These methods can be based on either detailed instream habitat surveys (e.g., System for Environmental Flow Analysis, SEFA) and habitat suitability curves, quick surveys (WAIORA), or river information from a GIS type system (NIWA’s River Environment Classification) and generalised habitat suitability curves.

[8] Usually median flow

[9] Instream habitat surveys are detailed measurements of water depths and velocities at closely spaced points across pools, runs, and riffles in a section of river. The surveys are calibrated so that they can be used to predict depths and velocities at other flows which in turn can be used to predict changes in habitat.

[10] Waiwhakaiho at SH3, Stony at Okato, Manganui at Tariki Road, Patea at Stratford, Kaupokonui at Skeet Road, Waingongoro at Eltham, Waiongana at SH 3A, Kapuni at SH 45, Mangoraka at Corbett Road, Kapoaiaia at Lighthouse, Tawhiti at Duffys Farm

A number of Regional Councils use minimum flows based on simple hydrological data such as the 5-year low flow or 90% of the 5-year low flow.

Biologically based rules-of-thumb, such as Tennant's method, do not appear to be used at present.

3.2 Research on the effects of water abstraction

Over the last 20 years, New Zealand has been at the forefront of research into the effects of flow change on aquatic ecosystems and there is a considerable amount of information available on environmental flow requirements and the effects of flow changes. The key milestones would be the first instream habitat survey of the Tekapo River in 1979 (Jowett 1982), the "100 rivers survey" (Biggs et al. 1990), development of habitat suitability curves (Hayes & Jowett 1994; Jowett & Richardson 2008), long term studies of fish populations in the Kakanui, Waipara and Rainy rivers (Hayes 1995; Jowett 1995; Jowett et al. 2005), case studies of the effects of flow change (Jowett & Biggs 2006), benthic production models (Hayes et al. 2014) and bioenergetic models (Hayes et al. 2016).

3.2.1 Relationship between flow and ecology

The flow regime has three components that control aquatic biota (fish, benthic invertebrates and periphyton) (Biggs et al. 2008; Jowett & Biggs 2008). The three components are:

1. the magnitude, duration and frequency of low flows,
2. the frequency and magnitude of floods and freshes, and
3. flows between the extremes, often represented by the median flow.

Although all three components have some effect on fish, invertebrates and periphyton, the degree to which component exerts the most control depends on the life cycle of the biota.

Low flows act as a "habitat bottleneck" for long-lived biota such as trout and native fish. This is because mortality occurs when flows are low and suitable fish habitat restricted, and the population can take several years to recover (Jowett et al. 2008). Flows need to be low for some time, probably 30 days or so, for significant mortality to occur (Jowett et al. 2005). The recovery of a population from a low flow event depends on the life cycle. For trout, the population recovers in 3 or so years if trout spawning is successful (Hayes 1995). For native fish, most species recover in a year. However, if low flows occur year after year then those flows will limit the populations, and in the case of native fish, supply of larvae to the seas around New Zealand would be reduced leading to a general decline in national populations. Hence the concept that the MALF, the low flow that occurs every second year or so, is a limiting hydrological parameter for fish populations (Jowett et al. 2008).

The frequency of floods and freshes is most important for periphyton because the velocities and the bedload movement that occurs during these events clean periphyton from the stones of the stream bed. Periphyton growth begins almost immediately after a flood with the growth rate depending on factors such as water temperature and nutrient levels (Jowett & Biggs 1997). The disturbance of the stream bed during floods also reduces benthic invertebrate densities, and their recovery is not as fast as that of periphyton. Trout can also be affected by large floods (Jowett & Richardson 1989), especially during incubation and emergence (Jowett 1995; Hayes 1995).

The flows between the extremes of low flows and flood flows influence the productivity of the stream for benthic invertebrates. As flows increase, benthic invertebrate populations increase with the improvement in habitat. The trout population will also be affected by the productivity of the stream, with the trout densities increasing as the invertebrate production increases (Jowett 1992).

Ideally, long-term solutions to river flow management need to take a holistic view of the river system, including geology, fluvial morphology, sediment transport, riparian conditions, biological habitat and interactions, and water quality, both in a temporal and spatial sense. In practice, only projects with a high degree of hydrologic alteration, such as major diversions and dams, require detailed consideration of all of these river processes.

Rivers can also be improved by means other than flow management. Riparian planting and improvements to water quality are examples of two ways in which the aquatic ecosystem can be improved as discussed more fully later.

3.2.2 Assessment of environmental flow requirements

The instream flow incremental methodology (IFIM; Bovee 1982) is an example of an interdisciplinary framework that can be used in a holistic way to determine an appropriate flow regime by considering the effects of flow changes on instream values, river morphology, physical habitat, water temperature, water quality, and sediment processes (Fig.3). Its use requires a high degree of knowledge about seasonal and life-stage requirements of species and inter-relationships of the various instream values or uses.

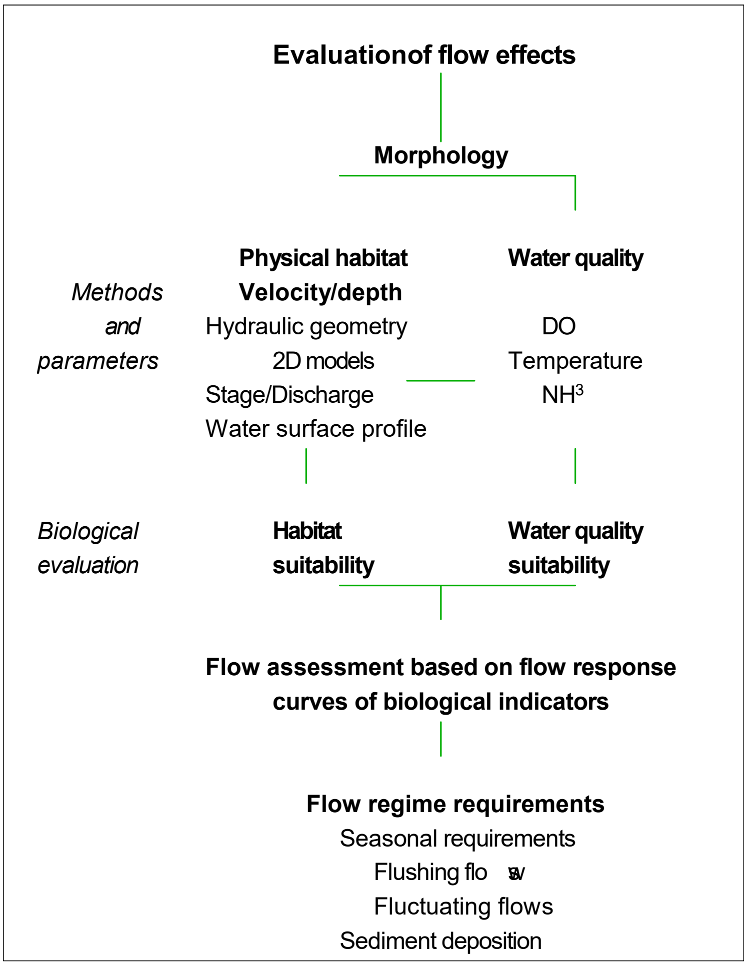

Figure 3: A framework for the consideration of flow requirements.

Other flow assessment frameworks are more closely aligned with the "natural flow paradigm", a concept that emphasises the need to partially or fully maintain or restore the range of natural intra- and interannual variation of hydrologic regimes in order to protect native biodiversity and the evolutionary potential of aquatic, riparian and wetland ecosystems (Poff et al. 1997). The range of variability approach (RVA) and the associated indicators of hydrologic alteration (IHA) allow an appropriate range of variation, usually one standard deviation, in a set of 32 hydrologic parameters derived from the 'natural' flow record (Richter et al. 1997). The implicit assumption in this method is that the natural flow regime has intrinsic values or important ecological functions that will be maintained by retaining the key elements of the natural flow regime. Arthington et al. (1992) described a holistic method that considers not only the magnitude of low flows, but also the timing, duration and frequency of high flows. This concept was extended to the building block methodology (BBM), which "is essentially a prescriptive approach, designed to construct a flow regime for maintaining a river in a predetermined condition" (King et al. 2000). It is 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 described in terms of their magnitude, duration, timing, and frequency.

A holistic consideration of every aspect of flow and sediment regime, river and riparian morphology, and their associations with the life cycles of the aquatic biota requires a degree of knowledge about individual rivers that is rarely available. The aim of the minimum flow is to retain adequate water depths and velocities in the stream or river for the maintenance of the critical values. Most flow assessments and habitat suitability criteria consider physical habitat at a meso- to macro-habitat level rather than microhabitat. In this way, suitable average depths and velocities can be maintained in the main habitats, with a degree of habitat diversity that is generated by the morphology of the river, and is largely independent of flow. The geomorphological and flow-related ecological processes that are associated with low to median flows are generally taken into consideration in instream flow methods. However, fish passage or seasonal flow requirements may need to be investigated in situations where fish passage may be an issue or where the species has distinct seasonal habitat requirements. Consideration should also be given to downstream effects. The effect of an abstraction is usually greatest immediately below the abstraction site, but diminishes as the river flow is supplemented by contributions from tributaries and the proportional change in flow reduces.

Commonly used methods of setting minimum flows can be classified into two basic types; historic flow and hydraulic-habitat methods.

Historic flow methods are coarse and largely arbitrary. An ecological justification can be argued for the mean annual low flow (MALF) and retention of the natural flow regime, and the concept of a low flow habitat bottleneck for large brown trout has been partly justified by research (e.g., Jowett 1992), but setting flows at lower levels (e.g., the 5 year 7 day low flow — $Q_{7,5}$) is rather arbitrary.

Hydraulic-habitat methods have a direct link to habitat use by aquatic species. They predict how physical habitat (as defined by various habitat suitability models) varies with flow, and the shapes of these curves provide the information that is used to assess flow requirements. Habitat based methods allow more flexibility than historic flow methods, offering the possibility of allocating more flow to out-of-stream uses while still maintaining instream habitat at levels acceptable to other stakeholders (i.e., the method provides the necessary information for instream flow analysis and negotiation).

3.2.3 Instream habitat methods

The ecological goal of habitat methods is to provide or retain a suitable physical environment for aquatic organisms that live in the river. Habitat methods tailor the flow assessment to the resource needs and can potentially result in improved allocation of resources. The consequences of loss of habitat are well known; the environmental bottom line is that if there is no suitable habitat for a species it will cease to exist. It is essential to consider all aspects such as food, shelter, and living space (Orth 1987; Jowett 1995) and appropriate habitat suitability curves are the key to the successful application of habitat based methods. The procedure for calculating habitat suitability and deriving the relationship between flow and habitat is described in Appendix I.

Habitat methods can also be used to determine flow regime requirements, in terms of both seasonal variation and flow fluctuations. Flow fluctuations are an important component of the habitat of most naturally flowing streams. Such fluctuations remove excess accumulations of silt and accumulated organic matter (e.g., from algal mats) and rejuvenate stream habitats. Extended periods without a flow disturbance in the Waipara River resulted in either an increase or no change in benthic invertebrate density with little change benthic community composition (Suren & Jowett 2006).

NIWA is developing a tool to use GIS type data (River Environmental Classification) to estimate morphological characteristics of streams and then to apply generalised models (Booker 2016).

Generalised curves are based on the analysis of flow-habitat relationships in a large number of New Zealand rivers. The flow-habitat relationships in this analysis are made dimensionless by plotting the average habitat index for each species against the flow per unit width of river (Lamouroux & Jowett 2005). Thus, if the variation of width with flow is known, it is possible to predict the generalised habitat-flow relationship. The application of generalised habitat models is simpler than instream habitat analysis and both rely on actual field measurements of stream morphology. The application of generalised curves is not advised for rivers with unusual morphology, such as braided and spring-fed (Jowett et al. 2008).

Instream habitat models can be incorporated into models of abundance, as described in Section 3.2.6, and these can give better estimates of the effects of flow on trout and benthic invertebrates than simple habitat models.

3.2.4 Instream habitat validation studies

Instream habitat analysis is widely used around the world (Tharme 1996) and the computer programme used for this analysis (SEFA and its predecessor RHYHABSIM) is used in many countries . The concept is simple. Water depths and velocities are predicted by a hydraulic model and the suitability of depths and velocities is assessed by comparing them with the depths and velocities that are used by the various fish species.

The strength of instream habitat analysis is that it is based on empirical data (rating curves derived from measurements of flow and water level) for the prediction of depths and velocities. Habitat suitability curves are (or should be) based on empirical measurements of density or presence absence of biota. An instream habitat analysis predicts the depth and velocity of each point in the river and evaluates its suitability. Hence, the combination of the hydraulic modelling and a habitat suitability curve should predict where biota are most likely to be found and the overall suitability of various flows for those biota. A simple test is to determine the suitability of various flows using instream habitat methods and then to observe whether those flows provide the conditions in which you are likely to find the biota. The flow in the Ohau River below Lake Ohau was set to provide good trout habitat and it is generally accepted that the flow does provide good habitat. Similarly flows in the Tekapo and Waiau rivers were set to provide good trout and food producing habitat and both maintain good invertebrate and trout populations despite the large reductions in flow.

The use of RHYHABSIM in New Zealand has been tested in a number of studies. Mosley & Jowett (1985) showed that the model was capable of predicting water depths and velocities in the Ashley River and Jowett & Duncan (2011) showed that the model could predict depths and velocities in the braided Hurunui River.

The brown trout regression model (Jowett 1992) uses trout and food producing habitat (as well as some other variables that do not vary with flow) to predict trout densities in NZ rivers. The model explained 87.7% of the variation in brown trout abundance at 59 sites in 57 different rivers around NZ. In those rivers there was a significant correlation between trout density and adult trout habitat (Jowett et al. 2008). In another test, the model predicted the distribution of brown trout in the Kakanui River (Jowett 1995). The regression model showed that both brown trout habitat and food producing habitat are required to predict trout abundance and that the flow requirements of food producing habitat are greater than those for adult trout habitat.

Jowett et al. (2008) showed that the ecological effects of flow regime changes in 6 rivers on trout, native fish or benthic invertebrates were consistent with instream habitat analyses. In the Waiau River an increase in flow increased trout numbers and that state of the fishery appears to be similar to that when the river flow was very much higher. In the Monowai River an increase in flow from 0.2 m^3/s to 6 m^3/s doubled invertebrate density and taxa richness. In the Moawhango River, an increase in residual flow from near zero to 0.6 m^3/s resulting in an invertebrate population similar to that above the flow modifications. When the 7 day annual minimum flow reduced from 66 to 20 L/s in the Onekaka River, there was a 61% reduction in koaro low flow habitat and a corresponding reduction of 80% in koaro numbers. Similarly, longfin eel numbers reduced by 52% compared to a 33% reduction in low flow habitat. Redfin bully numbers were low and variable and there was no obvious reduction in their numbers despite a 40% reduction in habitat.

The response of koaro to the flow change in the Onekaka River was similar to that observed for fast water species in the Waipara River (Jowett et al. 2005). In the Waipara River, torrentfish and bluegill bully numbers declined when flows were low for 30 days or more, but there was little effect on the numbers of Canterbury galaxias and upland bullies. The 3 year study of native fish in the Waipara River concluded that prolonged low flows reduced the abundance of fish species that prefer high water velocities, and favoured those that prefer low velocities. During periods of low flow, proportionally more fish were found in riffles than runs, implying that riffle habitat is important in the maintenance of fish stocks and biodiversity during periods of low flow. The key elements of the flow regime were the magnitude and duration of low flows, as well as the occurrence of spring floods that allowed recruitment of diadromous species[11] (Jowett et al. 2008).

3.2.5 Habitat observations

Suitable habitat is a necessary requirement for all aquatic species to live in rivers. Habitat requirements are usually relatively broad because narrow requirements would severely limit the establishment of an aquatic species. Habitat suitability is defined by observing the locations occupied by a species in a large number of streams and rivers. The definition can be based on meso-habitat types, such as pools, runs and riffles or on measures of physical habitat such as substrate type, depth and velocity. The description can also be widened to cover any attribute of a stream and river that contributes to the suitability for a particular species. The presence of cover elements for trout is one example.

[11] Species that migrate between the sea and freshwater as a necessary part of their life cycle

Benthic invertebrates and many species of native fish are most abundant in riffles (Pridmore and Roper 1985; Brown & Brussock 1991; Jowett & Richardson 1995). Jowett & Richardson (1993) showed that pools, runs and riffles could be classified by Froude number [12] and that the density of benthic invertebrate species was generally highest in depths and velocities classified as riffle habitat.

Habitat suitability is defined by the relative density of a species. The density is highest in the most suitable habitat, and the density is lowest or zero in the least suitable habitat.

For some species, it is easy to measure their density at a number of locations and to derive suitability criteria from that data. For other species, such as large trout, it is not practical to measure their density at a location. When living in a river, trout select specific locations for feeding, such as in runs or the heads of pools. Their habitat selections are determined by measuring the locations of a large number of trout. When these locations are and compared to the habitats that are present in the river, it is possible to calculate the density of trout in the various habitats and thus determine habitat suitability. Observations of brown trout behaviours while drift-diving Taranaki rivers (Teirney & Jowett 1990) did not indicate that they were behaving differently to brown trout in rivers used to define habitat suitability (Hayes & Jowett 1994).

Water velocity is probably the most important characteristic of a stream. Without it, the stream becomes a lake or pond. In small gravel bed rivers, an average velocity of at least 0.2-0.3 m/s tends to provide for most stream life. Velocities lower than this are unsuitable habitat for many fish species and stream insects, and allow deposition of sand and finer materials which is also unsuitable habitat. In large rivers, water depth of more than 0.4 m provides habitat for swimming species, but benthic fish are often found in shallower water.

The magnitude of the flow that provides good quality habitat will vary with the requirements of the species and with the morphology of the stream. Gradient is important because it determines stream energy. High energy streams contain a high proportion of riffle habitat and because of this they are more resilient to flow reduction than low gradient streams. The way in which depth and velocity change with flow tends to vary with the gradient. When flows reduce in a low gradient stream the reduction in water level is small compared to the reduction in velocity and velocities decrease faster than depths. In high gradient streams both water level and velocity tend to fall together so that the energy, as measured by the velocity to depth ratio or Froude number, tends to remain high.

The flow at which limiting conditions of depth and velocity occur varies with stream morphology. Generally, minimum flow increases with stream size simply because stream width increases with stream size. However, the relationship is not linear. In general, small streams require a higher proportion of the natural stream flow to maintain minimum habitat than do large rivers. This is because habitat modelling in small streams shows that a reduction in flow usually results in a similar reduction in habitat. However in large rivers, habitat modelling indicates that the reduction in habitat is often less than the reduction in flow. The boundary between small and large is probably in the order of 5-10 m^3/s, but this could vary depending on the species present in the river.

[12] Velocity divided by the square root of the product of depth and acceleration due to gravity

Brown trout

There are three sets of habitat suitability curves for adult brown trout based on data collected in New Zealand rivers. These were in Mataura[13], Travers[14], and Mohaka[15], in the Gowan River[16], and in the Clutha River[17] at the Lake Wanaka outlet .

The first study involved observing adult brown trout feeding locations in three rivers. This showed that the trout had selected similar locations in all three rivers (Hayes & Jowett 1994). Adult brown trout curves were derived from those data and showed an optimum velocity of 0.3-0.6 m/s.

Trout were surveyed in the Clutha River just below the Lake Wanaka outlet. A total of 51 adult brown trout were observed and the average depth and velocity of their locations were 3 m and 0.57 m/s, respectively. The habitat suitability curve derived from the Clutha data has an optimum velocity of 0.47-0.52 m/s (Jowett & Davey 2007, Jowett et al. 2008).

The Gowan River is a lake outlet with mostly boulder substrate, but is shallower than the Clutha River at the Lake Wanaka outlet. It has high water velocities and supports a very high trout numbers. It. Twenty-one adult brown trout were observed in the Gowan River in an average mean water column velocity of 0.69 m/s (range 0.25 m/s to 1.46 m/s). The average velocity at the fish location in the water column (velocity at the nose of the fish) was 0.34 m/s (range 0.06 m/s to 0.76 m/s) and the habitat suitability curve derived from these data has an optimum velocity of 0.6 m/s.

There is general agreement internationally on trout spawning requirements and in NZ brown trout spawning curves from Shirvell & Dungey (1983) are generally used.

Rainbow trout

There are three sets of suitability curves for rainbow adult trout based on observations in New Zealand rivers. These are based on measurements in the Tongariro, Clutha, and a set of Hawke Bay rivers.

The Tongariro data is based on trout angling locations identified by two experienced angling guides. These locations were surveyed and habitat suitability curves derived (Jowett et al. 1996).

A total of 104 large adult rainbow trout and about 80 medium rainbow trout were observed in the Clutha River at the Lake Wanaka outlet. The average depth and velocity of the location of the large trout were 2.95 m and 0.91 m/s, respectively. The habitat suitability curve derived from the Clutha data has an optimum velocity of 0.6 m/s. The velocities used in habitat analyses are the mean column velocities (velocity averaged over the full water depth) because this is the water velocity predicted by 1D and 2D hydraulic models. In the Clutha River, rainbow trout were found in mean water column velocities in excess of 1.2 m/s. However, the trout were actually near the bed of the river where the velocity would be less.

Habitat use by large and medium rainbow trout has also been surveyed in Hawke Bay rivers (88 trout in Ngaruroro and 114 in the Tutaekuri). The optimum depths and velocities for the(provisional)

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[13] Southland
[14] Nelson Lakes National Park
[15] Drains Kaimanawa Forest park to Hawkes Bay
[16] Outlet from Lake Rotoaira, Nelson Lakes National Park
[17] Otago

suitability curves derived from these data have optimum depths and velocities of >0.53 m and 0.33 to 0.8 m/s, respectively (Hayes & Addley 2013).

Native fish

Native fish are generally found in relatively low velocities compared to benthic invertebrates and adult trout. In large rivers, most species live along the margins of runs and riffles where depths are less than 0.5 m. In smaller rivers, they will be found across the width of the river in runs and riffles. Habitat suitability dictates where they will be found. As the velocity in runs falls, the fish will tend to move into riffles where velocities are higher (Jowett et al. 2005). As the flow changes in a river, they can also move laterally into areas with more suitable velocity (Jowett & Richardson 1994).

Longfin eels have been described as ubiquitous (Jowett & Richardson 1995), and although they are diadromous, their climbing ability allows them to gain access to the headwaters of most New Zealand rivers, often beyond the reach of other diadromous species.

Shortjaw kokopu, koaro, redfin bully, and banded kokopu have good climbing ability and occur relatively frequently with one another. Small bush-covered streams are the preferred habitat of these four communities (McDowall 2000). Banded kokopu streams contain pool habitat whereas koaro are usually in cascade habitat.

Shortfin eel, inanga, and torrentfish are usually found at lower altitudes than the shortjaw kokopu, banded kokopu, and redfin bullies. Inanga in particular are found at very low altitudes. Inanga streams typically have low velocity water for feeding (Jowett 2002) and a relatively high percentage of pool habitat.

Shortfin eels are found in farmed catchments rather than native bush and are often associated with silty substrate. Torrentfish live in riffles in open riverbeds (McDowall 2000). Riffles are also the preferred habitat of bluegill bullies. The non-diadromous Crans bully occurs only in the North Island (McDowall 2000) and usually well inland. It is absent from the Bay of Plenty and East Cape.

Suitability curves

Fish densities were measured at 5,184 locations in 124 rivers along with measurements of depth, velocity and substrate at each sampling location to define native fish and juvenile brown trout habitat suitability curves (Jowett & Richardson 2008). The results of this large sampling effort were similar to the results of sampling fish in runs and riffles in 34 rivers (Jowett & Richardson 1995).

Habitat suitability curves are available for longfin and shortfin eels in two size categories, <300 mm and > 300 mm. These curves are based on data collected by electro-fishing during the day and show that small eels are usually found in shallow water and low to moderate velocities; larger eels are found in deeper water. During the day, large eels are usually in cover in the form of large instream debris or overhanging banks. Although the water velocity in cover locations is near zero, the velocity associated with large eels refers was measured where the eels were captured after they were drawn from cover by electro-fishing.

During the night, eels emerge from cover and forage for food. Jowett & Richardson (2008) compare day and night habitat use by eels in the Waipara River (Table 2) and these show that the larger eels forage in shallow water (c. 0.25 m) with moderate velocities (riffle habitat) and that small eels may move into water with slightly shallower water (c. 0.16 m) with lower velocities (0.18 m/s). This study also showed that other native fish species occupied shallower water and lower velocities during the night than during the day (Jowett & Richardson 2008). The differences in day and night habitat for these species indicate that the flow requirements for day habitat would be greater than flow requirements for night habitat.

Table 2: Comparison of average day (394 sites) and night (612 sites) velocity and depth values for eels collected in the Waipara River, January and March 2005.

Species	Time	Velocity (m/s)	Depth (m)	N
Longfin eel	Day	0.25	0.41	14
	Night	0.15	0.25	76
Shortfin eel (<300 mm length)	Day	0.26	0.25	45
	Night	0.18	0.16	224
Shortfin eel (>300 mm length)	Day	0.17	0.60	69
	Night	0.33	0.22	223

Eel locations at night were also determining by spotlighting in the Waipara and Selwyn rivers. The average depth and velocity in which eels were found was 0.3 m and 0.33 m/s, respectively.

Benthic invertebrates and food production

Although many samples of benthic invertebrates have been collected in New Zealand rivers, few record the water depths and velocities in which the samples were collected and often sampling is standardised by sampling in consistent depths and velocities. The following studies have collected benthic invertebrate samples in a variety of depths, velocities and substrates.

Benthic invertebrates were surveyed in the Mohaka, Mangles, Waingawa and Clutha rivers (a total of 334 samples). Jowett et al. (1994) found that *Coloburiscus humeralis*, *Zelandoperla* spp., and *Aoteapsyche* spp. preferred coarse substrate and water velocities of more than 0.75 m/s. Invertebrate data suitable for the derivation of habitat suitability has also been collected in the Waitaki River (178 samples), Whanganui rivers (238 samples), Whatawhata streams (99 samples), Rainy River (393 samples), and Tongariro River (83 samples).

At present habitat suitability curves are available for the Mohaka, Mangles, Waingawa and Clutha rivers, for the Waitaki and for some species in the Rainy River. The Waitaki curves do not specify any depth suitability, although underwater observations in the river indicated that there might be some reduction in invertebrate density with depth.

Habitat suitability for benthic invertebrates appears to vary with river size (Jowett 2000) but Jowett (2003) was unable to find a consistent predictor of suitability in rivers of different sizes, although there appears to be a relationship with mean river velocity and depth (Fig. 4).

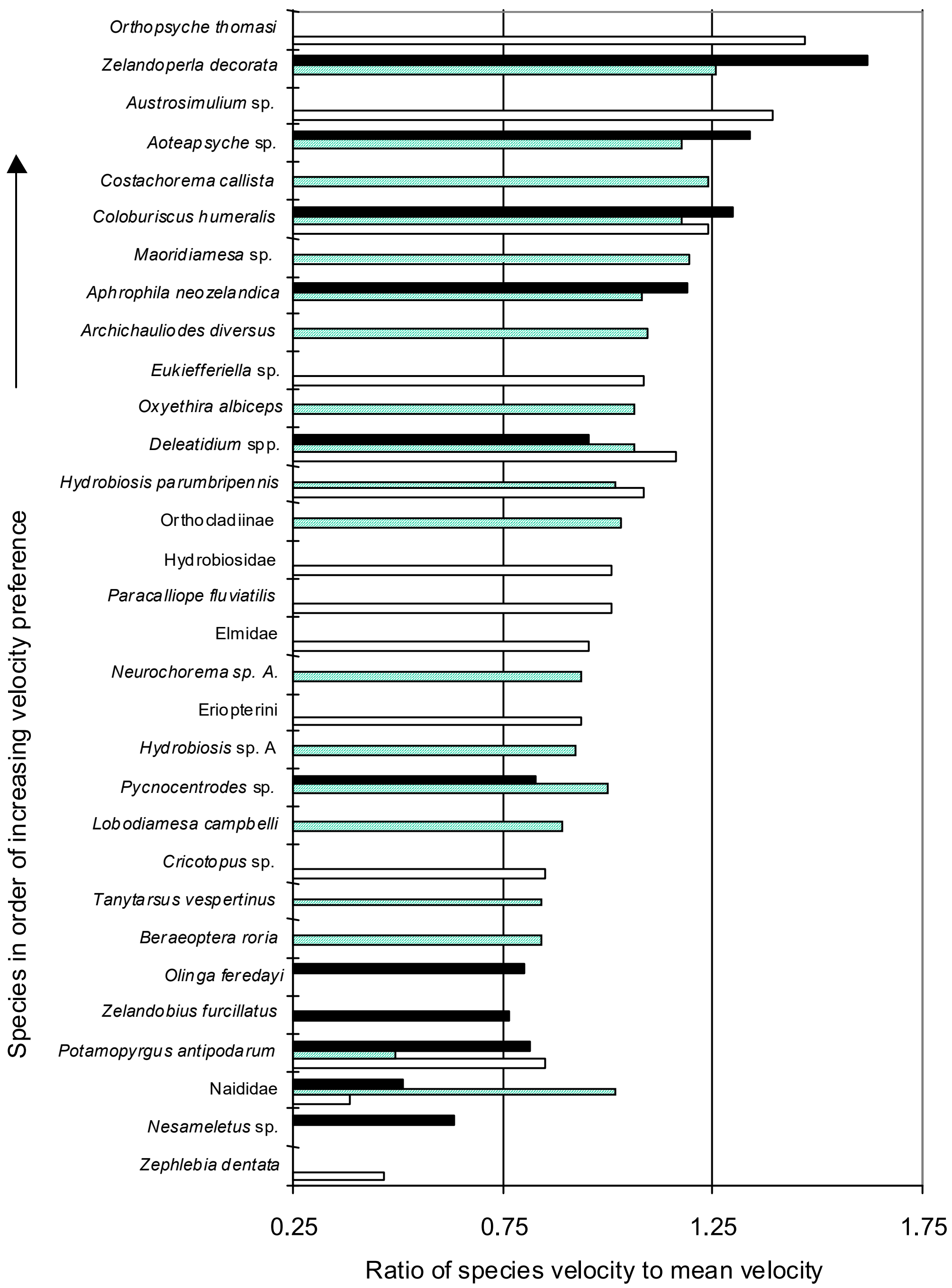


Figure 4: Relative velocity preferences of invertebrate species in small (<0.1 m^3/s) (no fill), moderate (1-10 m^3/s) (green hatched fill) and large (10-195 m^3/s) (solid black fill) rivers.

Summary of habitat suitability

Habitat use for trout, native fish, and benthic invertebrates appears to be associated with food availability and in the case of fish to be limited by swimming ability.

The velocities in which fish are found is related to swimming ability. Large bullies tend to be found in slightly faster and deeper water than small bullies. Large trout are found feeding in higher water velocities than small trout and even benthic invertebrate size tends to increase with water velocity (Jowett & Richardson 1990). Benthic invertebrates, particularly those with high MCI scores, are found in high water velocities and those velocities are higher than those in which most fish species are found. Only koaro are found in velocities approaching those of the high velocity invertebrates.

Brown trout densities have been found to be related to benthic invertebrate densities (Jowett 1992, Jowett et al. 1996) and many species of native fish live in riffles, where benthic invertebrates are abundant. Inanga feeding locations are in relatively low velocities, as dictated by their small size, but in areas where drifting food was concentrated (Jowett 2002).

Benthic invertebrates also tend to be abundant where their food sources are abundant. Jowett & Richardson (1990) found that the amount of periphyton was significantly related to *Deleatidium* abundance. Substrate with a slippery film of periphyton appeared to be the best habitat, clean substrate the worst, and substrate with a obvious layer of periphyton intermediate. The supply of plankton-derived food (seston) can result in an increase in the number of filter-feeders in a river downstream of a reservoir, as occurs in some natural lake outlets (Harding 1994).

Benthic invertebrates tend to be most abundant in average water depths, where there is coarse substrate and adequate light penetration or a food source, such as seston from a lake. Most benthic invertebrate species are not abundant in pools nor are they abundant in the stream margins where they can be exposed to the air by natural flow fluctuations (Jowett 2003). Pools have low velocities and contain little periphyton because the substrate is relatively fine and light penetration limited.

Trout can obviously live and feed in deep water, as they do in lakes. However in many rivers, the deep water is in pools where there are few drifting invertebrates available as food for the trout, so that trout tend to be found in runs or heads of pools below riffles. In the Clutha River, trout and their food source (filter-feeding invertebrates) were in water about 3 m deep.

3.2.6 Models of abundance

Brown trout abundance model

Using data collected for the "100 rivers survey", Jowett (1992) developed a model of the abundance of large brown trout in New Zealand rivers. Average habitat suitability (HSI) for trout habitat (space), and HSI for food production (food), plus seven other variables explained 87.7% of the variation in numbers of large brown trout in 59 New Zealand rivers. The model was:

Trout abundance per hectare = exp(1.095+3.2*trout HSI at low flow+0.132*%lake area-0.071*%sand+0.443*cover-26.7*sqrt(gradient)+3.7*food producing HSI-0.002*elevation-0.007*developed land)-1

The most important variables were HSI for trout habitat, HSI for food production, instream cover, and winter water temperature as an overriding factor. Other significant variables included percent sand substrate, % area of lakes in catchment, elevation, gradient, and percentage of the catchment developed for agriculture. Sand substrate is very poor food producing habitat and it is rare to observe brown trout in areas where the predominant substrate is sand; lake outlets are well known for their high trout stocks, probably because of the excellent food supply; the other factors also seem to be related to food production.

Perhaps the most interesting concept in the brown trout model is the flow at which the instream habitat variables (HSI) are calculated. In a natural river, flow and habitat vary with time. The quality of habitat was calculated at three flows; mean annual low flow, median flow, and mean flow. The quality of adult trout habitat at mean annual low flow was more closely related to trout numbers than the habitat available at the higher flows. This suggests that the quality of trout habitat at low flow is one of the limiting factors in the system – a kind of bottleneck. The quality of habitat for food production (benthic invertebrate habitat) at median flow was more closely related to trout numbers than the amount at either low or mean flow. Thus, it appears that even if there is adequate habitat at low flows, a trout population is likely to be controlled by the food producing capacity of the river rather than the capacity during more extreme events. Ideally, the food producing capacity should be derived by integrating the amount of habitat over the full flow regime of the river. However this was not available at the time and habitat at median flow appeared to be a reasonable estimate.

Bioenergetics trout model

Hayes et al. (2016) bioenergetics model of trout abundance assumes that invertebrate drift will increase with flow and predicts that trout abundance will increase with flow until velocities exceed those in which trout can feed. The bioenergetics model is a sophisticated mechanistic model. It uses similar concepts to those embodied in Chapman's (1966) paper describing food and space as determinants of salmonid abundance and Jowett's (1992) study that found that trout abundance was related to both suitable habitat for adult trout and the amount of food available to them, either as benthic invertebrate biomass or as food producing habitat. Although drift is the most common source of food for trout, they can also feed by foraging for invertebrates on the river bed or aquatic plants.

Invertebrate drift derives from invertebrates that live on the bed of the stream and at normal flows the number of invertebrates drifting is relatively small compared to the number on the stream bed. The distances that invertebrates drift are also relatively small. Although drift derives from the benthos and many species have been reported to drift in a density dependent way, there is no general relationship between drift density and benthic invertebrate density (Brittain & Eckeland 1988; Shearer et al. 2003). It is generally accepted that invertebrate drift increases with water velocity during spates and that an increase in flow after a long period of stable flow will cause an increase in drift (Brittain & Eckeland 1988; Irvine 1985). Drift can also increase with an increase in turbidity or a reduction in flow. High levels of drift occur during floods because of substrate disturbance. Habitat analyses indicate that higher flows will usually increase benthic invertebrate density, so higher flows are likely to increase drift rates. Measurements in the Mohaka, Waingawa, Mangles, Clutha and Waitaki indicate that benthic invertebrate density begins to decline at locations in the river where the velocity exceeds about 0.8 m/s.

Benthic invertebrate production model

The benthic production model is a conceptual time series model of hydraulic conditions (velocity, shear stress, dimensionless shear stress, substrate stability, habitat suitability) and the influence of those parameters have on benthic abundance. The model predicts indices of abundance and habitat suitability. For each time step, hydraulic parameters are calculated at each measurement point of the river model and the abundance of benthic invertebrates at the measurement point is adjusted according to a set of biological processes. The processes that are considered are population growth through immigration/reproduction, population loss through emigration/mortality, and population movement within the reach as habitat suitability changes.

The benthic growth process comprises two mechanisms, colonisation through drift of invertebrates and growth through population increase (e.g., egg-laying by insects and physical growth of invertebrates).

The factor influencing growth is habitat suitability with abundance increasing logistically towards an asymptotic maximum determined by the suitability of the hydraulic conditions at the measurement point.

Population change is influenced by three factors. If the population is greater than can be supported by the habitat suitability then the population will decline through emigration. If the measurement point is exposed to the air then 100% mortality is assumed, and if the shear stress is sufficient to move the average substrate size, 100% mortality at the point is assumed. Seasonality can be accounted for by varying the growth rate sinusoidally through the year.

The input data are a flow series, a model of the river hydraulics and substrate and a habitat suitability curve. The input parameters are the summer growth rate per day (r default 0.025), the migration rate as a proportion of the summer growth rate (default 0.5), and the ratio of winter to summer growth rates. An initial abundance between 0 and 1 is also specified (default 0.4 of the asymptotic maximum).

Abundance appears to increase faster after substrate disturbance than would occur with recolonisation of an inundated or totally clean substrate. This has been described as resilience and may be because invertebrates can shelter within the substrate matrix. This is modelled by using a higher initial growth rate for recolonisation after disturbance than after inundation.

3.2.7 Water quality

High water temperatures are often associated with low flows. This is because the climatic conditions conducive to low flows are also likely to result in high water temperatures and not because low flows cause high water temperatures. Maximum water temperatures usually occur in summer when the weather is warm and dry and this usually coincides with periods of low flow.

The effect of flow on water temperature can be predicted by models that are based on well known principles of physics (e.g., Hockey et al. 1982; Theurer et al. 1984; Rutherford et al. 1997). The heating and cooling of river water results from solar radiation after allowing for shade, radiation from adjacent banks and vegetation according to air temperature, radiation from the water surface, evaporative cooling dependent on relative humidity and wind velocity, conduction to and from the stream bed depending on ground temperature and conduction to and from water surface depending on air temperature.

As a river flows downstream it is heated by solar radiation and cooled by evaporation[18] until it reaches an equilibrium where the daily heating equals the daily cooling. If the amount of shade changes, radiation reaching the rivers changes and the equilibrium temperature and water temperature will change. If the source of water is cold, such as from a spring in summer, water temperatures will gradually increase as the water flows downstream until equilibrium temperature is reached. If the flow and velocity of the water is reduced, the point at which equilibrium temperature is reached will move further upstream. However, equilibrium temperature is usually reached within a few kilometres in small streams (Rutherford et al. 2004) so that daily mean water temperatures are usually at equilibrium and changes in flow have little effect on the daily mean temperature.

The TRC has a riparian programme which will have a number of ecological benefits. Riparian vegetation and shade will:

- decrease water temperatures (Rutherford et al. 2004),
- improve the benthic invertebrate composition (Jowett et al. 2009),

[18] These are only the main heating and cooling mechanisms. Net heat flux is calculated as the sum of heat to or from long-wave atmospheric radiation, direct short-wave solar radiation, convection, conduction, evaporation, streamside vegetation (shading), streambed fluid friction, and the water's back radiation.

- increase instream habitat diversity (Jowett et al. 2009), and
- provide cover for some fish species (Jowett et al. 2009).

Monitoring of the riparian programme in the Kapoaiaia Stream (TRC 2017) has shown significant improvements in the macroinvertebrate communities and periphyton cover overall, as well as a significant decrease in temperature. Similarly, a NIWA study (Graham et al. 2018) of Taranaki ring plain rivers has shown that riparian planting improved macroinvertebrate indices at 59 monitoring sites and decreased *E. ecoli* concentrations at 11 monitoring sites.

The magnitude of the flow only has minimal effects on the daily mean water temperature. However, flow will influence the maximum and minimum temperatures over a 24 hour period, especially at low flows when the water is shallow. A reduction in flow will increase diurnal fluctuation because when the water is shallow it will heat faster during the day and cool faster during the night. The night cooling balances the day heating so that there is little change in daily mean water temperature. Usually, a flow reduction can increase maximum daily water temperatures by up to 1°C and the effect on daily mean water temperature is insignificant. In contrast, stream shading can alter temperatures by 2°C or so.

Dissolved oxygen concentration (DO) can be influenced by flow. Diurnal fluctuations in DO are affected by three fundamental processes: re-aeration, plant and bacterial respiration, and photosynthesis. Low concentrations of oxygen can occur in early morning if streams containing dense plants (aquatic macrophytes). These plants absorb oxygen during the night (respiration) and give off oxygen during the day (photosynthesis). Field measurement of diurnal oxygen fluctuations are used to obtain estimates of re-aeration rate and rates of photosynthetic production and respiration by plant and micro-organisms.

Flow influences this process by changing the re-aeration rate – the rate of oxygen exchange between the stream and atmosphere. Re-aeration increases as velocity and turbulence increases, but the formulation of this relationship will vary from stream to stream making the prediction of oxygen concentration uncertain at low flows. However, there are relatively few streams where the density of aquatic plants is sufficient to cause lethal DO during low flows.

3.2.8 Summary of research

The research carried out in New Zealand has long highlighted the importance of food availability to trout. Allen (1951) stressed the importance of food for the Horokiwi Stream trout population. Jowett (1992) found that the density of adult brown trout in 59 rivers was related to an index of food abundance and that there was a high correlation between trout abundance and benthic invertebrate biomass. Juvenile brown trout were also more abundant where benthic invertebrate density was high (Jowett et al. 1996). The three year study of trout in the Kakanui River by Jowett & Hayes (1994) concluded “food supply and suitable habitat for the production of trout food are aspects that should be considered when evaluating instream flow requirements”.

Hayes bioenergetics model (2016) shows similar results to the statistical model of Jowett (1992). Both models show that maximum trout numbers are likely to be supported by a flow which is higher than the flow that provides maximum adult trout habitat. Both models predict that a reduction in low flow will usually cause a decline in trout abundance.

In contrast, native fish do not seem to be so dependent on food availability. Jowett et al. (1996) found no correlation between native fish density and benthic invertebrate density. Graynoth (2007) found no evidence that low flows in the Waipara River were affecting the ability of native fish to feed. However, most native fish do live in riffles where benthic invertebrate densities are highest so maintaining good riffle habitat will benefit both native fish and benthic invertebrates.

3.3 Principles for setting minimum flows and allocation

3.3.1 Minimum flow

The minimum flow is a protection mechanism to reduce the effect of abstractions on aquatic biota and other values, by setting a value below which abstractions cease or water restrictions are applied. In setting the minimum flow the concept is that it should provide an acceptable level of protection for the stream (Beecher 1990; Jowett 1997). Methods that set minimum flows are sometimes called "standard setting" (Annear et al. 2002).

As noted in Section 2, there are many reports that discuss methods for determining the effects of flow alteration but few describe how to progress from effects to minimum flow. The technical report (BECA 2008) associated with the proposed NES for ecological flows (MfE 2008) describes a hierarchy of methods. These range from simple hydrological rules of thumb to the application of bioenergetics models. Selection of a method depends on the complexity of the flow change (degree of hydrologic alteration) and the environmental values that are likely to be affected.

Methods that predict how stream characteristics change with flow are termed "incremental" (Annear et al. 2002). The incremental methods that have been used in New Zealand are:

1. Generalised habitat analysis (e.g., WAIORA), and
2. 1D or 2D instream habitat analysis.

These methods were discussed earlier and are discussed in more detail in Jowett et al. (2008) and Hay & Hayes (2007). In addition, there are models available that can evaluate the effect of flow changes on fish passage, water temperature, dissolved, oxygen, sediment transport, fish bioenergetics, periphyton accumulation, and benthic invertebrate production.

Two standard setting methods for minimum flow tend to be used in New Zealand. These are a percentage of a flow statistic (historic flow method) and methods that show how habitat changes incrementally with flow.

The easiest and probably most common method is to use a percentage of a flow statistic as the minimum flow. The 5-year low flow and 90% of the MALF are examples that have been used in New Zealand. The use of the MALF is preferable to the 5 year low flow because its computation is a simple arithmetic average of the annual minima and there is no need to fit a statistical distribution as required to estimate the 5 year low flow. A 7-day MALF is also better than a 1-day or instantaneous MALF because the 7-day moving mean smoothes any spikes or sudden fluctuations in recorded flow.

There are various ways of setting a minimum flow using incremental habitat methods, from maintaining a maximum amount of habitat, a percentage of habitat at low or median flow (habitat retention), or using a breakpoint (or "inflection point") on the habitat/flow relationship (Jowett 1997). While there is no percentage or absolute value associated with a breakpoint, it is a point of diminishing return, where proportionately more habitat is lost with decreasing the flow than is gained by increasing the flow.

The concept of a habitat retention method is that the minimum flow should retain a percentage of the suitable habitat available at the MALF for a target species. The level of habitat retention can be varied according to the perceived value of the species, as has been done by the Bay of Plenty Regional Council and the Southland Regional Council.

There is often only one minimum flow monitoring site on a river, so that comparisons with nearby streams and rivers must be used to establish flow statistics for sites that do not have a flow monitoring site Natural flows will vary along the length of the river and the same or varying level of protection can be applied along the length of the river, so that the “minimum flow” would be the protection level applied to the estimated natural flow. This means that the “minimum flow” in the headwaters would be less than the minimum flow further downstream. Conversely, if the river were to lose water naturally then the “minimum flow” would be less than that upstream of the losses.

The use of a flow statistic to set a minimum flow is simple, although there can be disagreement about estimates of the flow statistic where there is no flow record. Flow statistics also change with time as more record is collected.

Estimates of flow statistics from ungauged catchments are usually made by comparison with a nearby gauged river or group of rivers draining from a similar source. The simplest way of transferring a flow or flow statistic from one catchment to an ungauged catchment or from a recorder site to another part of the catchment is to scale it by the respective catchment areas. Adjustment for different catchment rainfalls can also be applied to the catchment areas. If there are sufficient flow measurements at the ungauged site, a correlation with the gauged site can be established and this can be used to estimate flows and flow statistics.

Minimum flows based on the percentage of habitat at MALF require field measurements as well as an estimate of the flow statistic MALF. The use of habitat methods is not universally accepted despite the logic behind the method and the validation studies described earlier.

3.3.2 Protection levels

Setting appropriate levels of environmental protection is a world-wide challenge. For example, in Canada, they have a policy of no net habitat loss for salmon. In South-Western Florida the 15% habitat loss protection level used since 2002 was reviewed. They found that “*Numerous programs throughout the world provide instream flow protection, establish minimum flows or levels, or ensure water reservations…. In each case, a determination is made about the limits of permissible water abstraction. Many criteria are based on hydrologic standards, the protection of a single species, or management goal. … Because neither a commonly accepted protection level nor a common measure of protection exists, comparing standards between regulatory agencies remains a challenge.*” The same could be said about New Zealand. Documents like the RMA and NPSFM give general guidance with statements like “minimum acceptable state” and a “healthy ecosystem appropriate to the river type”.

Water management plans rarely discuss the specific level of protection provided by their minimum flows.

Jowett & Hayes (2004) suggest that habitat retention levels should be set according to the perceived value of the fish species and management goals with the ultimate decision decided by consultation in the planning process. Although simple, a single level of protection for a region might not be the best way of managing water resources because not every river is the same. Site-specific studies might show that a higher or lower level of protection should be afforded to a river. The Bay of Plenty Regional Council and Southland Regional Council set protection levels in the water plans and the levels vary between 60% and 100% retention of the habitat available at MALF.

The balance between environmental protection and water use seems to vary between regions. Water short regions tend to value out of stream water use highly and other regions are more focussed on protecting the natural environment. Abstraction occurs in many New Zealand rivers and minimum flows have been applied to most abstractions. One would expect that we have gained some knowledge from this but there are very few documented cases of the effect of abstraction and the effectiveness of the minimum flow. This might suggest that the levels of protection are either appropriate or too conservative.

3.3.3 Allocation

The minimum flow is or should be the primary environmental protection mechanism because the detrimental effect of low flows on most aquatic organisms is shown in the research that has been carried out. A limit on total allocation can also act as a protection mechanism as well as a method of guaranteeing a certain reliability of supply to those granted consents for abstraction of water.

Total allocation affects the hydrology and ecology. The hydrological effects of increased allocation are:

- a reduction in mean and median flow,
- an increase in the duration of low flows and the amount of time at minimum flow, but
- no appreciable change in the magnitude and frequency of floods and freshes.

The main ecological effect of increased allocation is:

- a decrease in invertebrate production.

Total allocation and the minimum flow interact as protection mechanisms. If the total allocation is low, there is little point in setting a minimum flow. This was the case in the Motueka Conservation Order which allows 12% of the river flow to be abstracted without any minimum flow.

If total allocation is high then abstraction will reduce the river flow to the minimum each year, and the minimum flow becomes the ‘new MALF’ that limits fish populations. In such a case, the minimum flow would be set to provide an adequate level of protection with the expectation that flows are likely to reach the minimum flow each year.

The situation between these two extremes is when a moderate allocation results in the minimum flow being reached in some years but not in others. In this case the ‘new MALF’ is somewhere between the natural MALF and the minimum flow, and the difference between them can be regarded as the level of protection provided by the combination of the minimum flow and total allocation.

Little research has been carried out into methods for setting an allocation limit and in the past the limits have tended to be rather arbitrary and often set to provide reliability of supply to consent holders rather than for environmental purposes. For example, the Bay of Plenty Regional Council have allocated the flow difference between the minimum flow and the 5-year low flow so that consent holders would only have restrictions once every 5 years. Other councils have set a minimum flow at 95% of the 5 year low flow and allocated 5% of the 5 year low flow. Because the allocation with these methods is small, they are unlikely to have any environmental effect. The term “over allocation” simply means that more water has been allocated than the arbitrary limit. It does not mean that that over allocation will have a discernible environmental effect.

The interaction between the effects of allocation and minimum flows means that the level of protection for minimum flows should be related to the total allocation and the combined effect assessed. In theory, any combination is possible – from high allocation with a high minimum flow to low allocation with a low minimum flow.

4 Taranaki Regional Council Minimum Flow and Allocation

The minimum flow and allocation in the Council's Draft Plan is based on default recommendations in the proposed National Environmental Standard (NES) for ecological flows (MfE 2008).

The technical document supporting the NES (BECA 2008) does not discuss minimum flows, allocation or levels of protection. It sets out methods that could be used to help evaluate the physical and ecological effects of flow change. Many of the methods specified for high value steams with a high degree of hydrologic alteration are not necessary for typical water consents.

The discussion document (MfE 2008) specifies a default minimum flow and allocation based on stream size that would be used if no alternatives were specified by a Regional Council. The origin of these values is not specified in the report, but they were conservative values agreed to by a committee comprising representatives from Regional Councils, DOC, recreational canoeing, , Fish & Game, farming, irrigation, hydroelectric energy, Ngāi Tahu and the Ecologic Foundation. The minimum flow recommendation was conservatively based on the maximum levels of protection (90% of the habitat available at MALF) suggested by Jowett & Hayes (2004) and the principle that flow abstraction will have a relatively greater effect in small streams than in large rivers.

The MALF is the average annual minimum flow calculated as a running mean over a number of days. The following calculations are based on the 7 day MALF, except for the fish protection level which is based on a longer time period – the 30 day MALF.

A minimum of 90% of MALF was specified for rivers with a mean flow less than 5 m^3/s and a minimum of 80% of MALF for rivers larger than 5 m^3/s. The cut-off was based on mean flow rather than median or MALF because in ungauged rivers the mean can be estimated more easily and more accurately than the other hydrologic statistics.

The default minimum flows and allocations were intentionally conservative because they applied nationally to a wide range of rivers with different morphologies and flow regimes. The effect of abstraction varies with flow regime and morphology. The morphology of a river is determined by high flows which occur relatively infrequently, but biota are controlled by low flows which occur every year and for long periods. If the low flows are low compared to normal river flows, the depths and velocities and hence quality of the habitat are significantly lower than normal and any further reduction in flow will compound the detrimental effect. However, if the low flows are close to normal flow, there is relatively little reduction in depth and velocity and potentially less effect when flows are reduced. The relationship between low flows and normal flows is indicated by the ratio of MALF to median flow. In spring-fed, lake-fed and pumice streams, the ratio of MALF to median flow is high, in small east coast rivers the ratio is low and these rivers are most "at risk" from abstraction. In Taranaki, the rivers draining from the NW slopes of Mount Taranaki generally have relatively high ratios of MALF/median but most Taranaki rivers are in the normal range of 0.2-0.4 (Fig. 5).

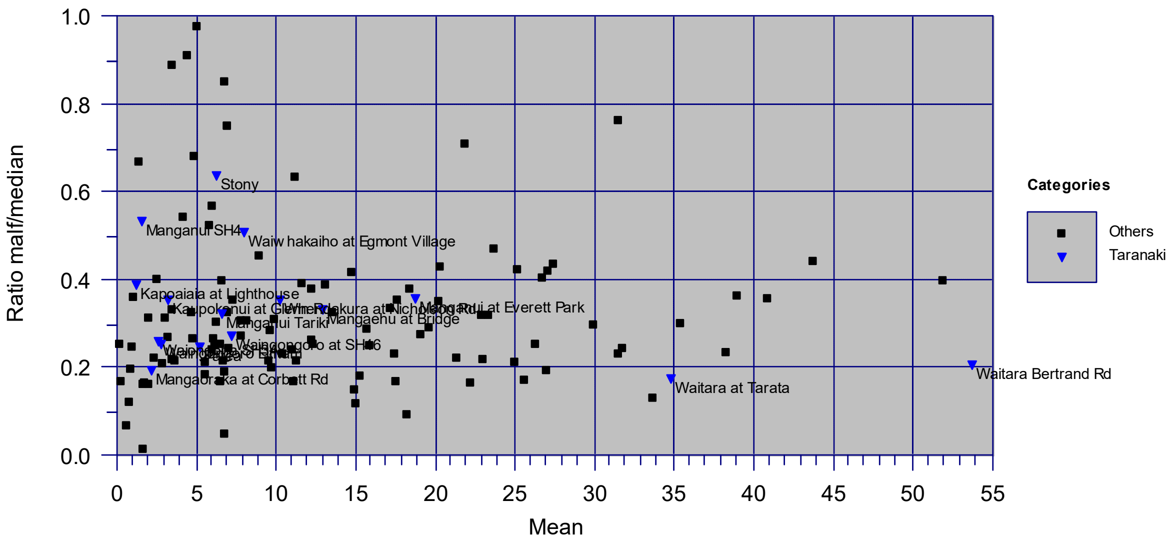
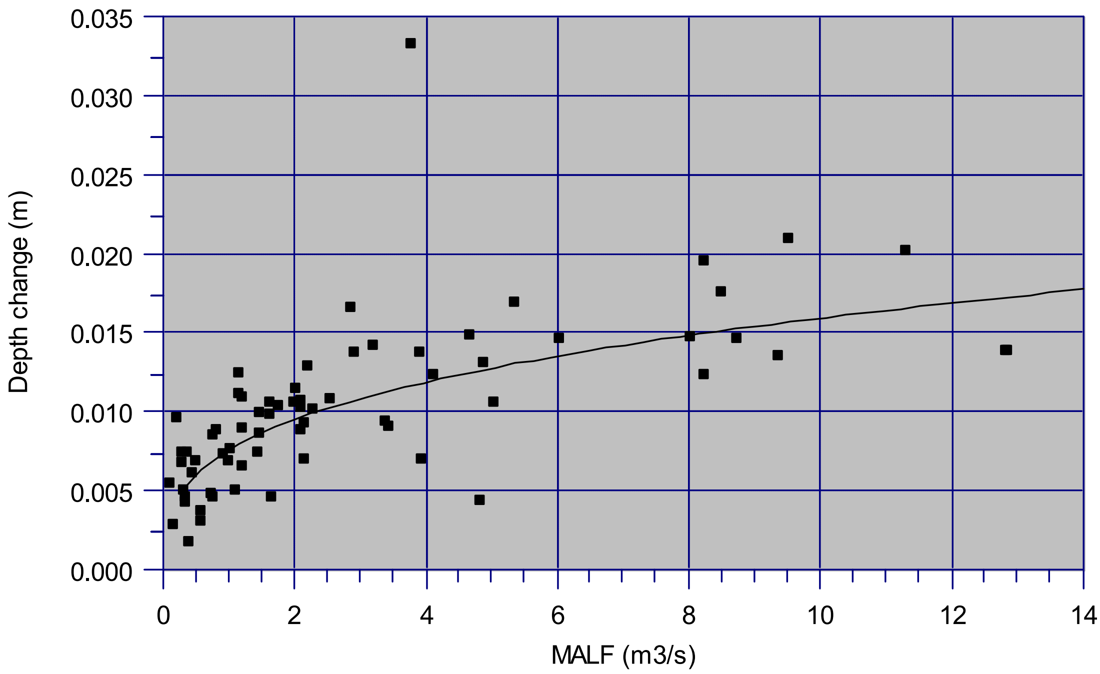


Figure 5: Relationship between mean flow and the ratio of MALF/median flow for Taranaki rivers and rivers elsewhere in New Zealand.

A 10% flow reduction below MALF would be barely detectable by flow gauging and would result in small changes in water depth and velocity. In 74 New Zealand rivers, the average reduction in depth for a 10% reduction below MALF was 10 mm (2.6% of the depth at MALF). For rivers with a mean flow less than 5 m^3/s, the median reduction in depth was 6 mm. The average reduction in velocity was 0.013 m/s (4.4% of the average velocity at MALF). The change in depth and velocity with flow varies with river size, with the amount of change increasing with river size (Fig. 6). This is the reason why the default minimum flow for rivers less than 5 m^3/s is greater than that for larger rivers.



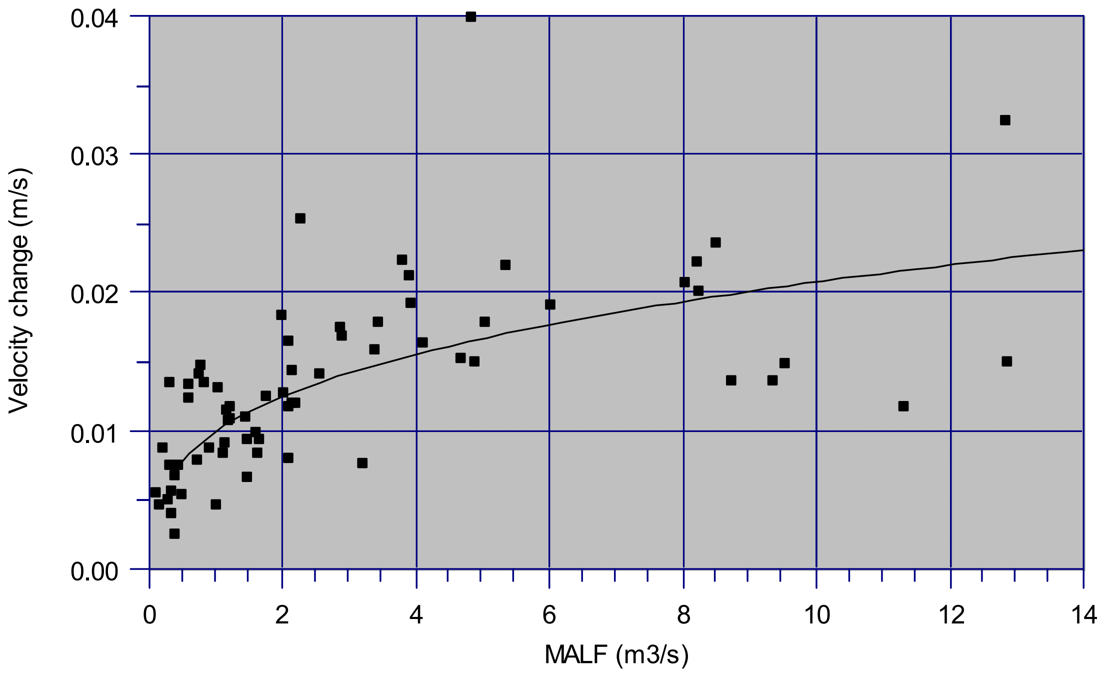


Figure 6: Relationship between change on average depth and velocity and mean annual low flow (MALF) when flow is reduced from MALF to 10% below MALF.

The default allocation specified in the discussion document (MfE 2008) is 30% of MALF for rivers with mean flows less than 5 m^3/s and 50% of MALF for larger rivers. These numbers were based on an analysis of the effects of allocation on periphyton accrual. The length of time since the last flood and fresh determines the amount of periphyton on the stream bed. Nutrient concentration and water temperature will affect the rate of accrual. The total allocation affects the length of time that the flow will be at minimum flow and hence the amount of periphyton that accrues. The length of time between naturally occurring flushing events (floods and freshes) depends on the climate. In the west, there are frequent heavy rainfalls but in the east there can be long periods between flushing events. Analysis of flow regimes in small east coast rivers indicated that 30% allocation would not increase the average time between flushing events sufficiently for nuisance levels of periphyton to accumulate. The effect of allocation on invertebrate production was not considered.

Of the 42 Taranaki rivers with consents to abstract water, allocation is less than 30% of MALF in 59% of rivers and less than 20% in 45% of the rivers. Of the remaining rivers, 20% have 30% to 50% of MALF allocated.

4.1 Flow Management objectives for TRC

The Draft Plan sets out its objectives. The most relevant to setting limits for minimum flows and allocation are:

3. Appropriate use and development

   Freshwater and soil resources in Taranaki are allocated and used efficiently and are available for sustainable use or development to support the social, economic and cultural well-being, and health and safety, of people and communities.

5. Ecosystem health and mauri of freshwater

The life-supporting capacity, mauri, ecosystem processes and indigenous species, including their associated ecosystems, of freshwater are safeguarded from the adverse effects of use and development including through achievement of the freshwater objectives identified in Schedule 2.

8. Freshwater quantity

   Freshwater quantity is maintained at sustainable levels through the management of efficient water allocation and efficiency of use.

9. Natural character

   Natural character of wetlands, lakes and rivers and their margins are protected from inappropriate use and development and the adverse effects of appropriate use and development.

10. Indigenous freshwater biodiversity

   Indigenous freshwater biodiversity is maintained and enhanced overall and areas of significant indigenous biodiversity are protected from the adverse effects of inappropriate use and development.

14. Use and enjoyment of freshwater bodies

   People's use and enjoyment of freshwater bodies, including amenity values, traditional practices is maintained and enhanced, and the health of people and communities as affected by secondary contact with freshwater is safeguarded, including through achievement of the freshwater objectives identified in Schedule 2.

Schedule 2 sets out the states for periphyton and water quality prescribed in the NPSFM. The Draft Plan does not specify a monitoring programme but they monitor benthic invertebrates routinely and are likely to include the 2017 NPSFM requirement for MCI monitoring.

Consideration of these objectives raises the issue of what flow and/or stream characteristic could be used to measure ecosystem health, mauri and biodiversity. One stream characteristic stands out as an indicator of ecosystem health - the state of the benthic invertebrate community. This can be represented by one index, either the MCI or benthic invertebrate density for taxa with high MCI scores.

Benthic invertebrates are used internationally and in New Zealand as a measure of ecosystem health. Benthic invertebrate abundance is related to trout abundance, benthic invertebrates are most abundant in riffles, where native fish are also most abundant, and MCI was identified as the one measure that was most closely related to Maori cultural values (Tipa & Teirney 2003). Benthic invertebrate life cycles are relatively short and for most species not all of their life is spent in water. As a result, their populations can recover from severe events such as floods and droughts.

The effect of the minimum flow and allocation on the flow regime and benthic productivity of a river, in terms of either MCI or total invertebrate density, can be assessed applying the benthic production model to flows over a number of years. This model will predict "production with and without abstraction" so that an appropriate minimum flow and allocation can be based on the loss of production and an appropriate level of protection.

The life cycle of fish is longer than that of benthic invertebrates and the density of trout and native fish, particularly those that are found in swift water, can be limited by low flows if they persist for long enough. The reduction in the 30-day MALF was used as a conservative indicator of the potential effect on fish species. It is conservative because if the density of fish is low, a reduction in habitat is likely to result in a redistribution of fish rather than a loss of fish. It is also conservative for other fish species whose habitat is not affected by flow reductions as much as that of species such as torrentfish and adult trout that prefer swift water.

Various combinations of minimum flow and allocation levels were applied to a representative sample of nine Taranaki rivers to determine the effect on ecosystem health, as measured by the two types of protection level. Minimum flows varying from 60% to 90% of the MALF were tested. A minimum of 60% of the MALF is slightly less than the current minimum flow requirement and 90% can be regarded as a level at which there would be no measurable effect. Allocations of 0 to 50% of the MALF were tested. Currently, there is no allocation limit.

The NPSFM requires regional councils and unitary authorities to establish freshwater accounting systems for both water quantity and quality. The approach taken here is the risk based approach (MfE 2015) whereby the minimum flow and allocation were decided on the basis that they would not cause unacceptable environmental degradation as determined by a method that considers the density of benthic invertebrates with high MCI values. The flow requirements of this criterion are high and will be higher than any habitat requirements for fish species.

4.2 Method of assessing the combined effect of minimum flow and allocation on benthic invertebrate abundance

4.2.1 Development of suitability curves for high MCI score invertebrates

Suitability curves were developed using data from the Rainy, Clutha, Mangles, Waingawa, Mohaka, Whatawhata, Whanganui, and Waitaki rivers. The 11 taxa used to calculate benthic invertebrate density were all relatively common with MCI scores (NIWA 2015) greater than 5 (Table 3). A total of 1431 samples collected in a range of water depths and velocities were available for analysis. Each river was analysed separately to account for differences in numbers between the rivers and an average curve derived (Fig. 7). A filter was applied so that depths greater than 1 m were excluded as few sites contained deep water samples. The curves show a linear decline in species number with depth, an increase in numbers with velocity up to about 0.9 m/s and a decline when velocities exceed 1.35 m/s. The best substrate was cobbles and boulders (categories 6 & 7), with silt (category 2) unsuitable. This suitability model indicates that high quality invertebrate habitat will be shallow water with high velocity and coarse substrate.

Table 3: Invertebrate species and MCI scores used to derive relationships between total number of species and depth, velocity and substrate.

	Species	MCI score
Mayfly	*Aoteapsyche*	8
	Nesameletus	8
	Coloburiscus	9
	Deleatidium	7
Stonefly	*Zelandobius*	7
	Zelandoperla	8
Beetle	Elmidae	6
Caddisfly	*Hydrobiosis*	8
	Olinga	9
	Pycnocentrodes	6
True flies	*Aphrophila*	9

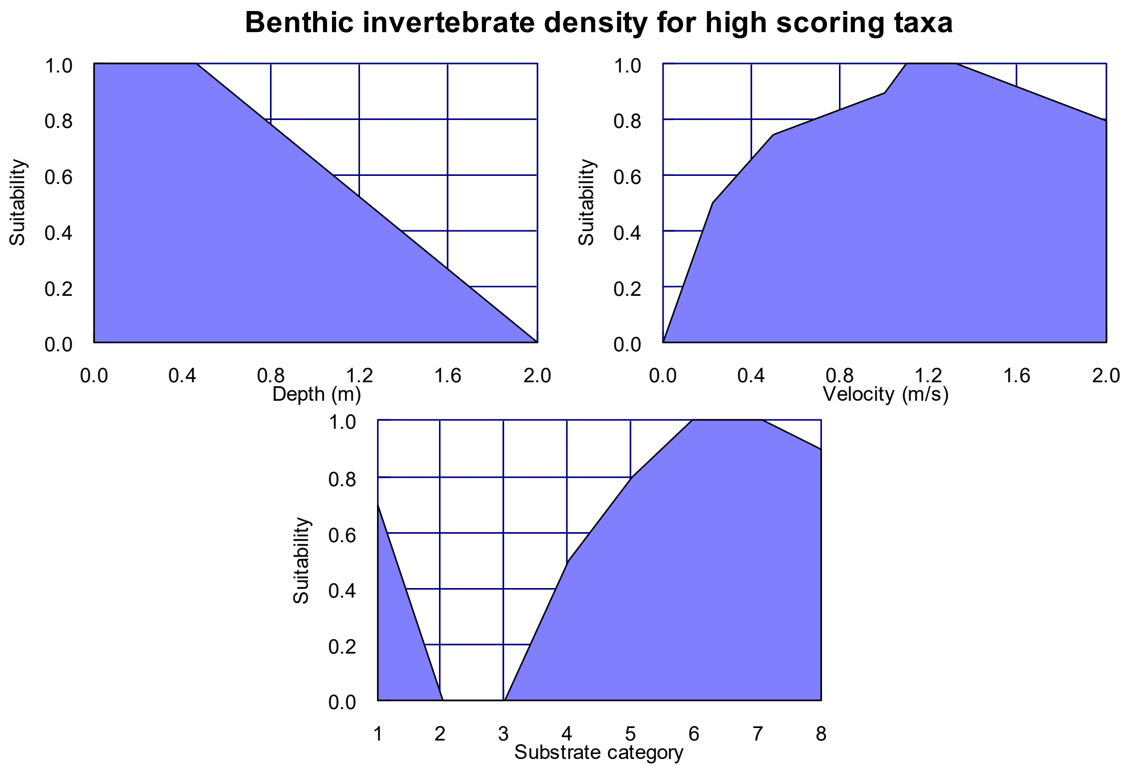


Figure 7: Habitat suitability criteria for density of high MCI score taxa.

4.2.2 Application of high MCI score curves to Taranaki rivers

The effect of flow abstraction with different minimum flows and allocations was evaluated in each of 9 Taranaki rivers. Instream habitat survey data were available for each river. The record of natural river flow was used to simulate the flows that would occur with full abstraction over range of minimum flows and allocations. Daily mean flow data for each river for the 11 year period 2006-2016 inclusive was used to calculate flows without any abstraction and flows with abstraction of up to 50% of MALF and minimum flows of between 50% of MALF and 100% of MALF. It was assumed that whenever the natural flow exceeded the minimum flow as much water as possible was abstracted up to the maximum allocation.

The number of days per year at or below minimum flow was calculated for each combination of minimum flow and allocation as well as the number of days that takes might be restricted. The simulated flows are conservative because actual takes are usually about half of total allocation (MfE 2015). As explained in Section 2, total allocation is the sum of maximum rates, and in most cases maximum rates of take only occur when the demand, whether it is irrigation, town water supply or other form of take, requires it. Thus actual flows with abstraction are likely to be higher than the flows that have been simulated.

The natural river flows and the sets of simulated flows were used to calculate an index of benthic invertebrate density for high MCI score taxa for each day for the 11 year period 2006-2016. The average benthic density was calculated as the average over the 11 year period for each flow regime and contours plotted to show the effect of combined effect of minimum flow and allocation on potential benthic invertebrate density.

The level of protection afforded by each combination of minimum flow and allocation was expressed as a percentage of the average index of benthic invertebrate density for the natural flow regime. Opinions about an appropriate level of protection will differ, but assuming that some reduction in the numbers of high MCI score invertebrate species is acceptable, a retention level of 80-90% (10-20% reduction) is in accordance with the levels of protection in the proposed National Environmental Standard (NES) for ecological flows (MfE 2008).

5 Other matters to consider when setting environmental flow limits

5.1 Submissions

The Draft Plan received a number of submissions which dealt with the issue of minimum flows and allocation. These are shown in Appendix II.

A common concern was how policies 7.7 (allocation) and 7.8 (minimum flow) worked together, both for environmental protection and the effect on reliability of supply. These matters have been addressed in Section 4 of this report.

5.2 Flexibility

The dilemma faced by planners is that in setting minimum flows and allocation, they do not know what the future water uses will be and how often that water will be abstracted. For example, high abstraction throughout the year will reduce benthic production. High abstraction for a short period of time will have little if any effect on benthic production or fish. Thus, consents for emergency or short term (< week) abstraction above the allocation limit will have little effect.

Not all rivers are the same and river specific analyses may show that the effects of an alternative minimum flow and abstraction limit are within an acceptable level of protection. While a default minimum flow and allocation as in the Draft Plan is simple, there should be provision to allow other settings to be adopted after consideration of effects.

5.3 Group schemes

The possibility of forming group schemes should be considered on rivers where there are multiple users and the possibility of low reliability of supply. Group schemes have several advantages. They provide for a more efficient allocation of resources. Basically, the scheme has an allocation, which is often less than the sum of the allocations required by the individuals. On any particular day, the available water is shared amongst the group by the group administrator. Group schemes are inherently fairer than the first in first served system and can reduce consenting costs when multiple consents are combined into one allocation. This will help meet Objective B3 of the NPSFM, which requires councils to improve and maximise the efficient allocation and use of water.

5.4 Exemptions to minimum flows

The Draft Plan allows for water to be taken when the river flow is below the minimum flow in special cases. Such a case might be for town water supplies, where public health concerns would warrant reducing the level of protection being applied to a river. Another case might be an emergency take for fire fighting which does not require a consent.

6 Taranaki Rivers

Hydrological, water quality and benthic invertebrate data were analysed to show a range of parameters for rivers in 2 of the 4 FMUs, ring plain rivers (FMU B) and eastern hill country (FMU C).

There were no streams or rivers with a sufficiently long flow records in coastal terrace streams (FMU D). In some cases, the flow regimes in these streams might be more like spring-fed streams because they may be fed from ground water.

Flows in the river classified as an outstanding water bodies (e.g., Stony River FMU A) have a high level of protection and only allow minimal abstraction, with the 7-d MALF as the minimum flow and a maximum allocation of 10% of MALF. The Stony River drains from Mt Taranaki and its flow regime would be similar to the Waiwhakaiho River.

The following analyses of hydrology, benthic invertebrates and water quality are intended to show general trends and values rather than a comprehensive analysis of all flow and water sampling sites in Taranaki.

6.1 Hydrology

Flow records were converted to daily mean values for the 11 year period 2006-2016 inclusive to give a consistent period of record for comparison. Flows in the Waitara River at Tarata and in the lower Manganui River are affected by the Motukawa hydroelectric scheme (average flow 3.3 m^3/s) and although there is record of the diversions there is too much missing data in the record to allow the flows for these two sites to be naturalised. The amount of runoff in the rivers varies according to the catchment’s exposure and the average catchment elevation. Rivers exposed to the west tend to have high runoff whereas those exposed to the east have low runoff (Table 4). Because of this rivers draining the eastern hill country (FMU D) tend to have less runoff (Fig. 8).

Table 4: Hydrological characteristics of some Taranaki rivers in order of runoff volume.

River	Catchment area (km^2)	Annual runoff (m)	Mean flow(m^3/s)	Median flow (m^3/s)	MALF (7-day) (m^3/s)	FRE3[1]	FMU
Kapoaiaia at Lighthouse	18.6	1.83	1.08	0.69	0.25	14	B
Kaupokonui at Glenn Rd	59.6	1.67	3.16	2.06	0.73	10	B
Mangaehu at Bridge	421	0.91	12.18	6.68	1.98	12.5	D
Manganui at SH3	11.3	4.52	1.62	0.9	0.45	17.5	B
Mangaoraka at Corbett Rd	53.9	1.17	1.99	1.25	0.23	9.9	B
Patea at Skinner Road	81.0	1.92	4.93	3.14	0.75	11.7	B
Waingongoro at SH45	226	1.03	7.41	5.31	1.32	8.2	B
Waiongana at SH3	38.64	2.03	2.49	1.45	0.38	14.7	B
Waitara at Tarata*	704.3	1.36	30.29	14.36	-	-	D
Waiwhakaiho at Egmont Village	61.2	3.94	7.76	3.89	1.83	17.9	B
Whenuakura at Nicholson Rd	443.8	0.71	9.95	5.19	2.03	13.4	D

[1] Annual frequency of floods/freshes greater than 3 times the median
* 3.3 m^3/s from the Motukawa PS subtracted from recorded flow.

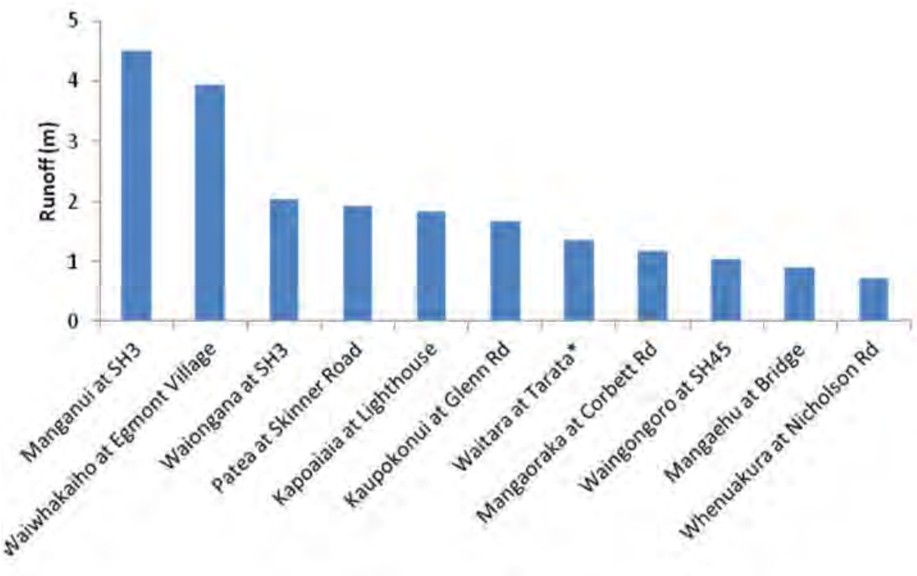


Figure 8: Annual runoff variation in nine Taranaki rivers.

6.2 Fish species

The New Zealand freshwater Fish database contains records of fish caught in New Zealand rivers. Rivers with access to the coast are dominated by diadromous fish species, which migrate from the sea as juveniles and spend their adult lives in freshwater. In general, a similar species assemblage is found in each of the nine rivers with longfin and shortfin eels, brown trout, common bullies and inanga in most rivers. The species list is probably not comprehensive and additional sampling is likely to find that more native fish species are present than are listed in Table 5. For example, although torrentfish have not been reported in all rivers (Table 5, Fig. 9), they are likely to be present in all rivers with access to the sea. The Mangaehu Stream and upper Patea River sites are upstream of the Patea Dam and diadromous fish populations will be impacted. The Patea dam monitoring report (TRC 2018) shows that large numbers of elvers and good numbers of koaro and banded kokopu have been transferred upstream. Monitoring of the upstream fish populations has shown that longfin and shortfin eel populations had both increased in abundance, and had an improved size class distribution since the 2012 survey was completed. In addition, adult koaro were recorded in the upper Patea River, a species that had died out in the upper catchment prior to the change in transfer methodology. However, there was no improvement in the banded kokopu population.

Table 5: Number of occurrences of fish species in nine Taranaki rivers. The number refers to the number of records that report the occurrence of the species and reflects the sampling effort rather than the number of fish found. "YES" indicates that the TRC has recorded the species as present, although not yet recorded in the New Zealand Freshwater Fish Database.

Species	Kapoaiaia	Kaupokonui	Manganui	Mangaoraka	Tangahoe	Waingongoro	Waiongana	Waiwhakaiho	Whenuakura
Banded kokopu	1	1		5			7	3	
Bluegill bully								2	
Brown mudfish						22			
Brown trout	8	12	43	7		33	22	32	2
Common bully	1		10	3	2	8	4	14	2
Common smelt		1				3		1	2
Crans bully			60			6		1	1
Giant bully					1			1	
Giant kokopu	1				1	1			
Inanga	1	1	3	8	2	YES	9	7	2
Koaro		1					3	10	
Lamprey	YES	1			YES	1	1	2	
Longfin eel	11	18	74	14	1	28	50	74	4
Rainbow trout		YES				12			
Redfin bully	12	10	14	8	2	5	28	48	2
Shortfin eel	5	3	5	10	1	5	19	6	
Shortjaw kokopu	1	YES	3	3			5	1	1
Torrentfish		YES	10		2	4	3	11	1
Upland bully			4			7			1

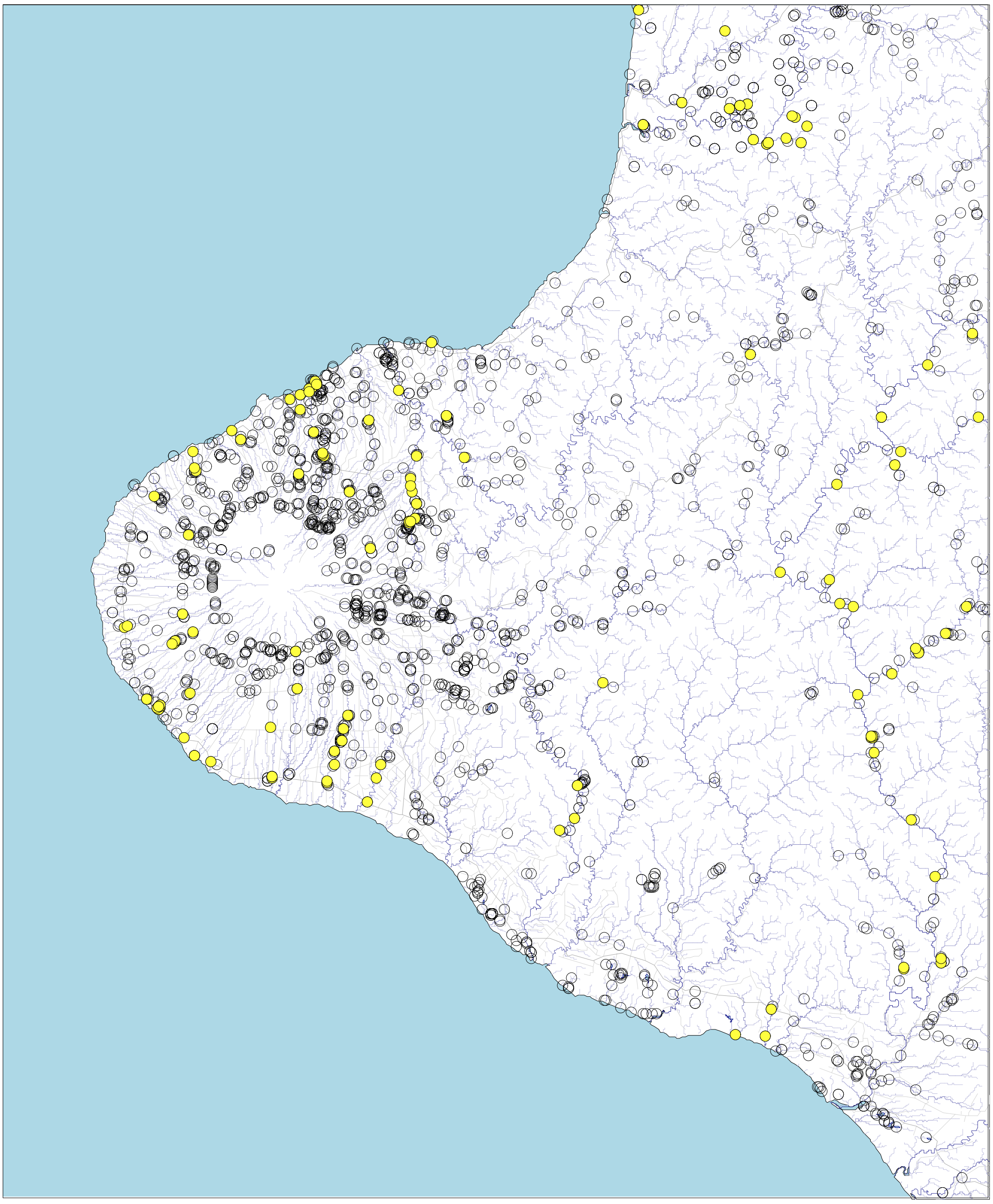


Figure 9: Torrentfish distribution in Taranaki rivers. Torrentfish locations shown as yellow circles, sampling sites as open circles.

6.3 Water Quality

Water quality has been regularly sampled at some sites and for some parameters since 1980 but there are relatively few samples collected from the Kapoaiaia and Tangahoe, so rankings for these sites cannot be considered definitive (Table 6). The four sites in FMU D were the most turbid (Fig. 10), as would be expected with sedimentary rock catchments. The only significant statistical difference in median water quality parameters between the 4 FMU D sites and the 6 FMU B sites was for turbidity (Kruskal-Wallis, P=0.01).

Table 6: Water quality measurements in ten Taranaki rivers. N = number of samples.

River	Conductivity @ 20'C (mS/m)		Dissolved reactive phosphorus (g/m^3)		Nitrite/nitrate nitrogen (g/m^3)		Ammoniacal nitrogen (g/m^3)		Turbidity (NTU)	
	N	Median	N	Median	N	Median	N	Median	N	Median
Kapoaiaia at Lighthouse	6	11.9	6	0.030	6	0.71	6	0.007	4	1.2
Kaupokonui at Glenn Rd	243	9.8	48	0.017	105	0.50	238	0.017	133	1.1
Mangaehu at bridge	269	9.9	279	0.006	252	0.10	274	0.012	147	4.3
Manganui at Bristol Rd bridge	277	10.0	2	0.006	2	0.30	1	0.016	158	0.8
Mangaoraka at Corbett Rd	277	14.5	266	0.009	241	0.86	267	0.021	150	2.1
Tangahoe below railbridge	3	23.2	1	0.026			1	0.037	2	6.3
Waingongoro at SH45	271	16.4	260	0.053	257	1.89	264	0.032	155	3.2
Waitara at Autawa Rd	27	8.8	27	0.007	26	0.16	27	0.018	26	19.0
Waiwhakaiho at Egmont Village	319	12.6	278	0.025	243	0.12	279	0.007	147	0.7
Whenuakura at Nicholson Rd	28	18.9	28	0.016	26	0.36	28	0.027	26	34.0

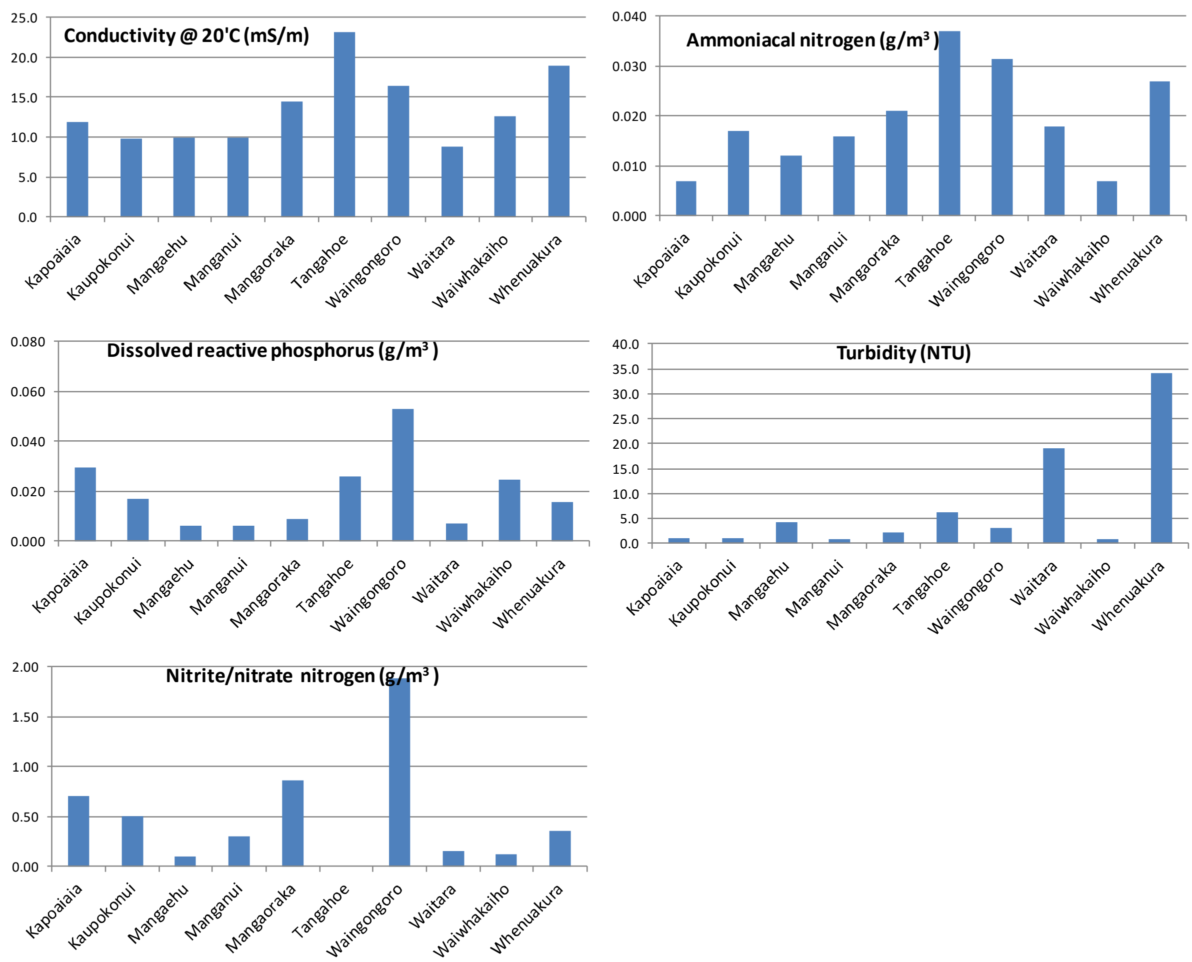


Figure 10: Water quality variations of median values in ten Taranaki rivers.

All available water quality were analysed and it is noted that the water quality has improved with time at some sites such as the site on the lower Waingongoro River (Fig. 11).

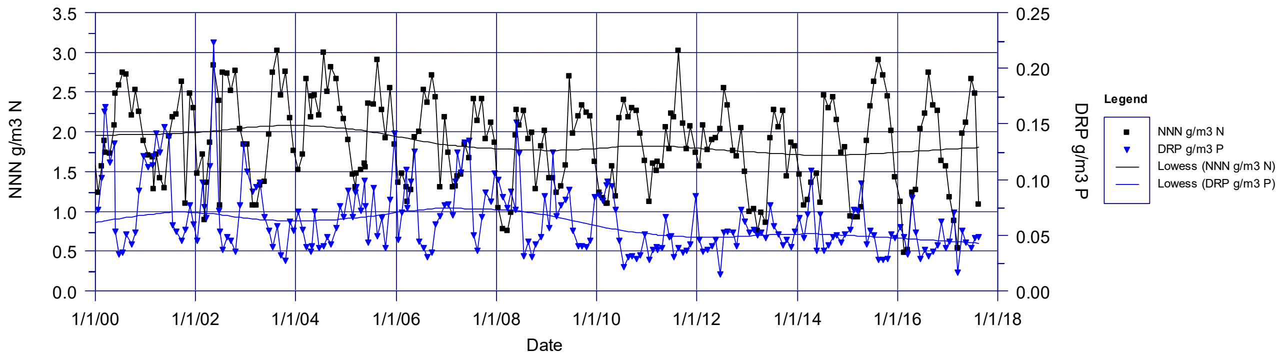


Figure 11: Waingongoro reduction in concentrations of dissolved reactive phosphorus and nitrite/nitrate nitrogen with time.

6.4 Benthic Invertebrates

Benthic invertebrate samples have been collected by kick sampling twice yearly since about 1996. There does not appear to be any clear pattern in the benthic invertebrate indices and there is not a lot of variation between the highest and lowest values. The proposed amendments to the National Policy Statement for Freshwater Management (2017b) suggest that an MCI of less than 80 would require the Council to investigate the reason for the low value and to take measures to increase it if caused by other than natural processes. There is relatively little variation in the two measures of stream "health" MCI and %EPT, the percent of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) in a sample (Table 7, Fig. 12). MCI values in ring plain rivers and their relationship with elevation and distance from source are discussed in detail in Stark & Fowles (2009).

Table 7: Measures of stream "health" MCI and %EPT (percent of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) in a sample) in ten Taranaki rivers. N = number of samples.

River	**N**	**% EPT taxa**		**MCI (national)**		**MCI (Taranaki)**	
		Median	Range	Median	Range	Median	Range
Kapoaiaia at lighthouse	36	32	11-47	89	75-103	86	75-101
Kaupokonui at Glen Rd	44	37.5	14-57	93	70-114	90	66-110
Mangaehu at Bridge	44	40	13-60	94	77-108	91	77-104
Manganui at Bristol Rd bridge (Waitara)	43	45	29-60	102	81-120	98	76-115
Mangaoraka at Corbett Rd	43	37	9-55	92	78-107	90	75-105
Tangahoe below railbridge	21	38	25-53	96	83-107	94	78-103
Waingongoro at SH45	45	38	15-56	97	75-111	94	73-106
Waitara at Autawa Rd	4	44.5	42-50	102	96-106	98	95-102
Waiwhakaiho at Egmont Village	43	53	32-65	117	87-134	110	87-125
Whenuakura at Nicholson Rd	4	31	28-34	93.5	86-98	86.5	81-94

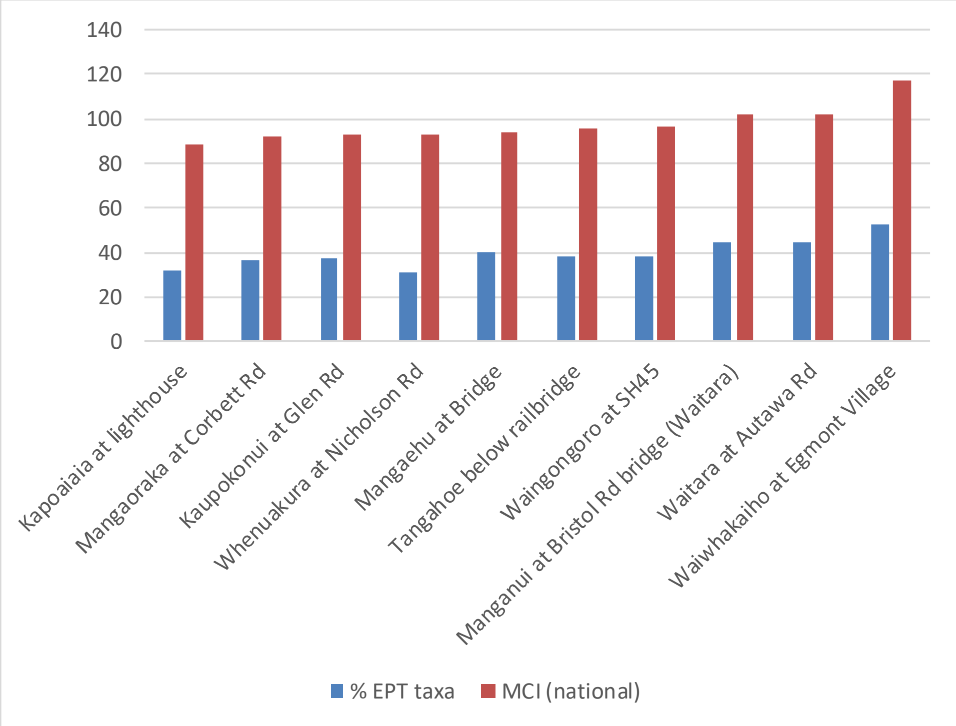


Figure 12: Variation of measures of stream "health (national MCI and %EPT) in ten Taranaki rivers.

7 Method for determining environmental flow requirements

7.1 Minimum flows and allocation to protect the state of the benthic invertebrate community

The combination of minimum flow and allocation affects the "health" of the river, as indicated by the average density of invertebrate taxa with high MCI scores.

Minimum flow and allocation affects the amount of time that the flow is at or below the minimum flow. This is sometimes called "flat-lining, but it is not detrimental unless the flow is "flat-lined" for more than about 30 days without an intervening fresh. This is unlikely in Taranaki rivers where there are frequent freshes (FRE3 >8 as shown in Table 4).

In order to abstract water without restriction, the river flow must be equal to or higher than the minimum flow plus the total allocation. The reliability of supply is the average number of days per year that the flow is less than the sum of the minimum flow and allocation. Total restrictions apply when the river is at or less than the minimum flow.

Nine rivers with mean flows (Table 8) varying from 1.08 m^3/s (Kapoaiaia Stream) to 7.76 m^3/s (Waiwhakaiho River) were analysed.

For each river, flows with the various combinations of minimum flow and allocation were simulated from instream survey data and natural river flows, assuming that all allocated water was abstracted whenever possible. This is conservative because it is unlikely that the maximum abstraction would occur all through the year, and in many cases abstraction is unlikely to reach the maximum allocated.

Instream habitat survey sites and long-term flow records were not necessarily collected at the same locations (Fig. 13). Factors used for estimating values for rivers without flow recorders at the instream habitat site are listed in Appendix II.

Table 8: Nine rivers with instream habitat survey data that were analysed to determine the effects of minimum flow and allocation on the index of benthic invertebrate density for high MCI scoring taxa and their estimated means and 7-day mean annual low flows (MALF).

River	Mean flow (m^3/s)	MALF (m^3/s)
Kapoaiaia Stream at lighthouse	1.08	0.25
Kaupokonui River at Skeet Road	1.58	0.375
Manganui River at Croyden Road	4.17	1.16
Mangaoraka River at Corbett Road	1.99	0.23
Patea River at Stratford	1.64	0.25
Tangahoe River below railbridge	4.33	0.972
Waingongoro River at Normanby	6.45	1.15
Waiongana Stream at SH 3A	2.49	0.38
Waiwhakaiho River at Egmont Village	7.76	1.83

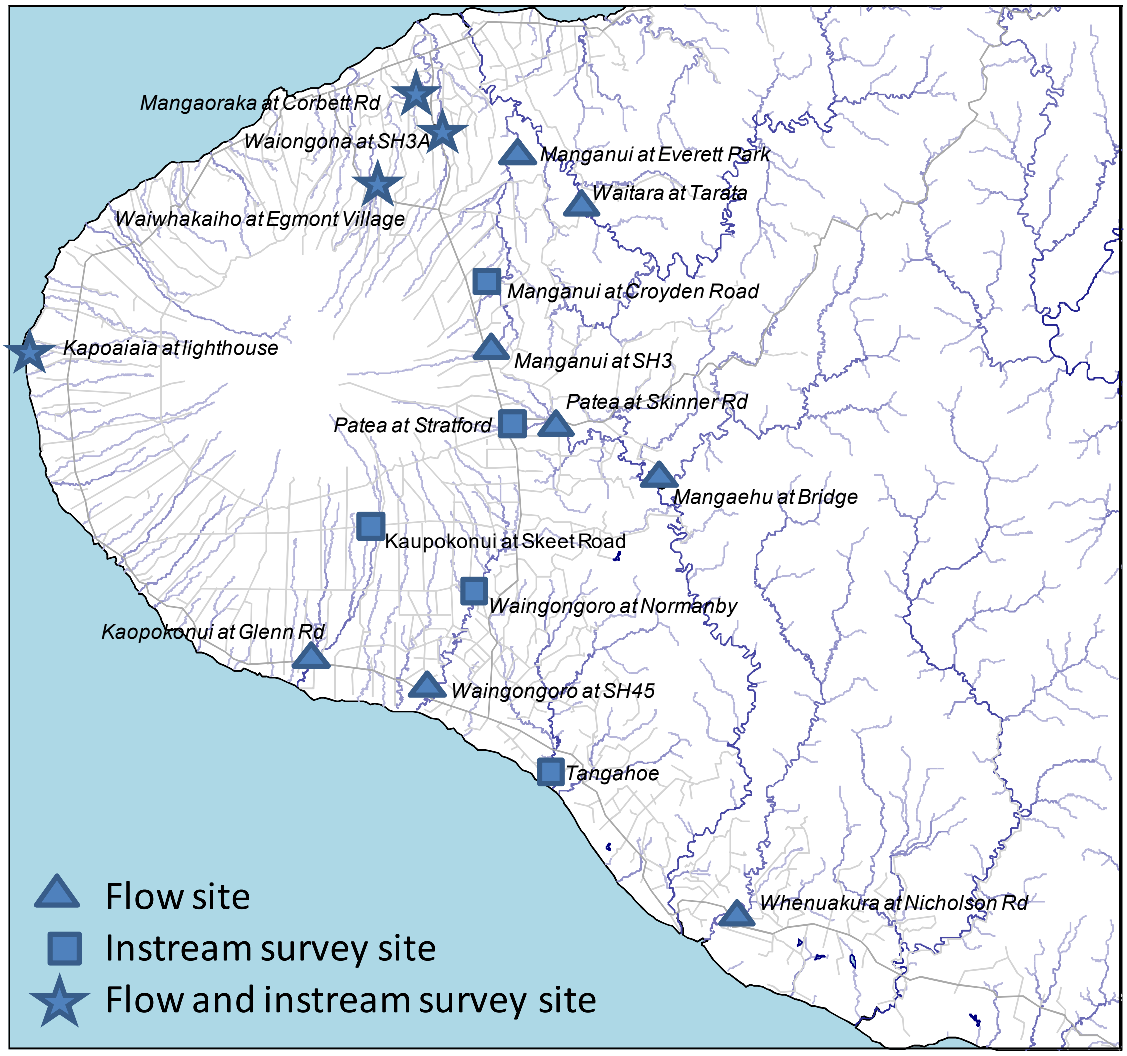


Figure 13: Location of flow monitoring sites and instream habitat surveys mentioned in text.

The benthic invertebrate protection level is the index of benthic invertebrate density for high MCI scoring taxa with full abstraction as a percentage of the index of benthic invertebrate density for high MCI scoring taxa without any abstraction calculated over 11 years. The number of days per year on which abstraction would be partially restricted and the number of days on which there would be total restriction of abstraction were also calculated over the 11 year period. The average index of benthic invertebrate density for high MCI species and the number of days per year that water restrictions would apply were averaged over the rivers.

The protection level for the benthic invertebrate community varied from 98% with a minimum flow of MALF and 10% abstraction to 77% for a minimum flow of 50% of MALF and 50% abstraction (Table 9, Fig. 14). There was relatively little variation between rivers as indicated by the standard deviations.

Results for each river are shown in Appendix II.

Table 9: Average benthic invertebrate protection levels (as % of benthic index at MALF) and standard deviations for minimum flows from MALF (100%) to 50% of MALF and allocations of 10-50% of MALF.

Allocation as % MALF	Minimum flow as % MALF					
	100	90	80	70	60	50
50	92.0 ± 4.0	89.3 ± 3.9	86.6 ± 4.4	83.4 ± 4.0	80.1 ± 4.6	76.8 ± 5.0
40	93.3 ± 3.2	91.0 ± 3.3	88.6 ± 3.9	85.8 ± 3.6	83.2 ± 4.1	81.1 ± 4.3
30	94.8 ± 2.5	92.8 ± 2.6	90.9 ± 3.2	88.6 ± 3.1	86.8 ± 3.3	85.4 ± 3.4
20	96.2 ± 2.0	94.6 ± 2.2	93.1 ± 2.1	91.7 ± 2.2	90.9 ± 2.4	90.4 ± 2.1
10	97.8 ± 1.4	96.9 ± 1.4	96.2 ± 1.4	95.5 ± 1.4	95.2 ± 1.3	95.0 ± 1.2

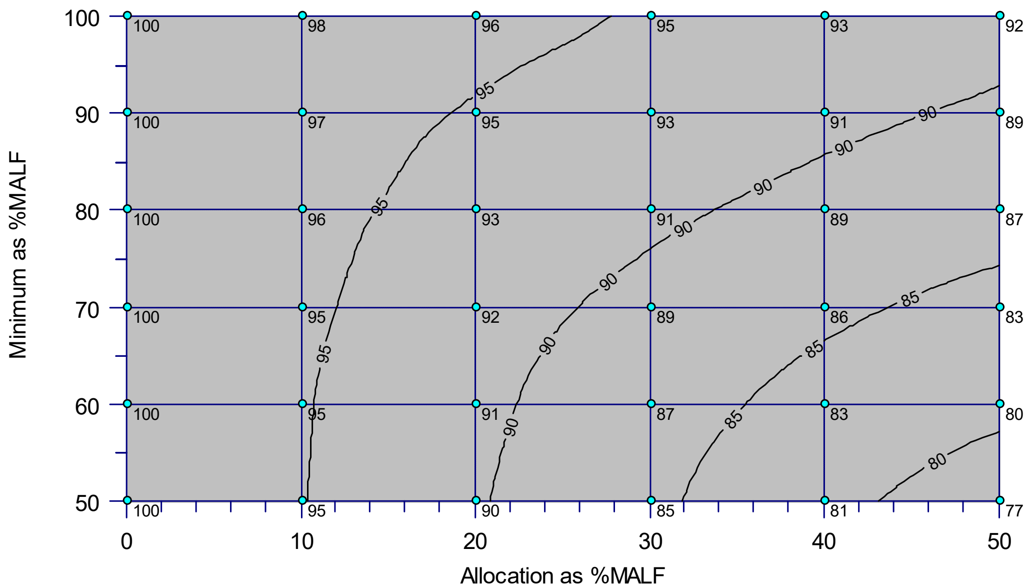


Figure 14: Contours of average percent retention in density of high MCI invertebrate species. Calculated values are shown at intersections of axes.

The number of days that no abstraction would be allowed varied with the minimum flow, from 18 days per year with a minimum of 100% of MALF to no days per year with a minimum flow of 50% of MALF (Table 10). Restrictions varied between rivers as indicated by the relatively high standard deviations (Table 10, Table 11). Rivers to the north and west of Mt Taranaki would provide a more reliable water supply than those to the south and east. The number of days per year with partial restrictions increased with allocation from 0 to 18 for a minimum flow of 50% of MALF and from 18 to 64 for a minimum flow of 90% of MALF (Table 11, Fig. 15). Increasing allocation by 10% of MALF had a similar effect on partial restrictions as decreasing the minimum flow by 10% of MALF, so that a minimum of 90% of MALF and 30% of MALF allocation resulted in a similar number of restrictions as a minimum of 80% of MALF and an allocation of 40% of MALF.

Table 10: Average number of days per year with total abstraction restriction (i.e., natural flow at or below minimum flow) and standard deviations for minimum flows from MALF (100%) to 50% of MALF and allocations of 10-50% of MALF.

Minimum flow as %MALF	Days per year of full restriction ± std. dev.
100	18.01 ± 8.1
90	8.58 ± 5.8
80	2.97 ± 2.9
70	0.70 ±1.0
60	0.02 ± 0.04
50	0.00

Table 11: Average number of days per year with partial abstraction restriction (i.e., natural flow less than the minimum flow plus total abstraction) and standard deviations for minimum flows from MALF (100%) to 50% of MALF and allocations of 10-50% of MALF.

Allocation as % MALF	Minimum flow as % MALF					
	100	90	80	70	60	50
50	74 ± 19	64 ± 16	53 ± 13	42 ± 11	30 ± 9	18 ± 7
40	64 ± 16	53 ± 13	42 ± 11	30 ± 9	18 ± 7	9 ± 5
30	53 ± 13	42 ± 11	30 ± 9	18 ± 7	9 ± 5	3 ± 2
20	42 ± 11	30 ± 9	18 ± 7	9 ± 5	3 ± 2	1 ± 1
10	30 ± 9	18 ± 7	9 ± 5	3 ± 2	1 ± 1	0 ± 1

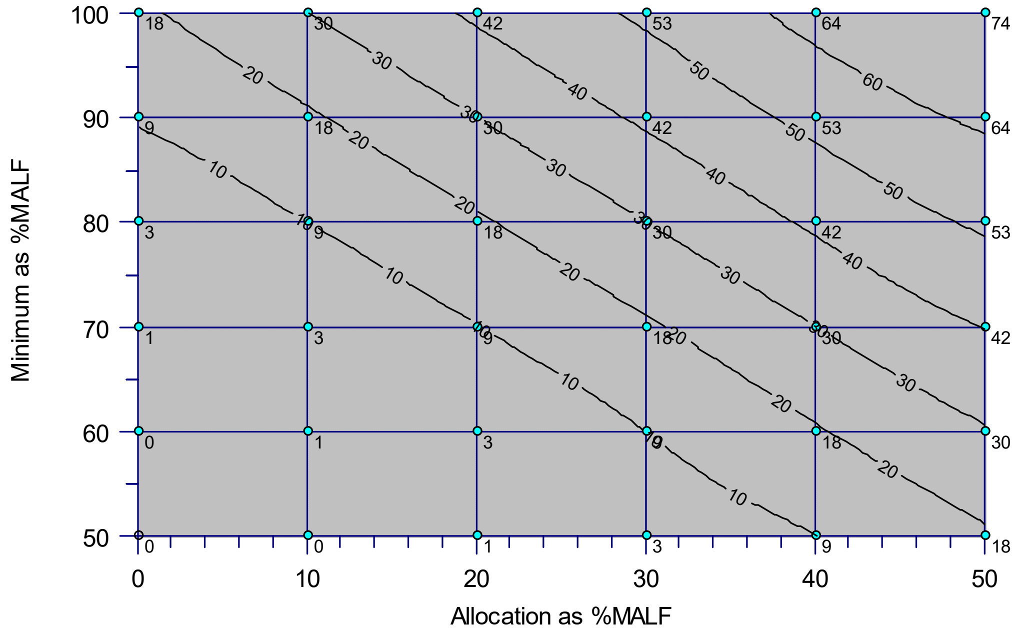


Figure 15: Contours of average number of days per year with partial abstraction restriction. Calculated values are shown at intersections of axes.

7.2 Habitat at 30-day low flow to protect the fish community

As described in Section 3.2, the minimum flow affects the amount of habitat available for aquatic species and at low flows the amount of habitat decreases as the flow decreases for most species. If the flow is at or less than the minimum flow for a sufficient length of time, native fish and trout populations can be affected.

Low flows act as a “habitat bottleneck” for long-lived biota such as trout and native fish. This is because mortality occurs when flows are low and suitable fish habitat restricted, and the population can take several years to recover (Jowett et al. 2008). Flows need to be low for some time, probably 30 days or so, for significant mortality to occur (Jowett et al. 2005). The recovery of a population from a low flow event depends on the life cycle. For trout, the population recovers in 3 or so years if trout spawning is successful (Hayes 1995). For native fish, most species recover in a year. However, if low flows occur year after year then those flows will limit the populations, and in the case of native fish, supply of larvae to the seas around New Zealand would be reduced leading to a general decline in national populations. Hence the concept that the natural MALF, the low flow that occurs every second year or so, is a limiting hydrological parameter for fish populations (Jowett et al. 2008).

The reduction in the amount of habitat at the 30-day MALF can be used as an index of the effect of minimum flows and allocation on fish. For fish species that prefer high velocities and/or deeper water, such as torrentfish and adult trout, there is an almost linear decline in available habitat as flows fall below MALF (Fig. 16). Other fish species, like redfin bullies do not experience such as sharp decline in habitat as flows reduce below MALF and are not affected by the flow reduction until flows are considerably less than MALF (Fig. 16). In assessing the potential effect of reduced flows on fish, the conservative assumption was made that fish habitat declined linearly below MALF, so that the potential effect is the % reduction in the 30-day MALF below the 30-day MALF with no abstraction.

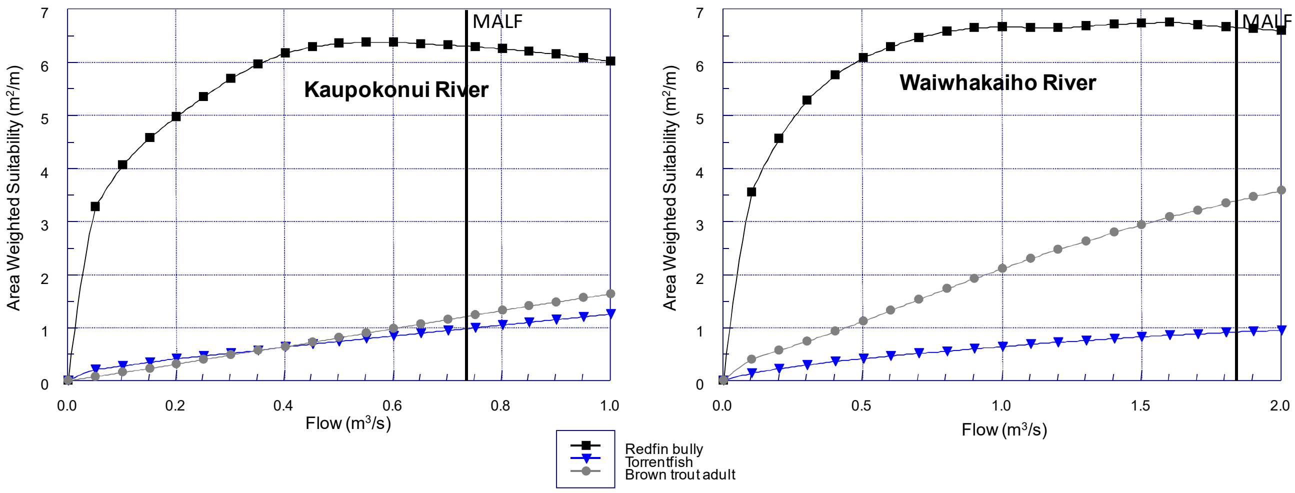


Figure 16: Examples of a linear decline in torrentfish and adult brown trout habitat below MALF compared to the change in redfin bully habitat.

As with the measure of stream "health", it is necessary to set a standard of protection for the reduction in 30-day MALF. With fish populations a change of 20% is likely to be undetectable given the natural variability of the population and annual recruitment from the sea for most native fish species.

Flows in each of the 9 rivers were modelled for various minimum flows and allocations and the 30-day MALF was calculated for each minimum flow and allocation scenario and the average calculated (Table 12, Fig. 17). There was relatively little variation between rivers, as shown by the standard deviations in Table 12.

Table 12: Average reduction in 30-day MALF ± standard deviation below natural 30-day MALF. Fish habitat protection levels are 100 minus the average reduction in 30-day MALF.

Allocation as % MALF	Minimum flow as % MALF					
	100	90	80	70	60	50
50	14.7 ± 2.1	18.7 ± 2.9	23.6 ± 3.5	28.8 ± 3.0	33.0 ± 2.9	36.2 ± 2.7
40	12.9 ± 1.9	16.6 ± 2.8	20.9 ± 3.4	25.2 ± 2.7	28.3 ± 2.3	30.2 ± 2.2
30	10.9 ± 1.7	13.9 ± 2.6	17.3 ± 3.0	20.5 ± 2.1	22.4 ± 1.7	23.3 ± 1.6
20	8.1 ± 1.5	10.3 ± 2.1	12.8 ± 1.7	14.5 ± 1.4	15.4 ± 1.1	15.7 ± 1.1
10	4.6 ± 0.9	5.7 ± 1.2	6.9 ± 0.8	7.6 ± 0.6	7.8 ± 0.6	7.9 ± 0.6

Contour plots of % reduction in MALF versus allocation and minimum flow are shown for each river in Appendix II.

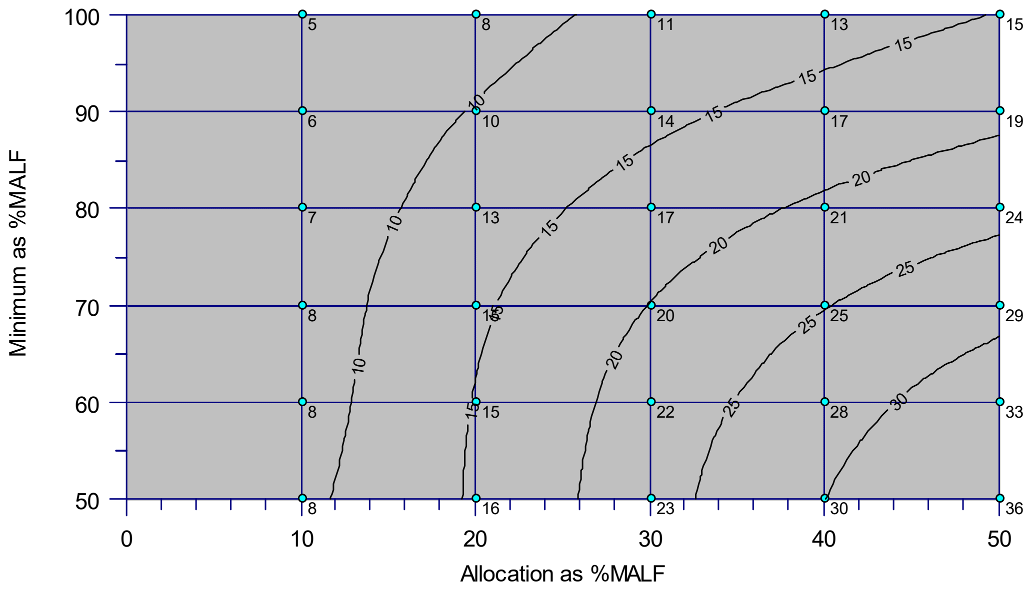


Figure 17: Contours showing the average reduction in 30-day MALF below natural 30-day MALF

8 Review of environmental flows in Draft Plan

The Council's Draft Plan specifies a minimum of 90% of MALF for rivers with a mean flow less than 5 m^3/s and a minimum flow of 80% of MALF for rivers larger than 5 m^3/s. The Draft Plan also specifies a maximum allocation of 30% of MALF for rivers with a mean flow less than 5 m^3/s and 50% of MALF for rivers larger than 5 m^3/s.

Only two of the nine rivers analysed had larger mean flows than 5 m^3/s. These were the Waiwhakaiho and Waingongoro. For the same minimum flows and allocations[19], there were no significant differences between the benthic invertebrate protection levels in these two rivers and the levels in the other 6 rivers (Kruskal-Wallis, $P > 0.55$).

Thus, there does not appear to be much difference between the flow requirements in rivers with flows greater than 5 m^3/s and those with flows less than 5 m^3/s. However, the two larger rivers had mean flows that were only slightly greater than 5 m^3/s and it is possible that a flow requirements in larger rivers (e.g., with mean flows greater than 10 m^3/s, such as the Waitara) might be differ from those analysed here. Specific studies would be needed to determine flow requirements in the lower Waitara River.

There is a high degree of correlation between the benthic invertebrate protection levels and the fish protection levels.

Benthic invertebrate protection level = 0.61x Fish protection level+40 $r^2 = 0.99$

The Draft Plan specifies a minimum of 90% of MALF and an allocation of 30%. This would give a benthic invertebrate protection level of 93% (Table 9) and a fish protection level of 86% (Table 12).

A minimum flow of 85% of MALF and a maximum allocation of 40% of MALF would give protection levels of 80% for fish populations and 90% stream "health" (Table 13). There would be up to 49 days

[19] as a % of their respective MALFs

per year with total abstraction restriction, but this would reduce significantly if actual allocation were 30% or less.

Table 13: Minimum flows, allocations and days of partial and total restriction for protection levels of 95% to 85%. Protection levels are percentages of benthic invertebrate production or fish habitat relative to benthic production and habitat at MALF

Benthic protection level	Fish habitat protection level	Minimum flow as % MALF	Allocation as % MALF	Days of partial restriction per year	Days of total restriction per year
95	90.2	50	10	0	0
		90	20	30	8.6
		100	30	53	18.0
90	82.0	55	20	2	0
		76	30	24	1.8
		86	40	48	5.8
85	73.8	50	30	3	0
		66	40	30	0.4
		74	50	47	1.7

The current minimum flow requirement of 66% of MALF[20] would give a fish habitat protection level of 77% and 87% benthic invertebrate protection at an inferred abstraction level of 33% of MALF. The number of days with partial and total restrictions would be 18 and 0 days, respectively.

9 Recommended environmental flow limits for Taranaki

9.1 Application of environmental flow limits in freshwater management units

The analyses of hydrology, fish communities, benthic invertebrate indices and water quality in the rivers of the B and D FMUs did not show any strong differences other than lower runoff and higher turbidity in the FMU D eastern hill country than in the ring plain rivers of FMU B. Thus with the data available, there does not appear to be any ecological reason for setting different flow limits in these two FMU zones. There is little data for the northern and southern coastal zones and if streams in these areas have good access to the sea, then there would be no ecological reason for different flow limits.

9.2 Protection levels

Two types of protection level can be applied. The first is to protect the state of the benthic invertebrate community and the second is to protect the fish community.

Benthic invertebrate density is related to trout abundance, benthic invertebrates are most abundant in riffles, where native fish are also most abundant, and MCI was identified as the one measure that was most closely related to Maori cultural values (Tipa & Teirney 2003).

[20] The existing minimum flow requirement where the minimum flow retains 66% of the habitat available for adult brown trout and food production available at mean annual low flow (MALF) is equivalent to 66% of MALF in small streams because the relationship between trout and food habitat and flow is linear at low flows.

The life cycle of fish is longer than that of benthic invertebrates and the density of trout and native fish, particularly those that are found in swift water, can be limited by low flows if they persist for long enough. The reduction in the 30-day MALF was used as a conservative indicator of the potential effect on fish species. It is conservative because if the density of fish is low, a reduction in habitat is likely to result in a redistribution of fish rather than a loss of fish. It is also conservative for other fish species whose habitat is not affected by flow reductions as much as that of torrentfish and adult trout.

The state of the benthic invertebrate community was represented by the average benthic invertebrate density[21] for taxa with high MCI scores. This average was calculated for the natural river flows over the full flow record (11 years) and for the river flows assuming that full abstraction was occurring according to the minimum flow and allocation. The protection level is the predicted benthic invertebrate density with abstractions as a percentage of the natural benthic invertebrate density.

The index of average benthic invertebrate density for high MCI scoring taxa will help meet MCI requirements of the National Policy Statement for Freshwater Management (MfE 2015). High MCI will also lead to high biodiversity.

The fish community protection level was that full application of the abstractions should not reduce the 30-day MALF by more than a percentage of the natural 30-day MALF. This is intended to protect the habitat and populations of trout and native fish species with high flow demands such as torrentfish. In some streams, there may be no fish access to the sea because of cliffs and waterfalls. If this were the case the fish protection level could be relaxed.

9.3 Minimum flow and allocation

The analyses carried out in Section 8 give a large number of choices for an appropriate minimum flow and allocation. Table 14 shows some of the possible choices. The alternative choices provide a fish protection level of 80% on the basis that the effects of a 20% reduction in the fish protection level is probably not detectable and that the reduction would only occur if the fish population were habitat limited. Similarly, a reduction of 10% in the state of the benthic invertebrate community is small and probably not detectable.

For example, the average number of large and medium-sized trout per kilometre of Taranaki rivers was about 19 per kilometre or 13 per hectare (Teirney & Jowett 1990). Alternative 2 in Table 14 would reduce trout protection level by 17% and benthic production by 9%. Applying the brown trout model (Jowett 1992) using average parameters for Taranaki rivers, this option would reduce trout numbers from 19 to about 15 per kilometre (from 13 to 10 per hectare), assuming that the trout density is controlled by habitat (fish protection level) and food (benthic protection level). The number of large trout (> 40 cm) would reduce from 7.4 per kilometre to 5.9 per kilometre. Alternative 1 would have a similar effect on trout. The current plan would reduce large plus medium trout numbers to about 13.6 per kilometre and the Draft Plan would reduce them to 15.8 per kilometre.

Actual effects on the benthic invertebrate community are probably less than would be indicated by the protection levels because the effects were calculated assuming that the maximum allowable allocation was abstracted all through the year and this would rarely be the case.

[21] The calculation gives an index of density

Table 14: Possible choices of minimum flows and allocation and the protection levels that they provide.

Description	Minimum flow as % MALF	Allocation volume as % MALF	Benthic invertebrate protection level	Fish protection level	Days of partial restriction
Current plan	66	33	87	77	18
Draft Plan	90	30	93	86	42
Alternative 1	85	40	90	81	46
Alternative 2	80	30	91	83	30

There are 45 Taranaki rivers or catchments with consents to abstract water. In these, the total amount of water allocated in the consents is more than 30% of MALF in 36% of the rivers, more than 33% in 27% of rivers and more than 40% of MALF in 24% of rivers. The median amount of water allocated in the consents for Taranaki rivers or catchments is 19% of MALF.

The large abstractions were often from lakes or reservoirs, from streams where there is no access to the sea, or for public water supplies.

Rather than setting a single allocation and minimum flow for all catchments, consideration could be given to:

- Setting the minimum flow according to the total catchment allocation, so that catchments with low demand could have a low minimum flow and high reliability of supply.
- Accepting reduced protection levels for abstractions where the consequences of a reduction in take might have serious effects on public health or the economy, as in Policy 2.3 of the Draft Plan. These could be listed in a schedule in the Plan.
- Varying protection levels according to the values listed in schedules of the Draft Plan.

There did not seem to be any reason to vary the limits with river size, but the mean flows in the rivers studied were all less than 10 m^3/s. It is possible that a lower minimum flow and higher allocation might apply to rivers with mean flows greater than 10 m^3/s.

9.4 Flat-lining

The length of time at or below the minimum flow is not sufficiently long to cause any problems with periphyton growth because of the frequent floods and freshes that occur in Taranaki rivers.

9.5 Reliability of supply

The environmental limits would cause problems in rivers where the full allocation is taken up. Restrictions on the amount of water taken would occur on up to 50 days per year on average and these would mainly be in the season of high demand for irrigation and water supply. An increase in the reliability of supply could be achieved by a reduction in total allocation or decrease in minimum flow. Such cases would need to be considered on a catchment by catchment basis considering the seasonal water needs, the effects of restrictions, and the possibility of group schemes (Section 5.3).

9.6 Flexibility

A regional minimum flow and allocation as proposed is simple but not all rivers are the same. For example, spring-fed streams and rivers larger than 10 m^3/s might merit special treatment in terms of environmental flow and there seems to be limited information on the coastal streams of FMU C.

It is impossible for a plan to foresee all possible future developments and some of these might be of high economic or social value, such as municipal takes and energy projects. The minimum flows and allocation limit in the plan should not prevent such future development and the consent process would allow appropriate limits to be adopted after consideration of instream values and effects of abstraction or diversion.

10 Stakeholders

The setting of minimum flows and allocation limits is a collaborative process that involves the Regional Council and community in order to achieve the best water management outcomes for the region. This report has been prepared to inform this process by advising on some principles of flow assessment, relevant scientific research and by carrying out analyses to determine the environmental effects of various combinations of minimum flow and allocation. It is probably the first study that has explicitly examined the environmental effects of minimum flow and allocation together.

The key to deciding appropriate levels of minimum flow and allocation is to decide on protection levels. The levels suggested in this report are broadly based on limits that are seen as acceptable by some other regional councils and in the MfE (2008) discussion document. However, invariably some stakeholders might want lower standards and others higher standards.

Stakeholder involvement is important and a series of workshops is recommended to be held to discuss the findings of this report, particularly the levels of protection and the suggested minimum flow and allocation for various types of take. The Taranaki Regional Council intends to use this report to inform these community discussions from a technical perspective.

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12 Appendix I – Instream Habitat Analysis

Modelling of instream habitat availability for selected species, over a range of flows, is a valuable tool when assessing potential effects of flow changes and making decisions about environmental flow requirements. This method is one of the most commonly used methods of assessing flow requirements (Tharme 2003). The background to methods used here is discussed in Jowett et al. (2008).

Habitat modelling entails measuring water depths and velocities, as well as substrate composition, across a number of stream cross-sections at a given flow (referred to as the survey flow). Points on the banks, above water level, along the cross-sections are also surveyed to allow model predictions to be made at flows higher than the survey flow. Calibration data for fitting rating curves are obtained from additional measurements of water level at each cross-section, relative to flow, on subsequent visits. The stage (water level) with no flow in the river (stage of zero flow) is also estimated at each cross-section to help fit rating curves. These data allow calibration of a hydraulic (instream habitat) model to predict how depths, velocities and the substrate types covered by the stream will vary with discharge in the surveyed reach.

12.1.1 Habitat mapping

The first step in the process is to carry out habitat mapping along the length of the reach between the dam and tailrace locations. The habitat types are assessed in the field after traversing the affected reach. The habitats would typically be classified as riffle, run, pool, and rapid. The length and location of each habitat type is recorded.

12.1.2 Cross-section selection

The number of cross-sections required depends on the morphological variability within the river, with homogenous stretches of river requiring fewer cross-sections than stretches that are highly varied morphologically. Studies have shown that relatively few cross-sections can reproduce the results from a survey in which a large number of cross-sections were sampled (see Jowett et al. 2008 for details).

The total number of cross-sections needed to generate a robust result should be proportional to the complexity of the habitat hydraulics, with 6 to 10 sampled for simple reaches and 18 to 20 for diverse reaches.

Each cross-section is given a percentage weighting based on the proportion of the habitat type in the reach that it represents. The underlying assumption is that the cross-sections measured provide a reasonable representation of the habitat throughout the reach. Reach results can be extended to longer sections of river, if the flows, river gradient and morphology do not change significantly.

12.1.3 Analysis

The procedure in an instream habitat analysis is to select appropriate habitat suitability curves or criteria (e.g., Fig. A1), and then to model the effects of a range of flows on the selected habitat variables in relation to these criteria. The habitat suitability index (HSI) at each point is calculated as a joint function of depth, velocity and substrate type using the method shown in Figure A1. Using the example in Figure A1, a given point in the river (representing an area of reasonably uniform depth and velocity) where the depth is 0.1 m, depth suitability is only 65% optimal, according to knowledge of the depth requirements of the fish. Similarly, the velocity recorded at the point is 0.25 m/s, which is optimal (suitability weighting of 1), and the substrate is fine gravel (sub-optimal, with a weighting of 0.4) and cobbles (optimal with a weighting of 1). Multiplying these weighting factors together gives a joint habitat suitability weighting of 0.455 for that point in the river for the selected fish species. If the depth had been 0.2 m and there had been only cobbles, then that point in the river would have been optimal (i.e., 1 for depth × 1 for velocity × 1 for substrate = 1).

The point suitability values weighted by their respective areas are summed to give a measure of area weighted habitat suitability (AWS) for the given species at the given flow. This process is repeated for a series of flows with the depths, velocities, and habitat suitability being modelled for each flow.

Area weighted suitability plotted as a function of flow shows how habitat for a given species varies with flow (Fig. A2). These graphs are then used to assess the effect of different flows for target organisms. Flows can then be set so that they achieve a particular management goal.

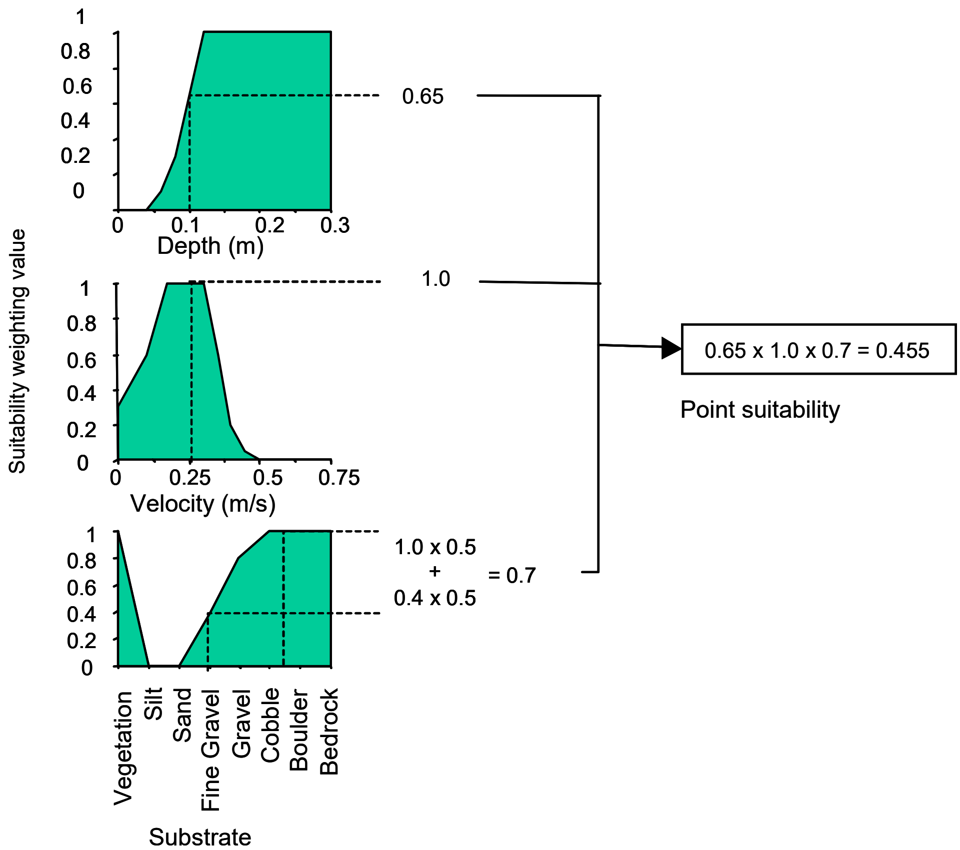

Figure A1: Calculation of habitat suitability for a fish species at a point with a depth of 0.1 m, velocity of 0.25 m/s, and substrate comprising 50% fine gravel and 50% cobble. The individual suitability weighting values for depth (0.65), velocity (1.0), and substrate (0.7) are multiplied together to give a combined point suitability of 0.455.

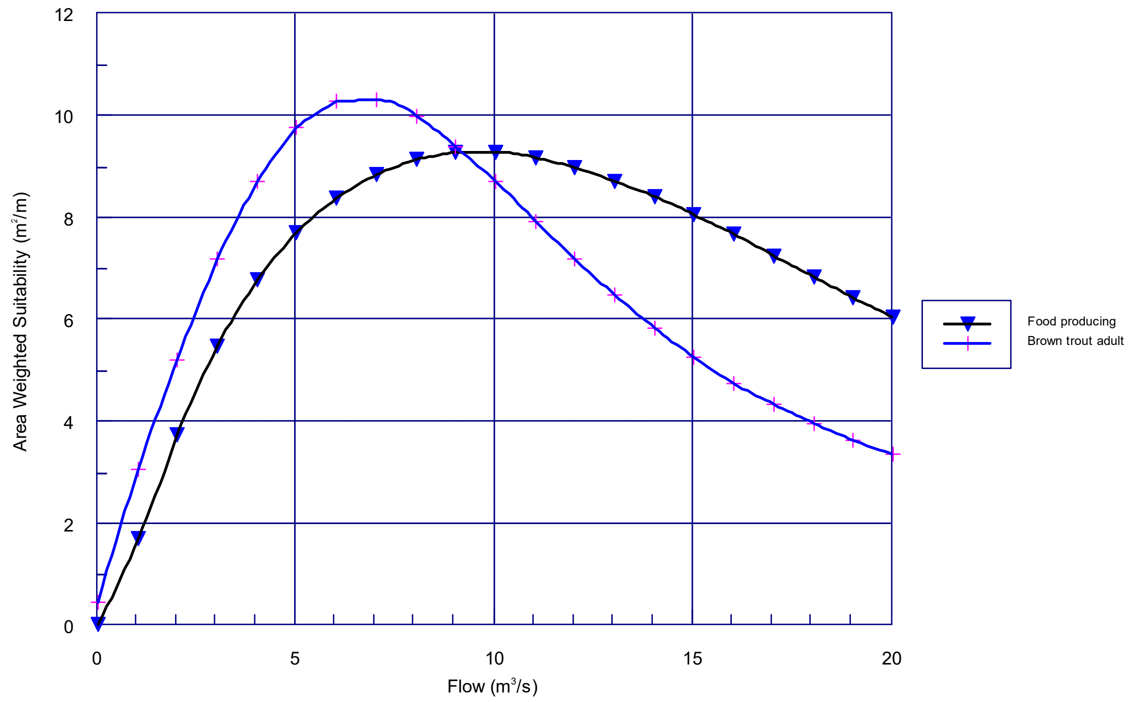

Figure A2: Example of graph showing how area weighted habitat suitability for adult brown trout and food production varies with flow.

13 Appendix I

5.2 Renewable Power Ltd

Policies 7.5 – 7.9	Opposed to the minimum flow requirements for rivers as it limits economic opportunity.

5.16 Contact Energy

	Supports in particular the introduction of minimum flows and river allocation limits
Minimum flows	Understands the reasons for needing to have minimum flows and river allocation limits. However, note concerns if water take is reduced too far, they may no longer be able to generate electricity as efficiently and cleanly as they can now, or at all.

5.24 DairyNZ

POL 7.5	Have serious concerns about the proposed blanket application of minimum flows, as it is not clear how this will impact on the reliability of supply for existing water users.
	Request defining allocable flows for water bodies must be set according to whichever is the greater of: - Existing consented and permitted water takes, or - A default method such as is currently proposed.
	Add a policy relating to review of consents for reasonable and efficient use if there is need for a minimum flow.
	Add an exception for dairy shed water takes and animal drinking water
Rule 46	As noted in relation to policies 7.5, 7.7 and 7.8, concerned about the imposition of minimum flows on existing consents, without a clear understanding of the impacts on security of supply for existing users. Suggest amending rule 46 to read: *'…(a) Actions to be taken when water bodies are at or below minimum flows…'*

5.27 Taranaki Fish and Game

Water takes	Suggest including provisions around ensuring that any takes are assessed against criteria which determines whether they are necessary, reasonable and efficient
	Suggest the renewal of existing consents should be required to meet plan requirements including ensuring that the take is first necessary and where it can show the take and use is necessary, the rate of take and volume taken should also have to be reasonable, given application of efficiency criteria
	Suggest existing takes should only be assessed as a controlled activity if they meet the conditions above and also meet the allocation and minimum flow limits and targets set in the Plan
	Suggest when existing takes fail to meet reasonable and efficient requirements, and/or fall outside of allocation limits and targets (core allocations and minimum flow) they should be assessed as discretionary activities
	Suggest where existing takes fall within over allocated catchments they will need to be clawed back over time
Allocation limits	Suggest that a new category be created within FMU B where water use is limited to no more than the existing level of use.
	Amend Policy 7.7 to clarify that MALF means the natural MALF unaffected by water takes and that as well as applying at the site of each take, the limits are also an overall catchment core allocation limit
	Suggest the inclusion of a new policy similar to that set out below. This should also apply to minimum flows: *The setting of limits for water quantity will be managed in a manner which:* ***(a)*** *Sustains the life supporting capacity of water bodies; and* ***(b)*** *Provides for the natural character of the waterbody which includes;* ***(i)*** *Natural elements, processes and patterns*

	(ii) *Biophysical, ecological, geological, geomorphological and morphological aspects; and* ***(iii)*** *The natural movement of water and sediment including hydrological and fluvial processes*
POL7.7	Amend to include a total water allocation limit for the Hangatahua (Stony) River of 30l/s
POL7.8	Suggest amending so that a minimum flow of MALF applies in FMUs A and B and in the small stream catchments (mean flow <5 cumecs) in FMU C

5.34 Department of Conservation

POL7.7	Would like to discuss the relationship between 7.7 and 7.8 to better understand how they work together.
	Seek clarification to understand whether Policy 7.7 is intended to apply per consented take, or cumulatively
	State that it is unclear how the provision for replacement of existing consents in Policy 7.5(b) will achieve the environmental outcomes sought by the policy.
POL7.8	Supports the minimum flow limits for FMUs A and B which are in line with the proposed NES
	Considers the minimum flow of MALF low for FMUs C and D. Refer to the proposed NES Suggest amending to: *(c) in Freshwater Management Units C and D is at or below:* *(i) ~~80%~~ 90% of the mean annual low flow for rivers with mean flows less than or equal to 5m^3/s; or* *(ii) 80% of the mean annual low flow for rivers with mean flows greater than 5m~~3~~/s ~~in Freshwater Management Units C and D; and~~*
	State that allocation limits for FMUs C and D have been set based on river/stream size, so it seems appropriate to do the same for minimum flows
	Questions if TRC has considered minimum water levels for wetlands
	Supports provision (d) which provides for pest fish eradication

5.4 Nga Ruahine

POL 7.7	Suggests that MALF levels set at 50% seems high even for large rivers. Would like more information/clarification around this.
POL 7.8	Would like clarification around MALF (7.7 and 7.8). Believes these points are contradictory.

5.32 Methanex NZ Ltd

Reference in the Draft Plan	Comment/decision sought
POL7.7	Seeks clarification on how the proposed allocation limits will be set for a site, whereby water is sourced from across two freshwater management units, as is the case for the Waitara River. As allocation data is not currently available, uncertainty exists to whether the current allocation limits will remain or be amended through the plan process. States that the availability of the allocation information is critical to making an informed submission on the draft plan

5.38 Trustpower

POL7.4, 7.5, 7.6, 7.7, 7.8	Support this policy

14 Appendix II

14.1 Waiwhakaiho River

The instream habitat survey for this river is described in Jowett (1993).

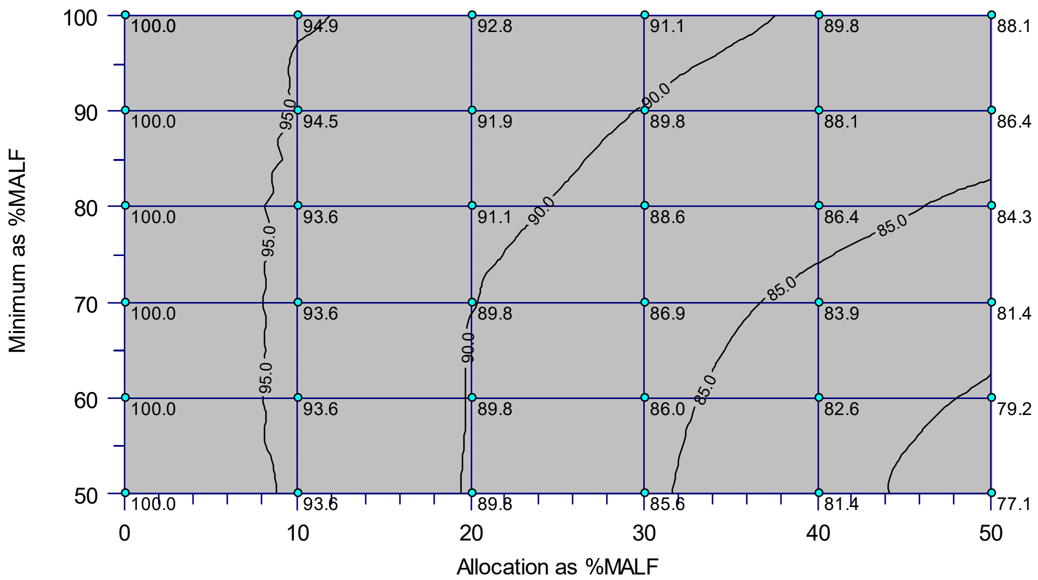

Figure A3: Contours of percent retention in density of high MCI invertebrate species for the Waiwhakaiho River. Calculated values are shown at intersections of axes.

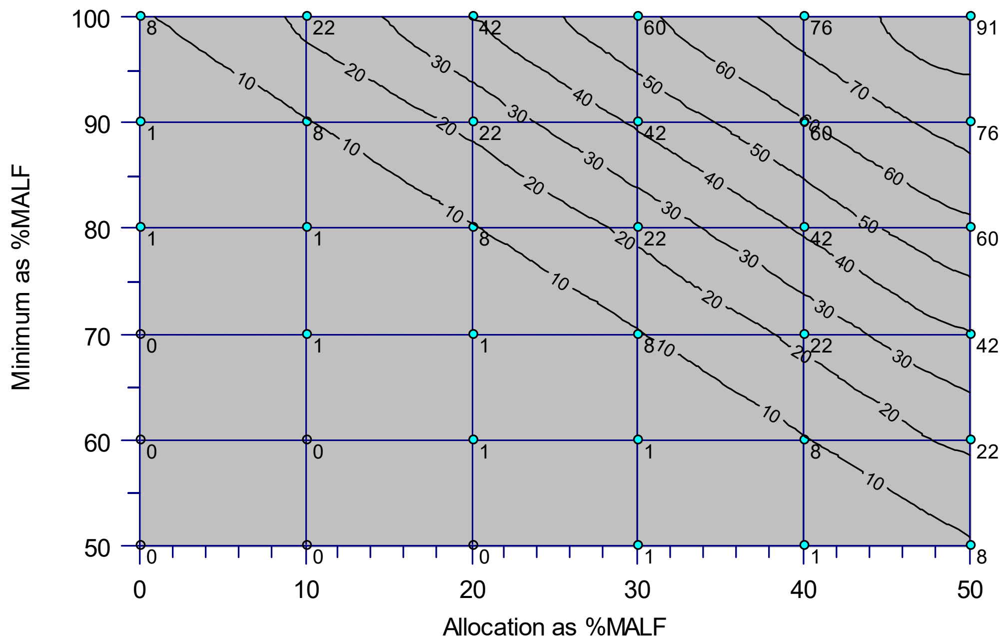

Figure A4: Contours of the average number of days per year of partial restrictions to abstraction from the Waiwhakaiho River. Calculated values are shown at intersections of axes.

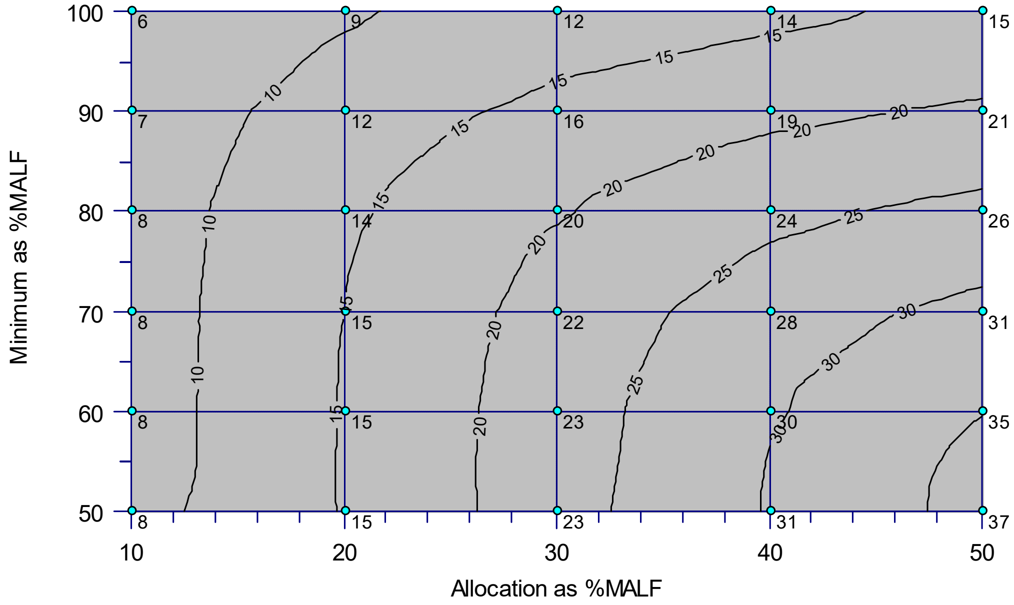

Figure A5: Contours of percent reduction in 30-day MALF from the Waiwhakaiho River. Calculated values are shown at intersections of axes.

14.2 Kaupokonui River

The instream habitat survey data for the Kaupokonui River were obtained at Skeet Road (Jowett 1993). The catchment area at Skeet Road is about half that of the flow recording site at Glenn Road, so Glen Road flows were divided by two before calculating indices of benthic invertebrate density for high MCI scoring taxa.

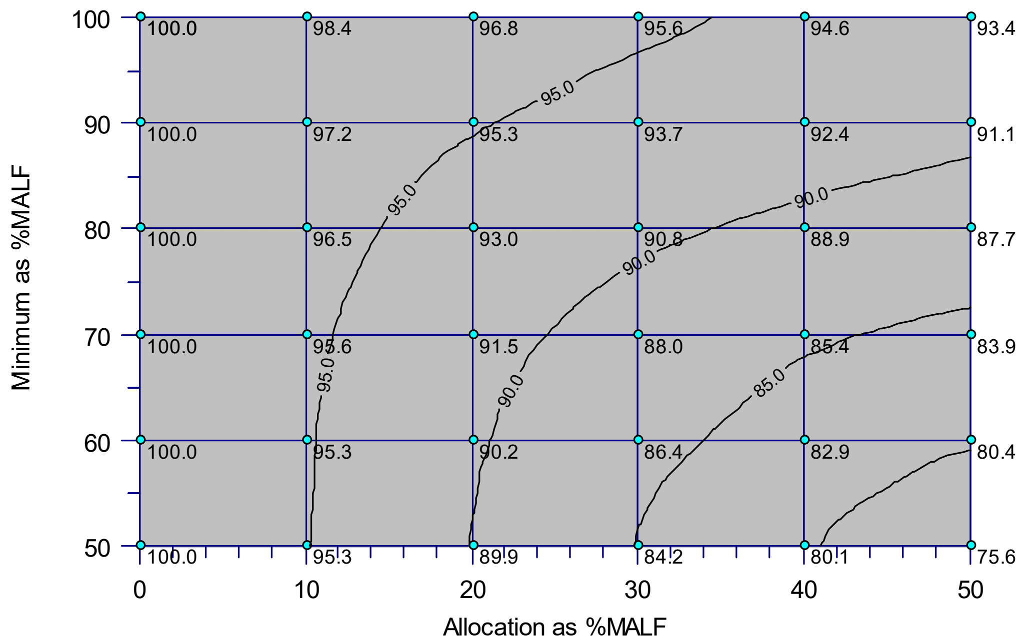

Figure A6: Contours of percent retention in density of high MCI invertebrate species for the Kaupokonui River. Calculated values are shown at intersections of axes.

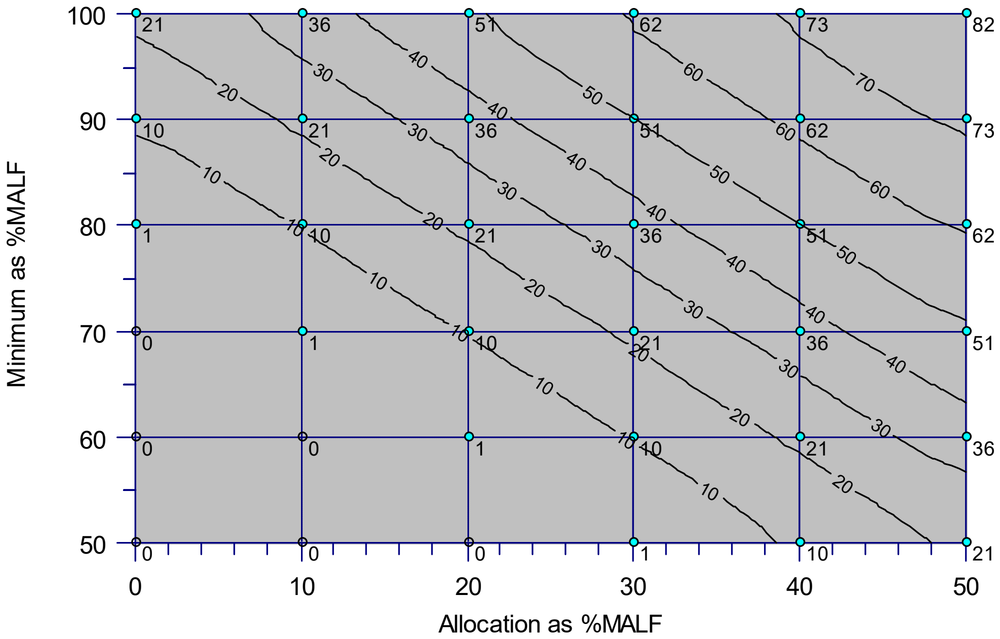

Figure A7: Contours of the average number of days per year of partial restrictions to abstraction from the Kaupokonui River. Calculated values are shown at intersections of axes.

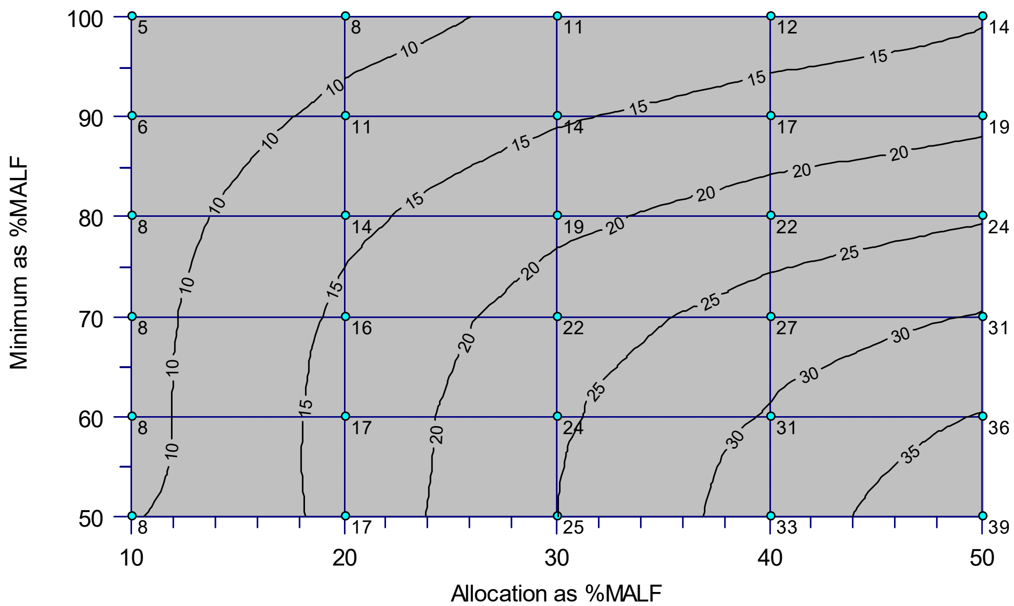

Figure A8: Contours of percent reduction in 30-day MALF from the Kaupokonui River. Calculated values are shown at intersections of axes.

14.3 Kapoaiaia Stream at lighthouse

The instream habitat survey for this Stream is described in Jowett (1993).

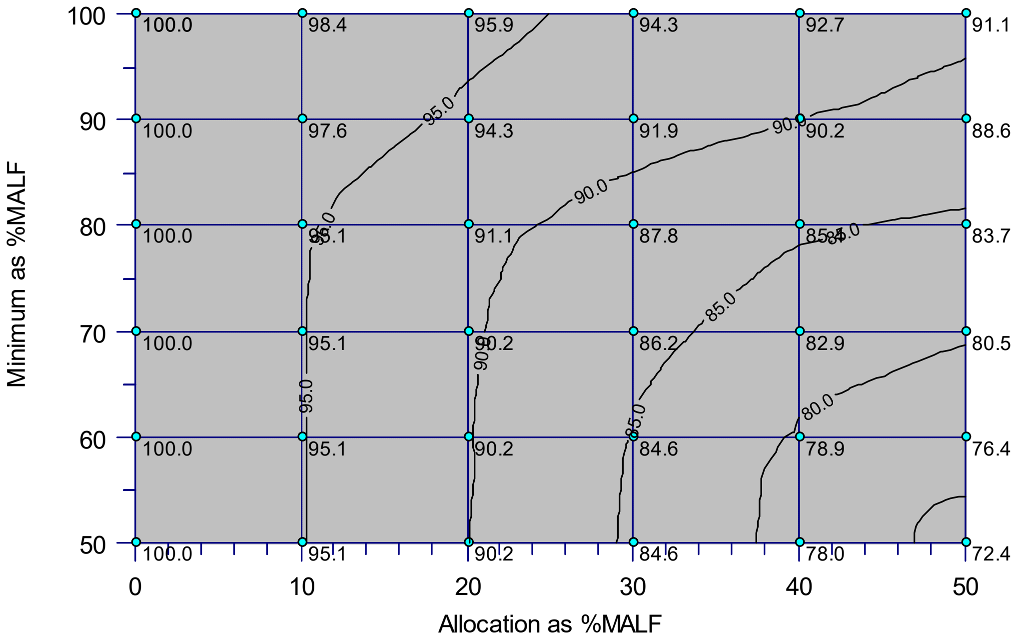

Figure A9: Contours of percent retention in density of high MCI invertebrate species for the Kapoaiaia Stream. Calculated values are shown at intersections of axes.

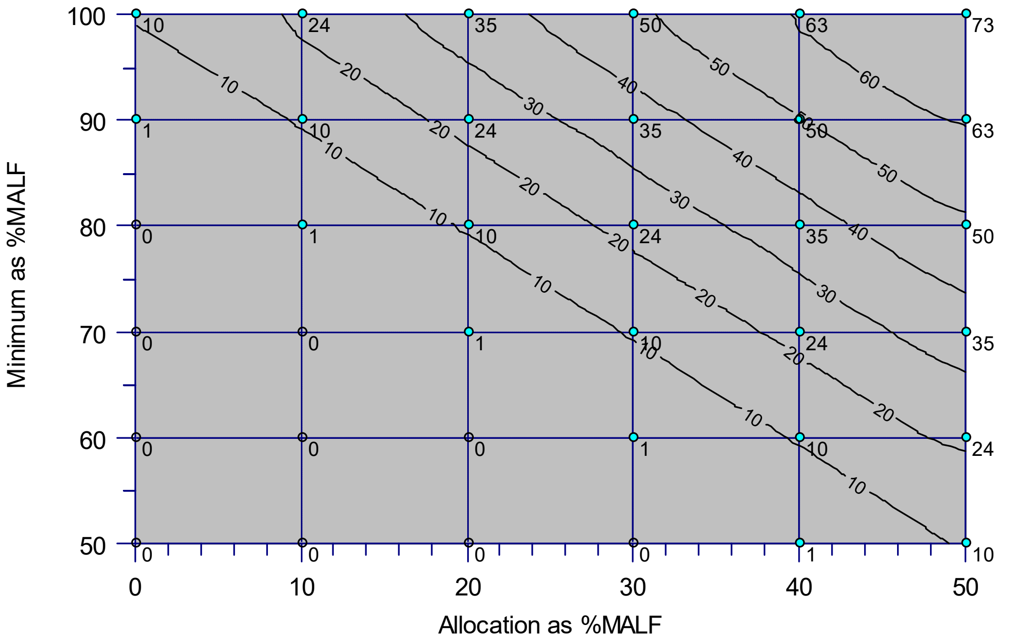

Figure A10: Contours of the average number of days per year of partial restrictions to abstraction from the Kapoaiaia Stream. Calculated values are shown at intersections of axes.

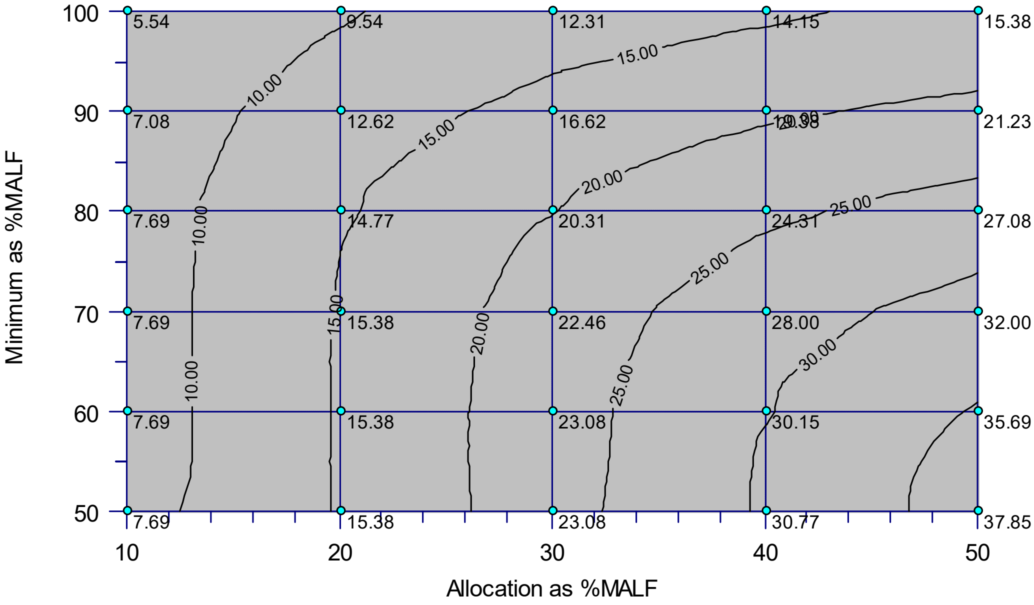

Figure A11: Contours of percent reduction in 30-day MALF from the Kapoaiaia Stream. Calculated values are shown at intersections of axes.

14.4 Patea River at Stratford

The instream habitat survey data for the Patea River were obtained at Stratford (Jowett 1993). The catchment area at Stratford is one third that of the flow recording site at Skinner Road, so Skinner Road flows were divided by one third before calculating indices of benthic invertebrate density for high MCI scoring taxa.

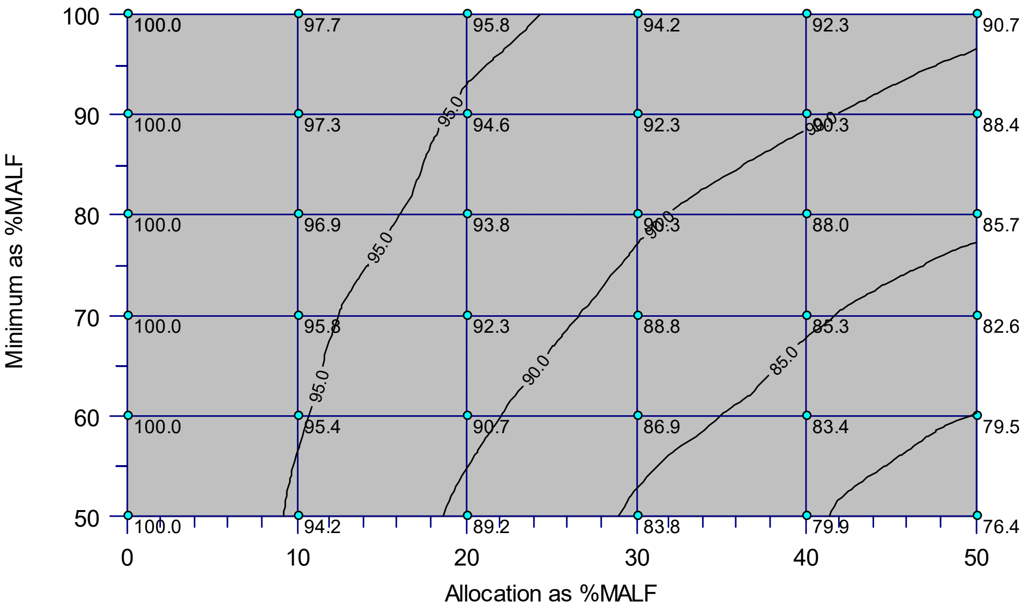

Figure A12: Contours of percent retention in density of high MCI invertebrate species for the Patea River. Calculated values are shown at intersections of axes.

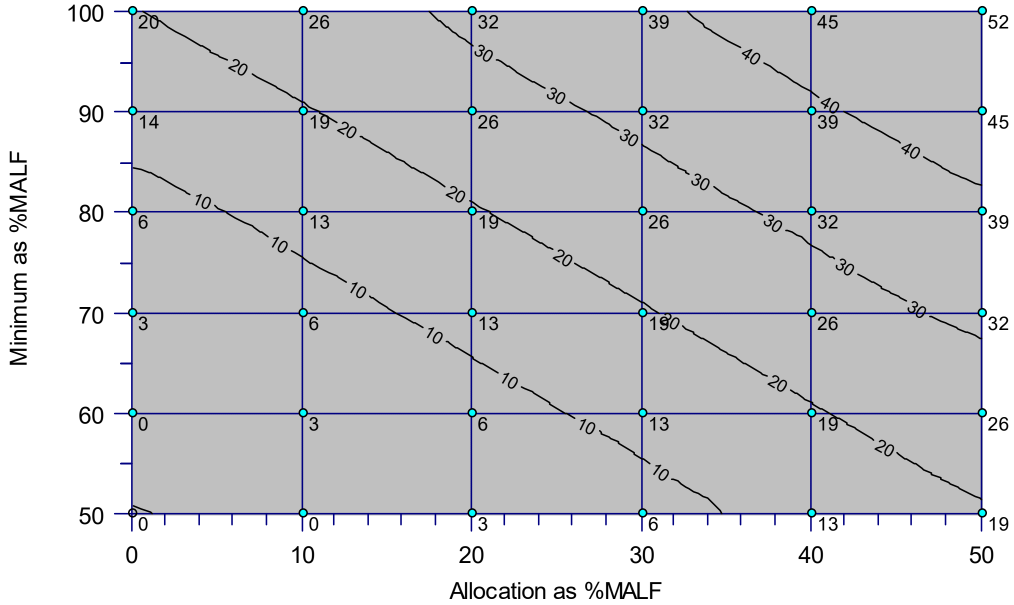

Figure A13: Contours of the average number of days per year of partial restrictions to abstraction from the Patea River. Calculated values are shown at intersections of axes.

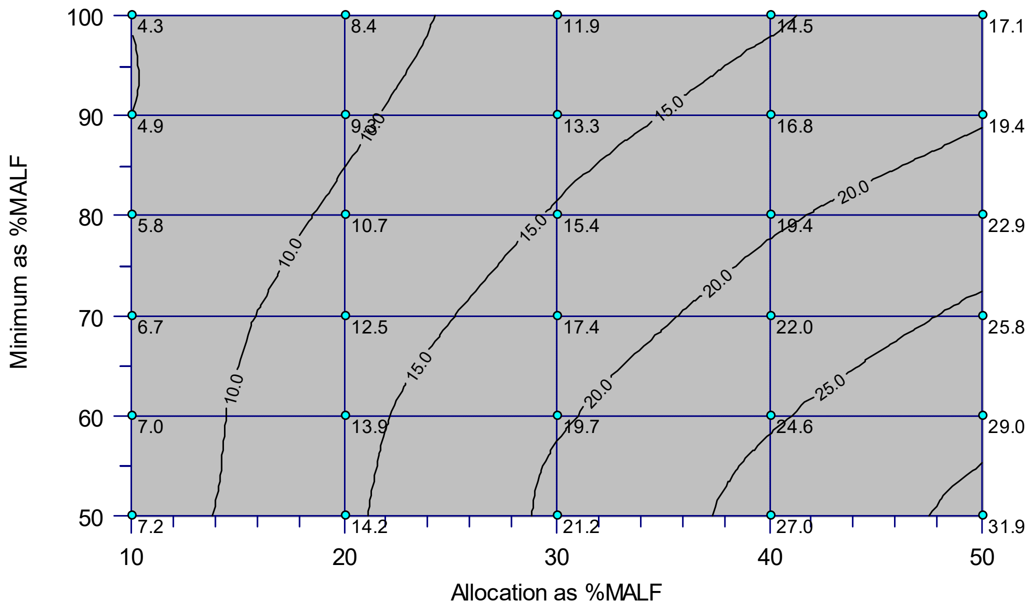

Figure A14: Contours of percent reduction in 30-day MALF from the Patea River. Calculated values are shown at intersections of axes.

14.5 Tangahoe River

There are no instream habitat survey data for the Whenuakura River so survey data from the Tangahoe River were used instead (Jowett 2014). The Tangahoe catchment is similar to that of the Whenuakura in that it drains the sedimentary eastern hill country. Both the flow recording site on the Whenuakura River and the Tangahoe instream survey data are near the coast. A short period of flow record for the Tangahoe River established that the Tangahoe River flow was 0.4337 times the flow in the Whenuakura River. Whenuakura River flows were divided by 0.4337 before calculating indices of benthic invertebrate density for high MCI scoring taxa.

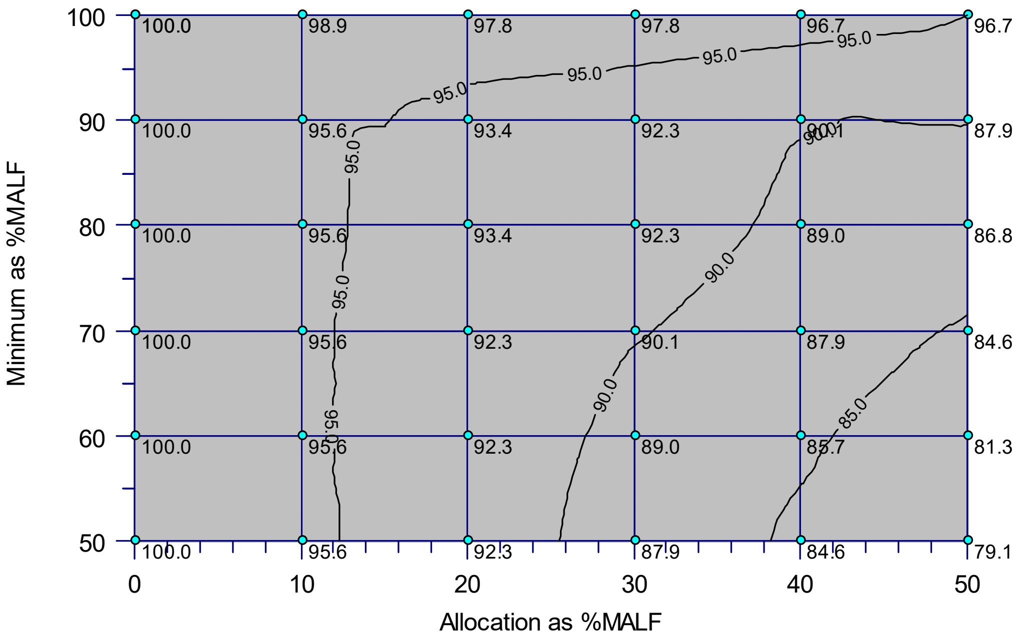

Figure A15: Contours of percent retention in density of high MCI invertebrate species for the Tangahoe River. Calculated values are shown at intersections of axes.

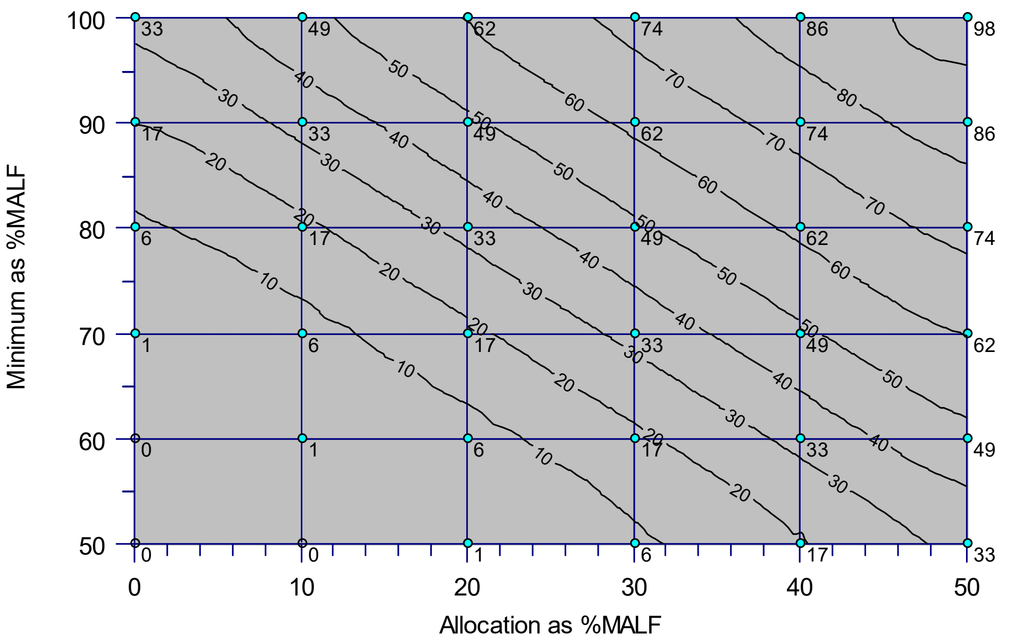

Figure A16: Contours of the average number of days per year of partial restrictions to abstraction from the Tangahoe River. Calculated values are shown at intersections of axes.

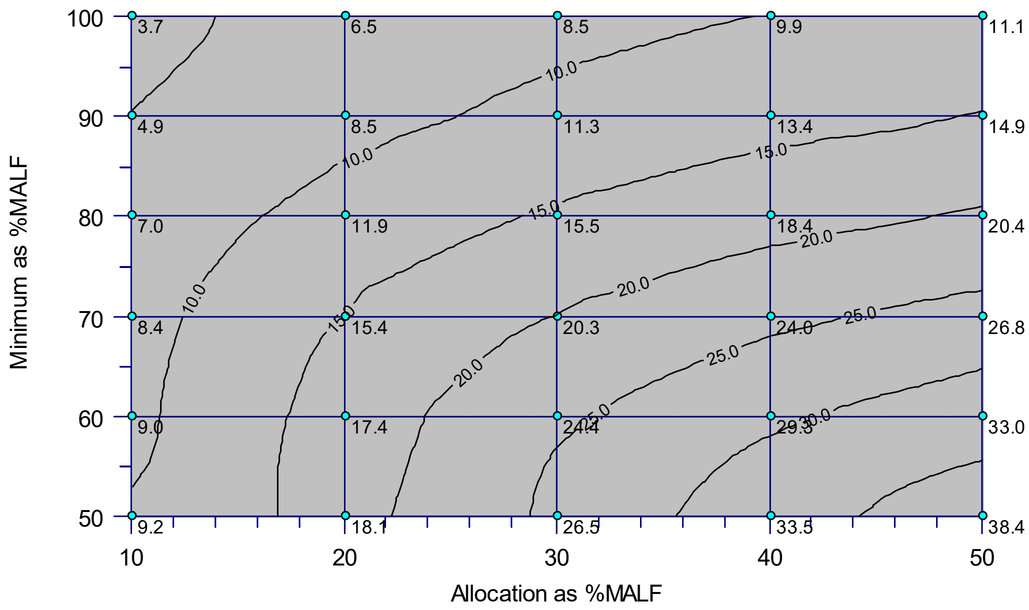

Figure A17: Contours of percent reduction in 30-day MALF from the Tangahoe River. Calculated values are shown at intersections of axes.

14.6 Mangaoraka River at Corbett Road

The instream habitat survey data for the Mangaoraka River is described in Jowett (1993).

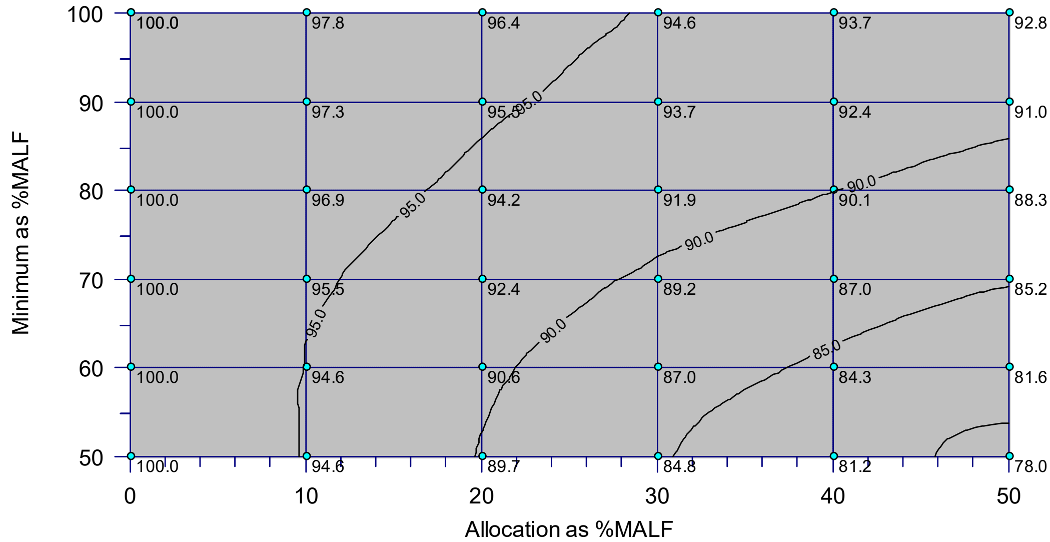

Figure A18: Contours of percent retention in density of high MCI invertebrate species for the Mangaoraka River. Calculated values are shown at intersections of axes.

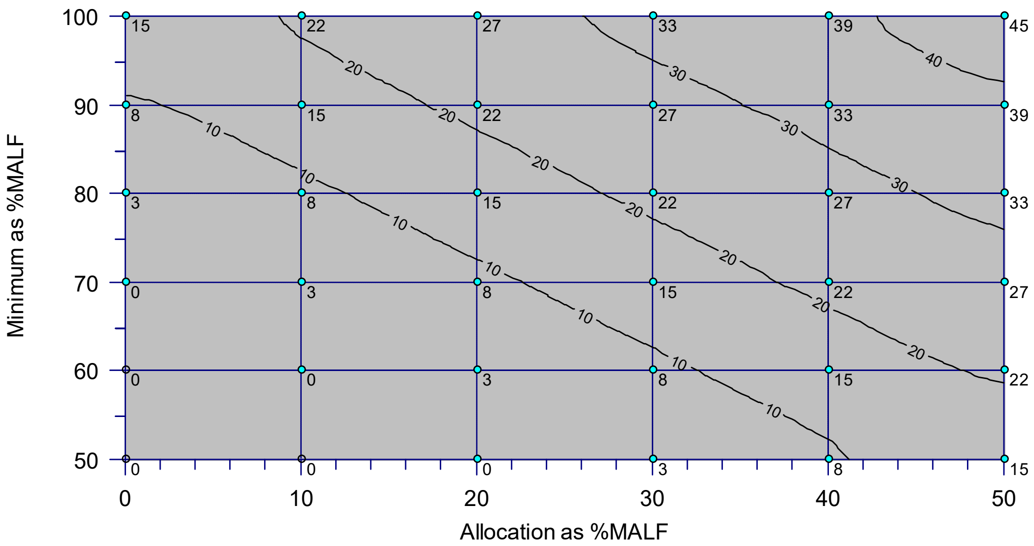

Figure A19: Contours of the average number of days per year of partial restrictions to abstraction from the Mangaoraka River. Calculated values are shown at intersections of axes.

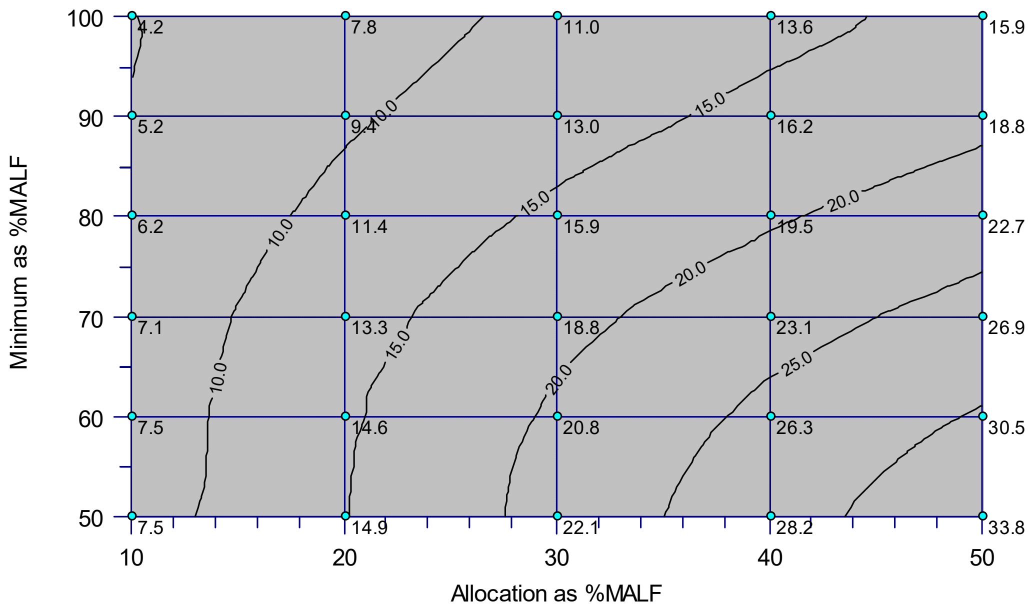

Figure A20: Contours of percent reduction in 30-day MALF from the Mangaoraka River. Calculated values are shown at intersections of axes.

14.7 Waingongoro River at Normanby

The instream habitat survey data for the Waingongoro River was carried out at the Normanby Loop and the flow data is from the SH45 site. SH45 flows were multiplied by 0.87 to give flows at the Normanby Loop.

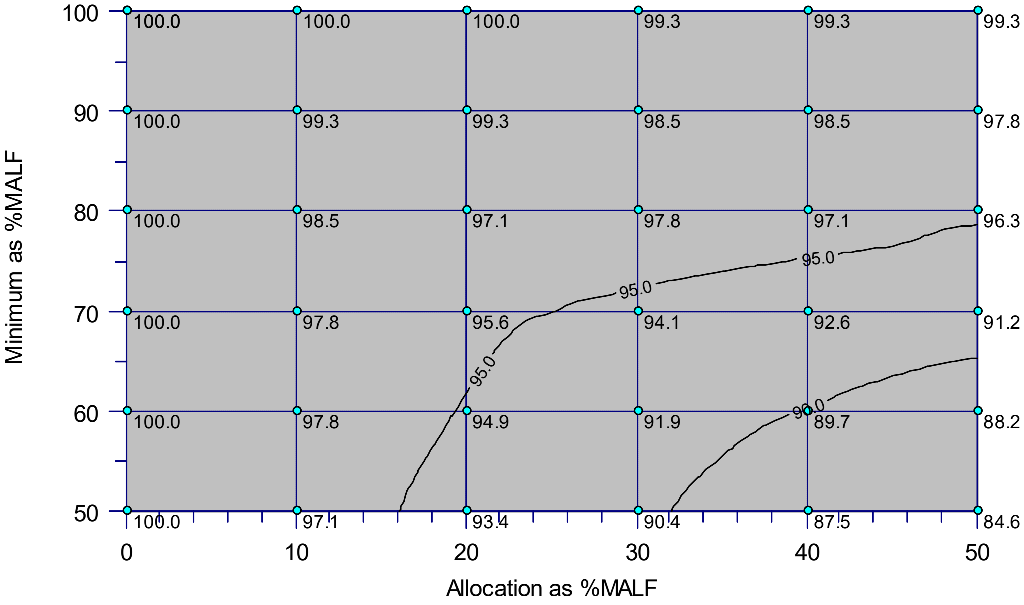

Figure A21: Contours of percent retention in density of high MCI invertebrate species for the Waingongoro River. Calculated values are shown at intersections of axes.

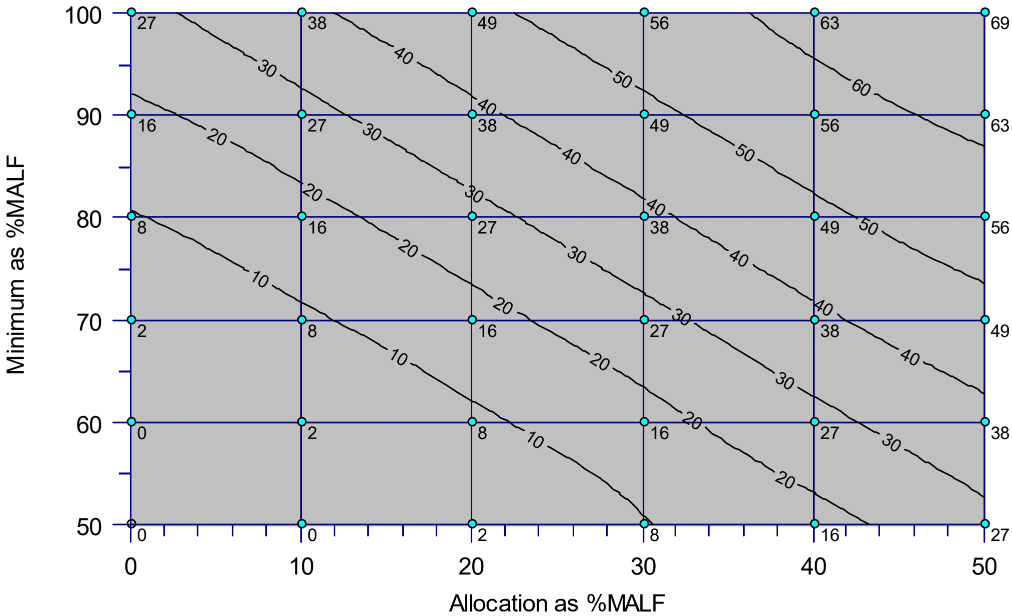

Figure A22: Contours of the average number of days per year of partial restrictions to abstraction from the Waingongoro River. Calculated values are shown at intersections of axes.

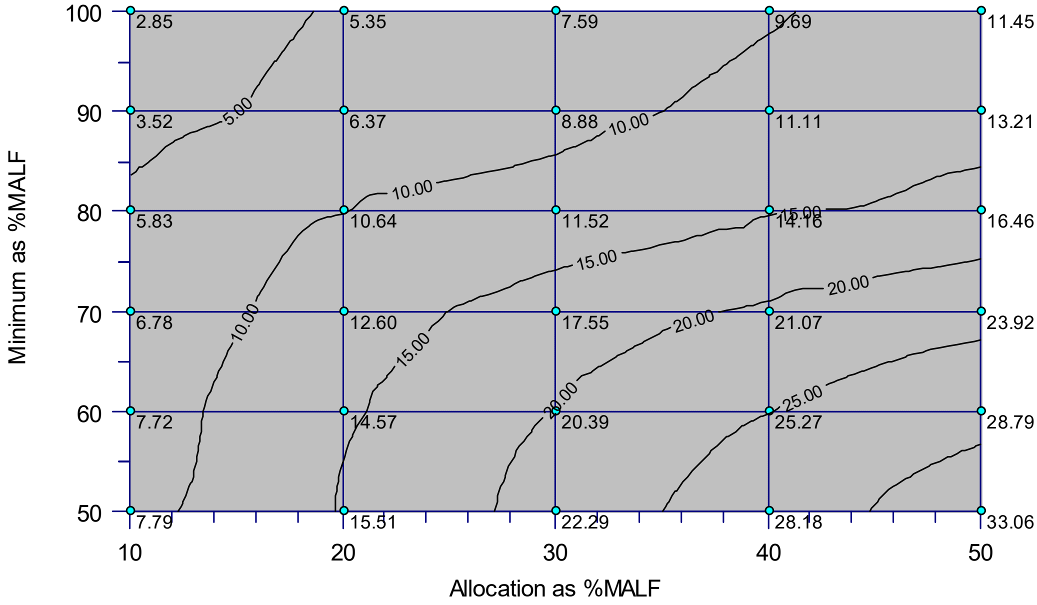

Figure A23: Contours of percent reduction in 30-day MALF from the Waingongoro River. Calculated values are shown at intersections of axes.

14.8 Manganui River at Croyden

The SH3 site on the Manganui River was used as the flow site for the instream habitat survey which was carried out at Croyden Road downstream of SH3. The MALF at SH3 is 0.45 m^3/s and the MALF at Croyden Road is 1.16 m^3/s, so flows at SH3 were multiplied by 2.58 before calculating indices of benthic invertebrate density for high MCI scoring taxa.

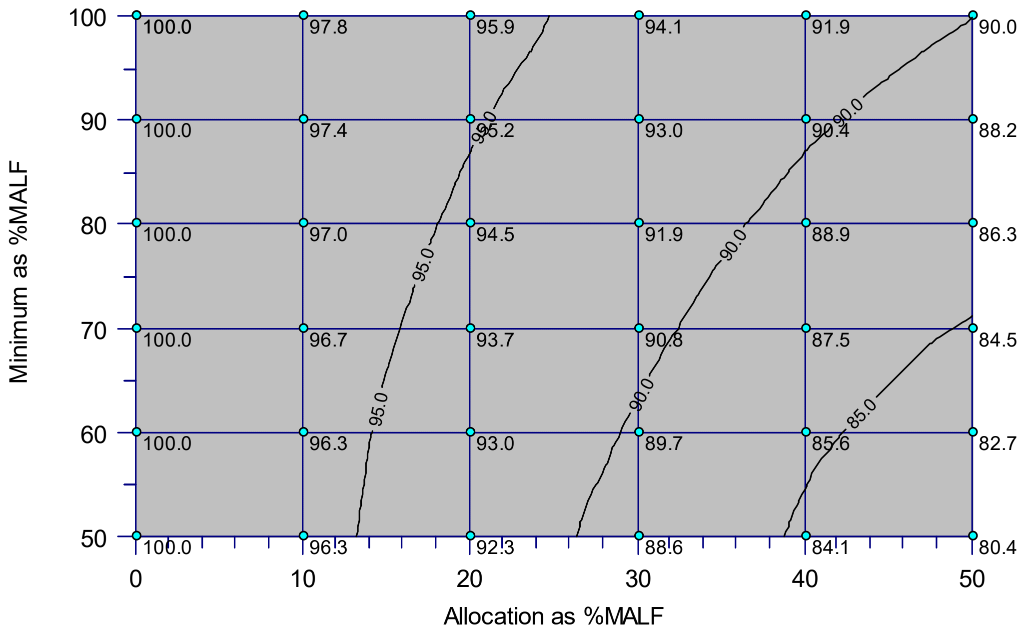

Figure A24: Contours of percent retention in density of high MCI invertebrate species for the Manganui River. Calculated values are shown at intersections of axes.

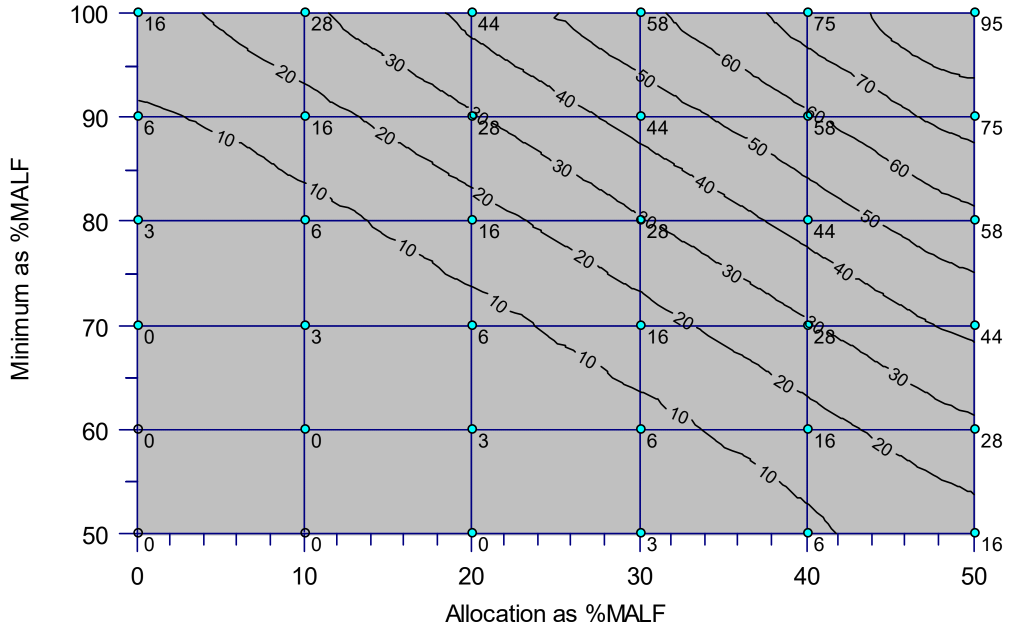

Figure A25: Contours of the average number of days per year of partial restrictions to abstraction from the Manganui River. Calculated values are shown at intersections of axes.

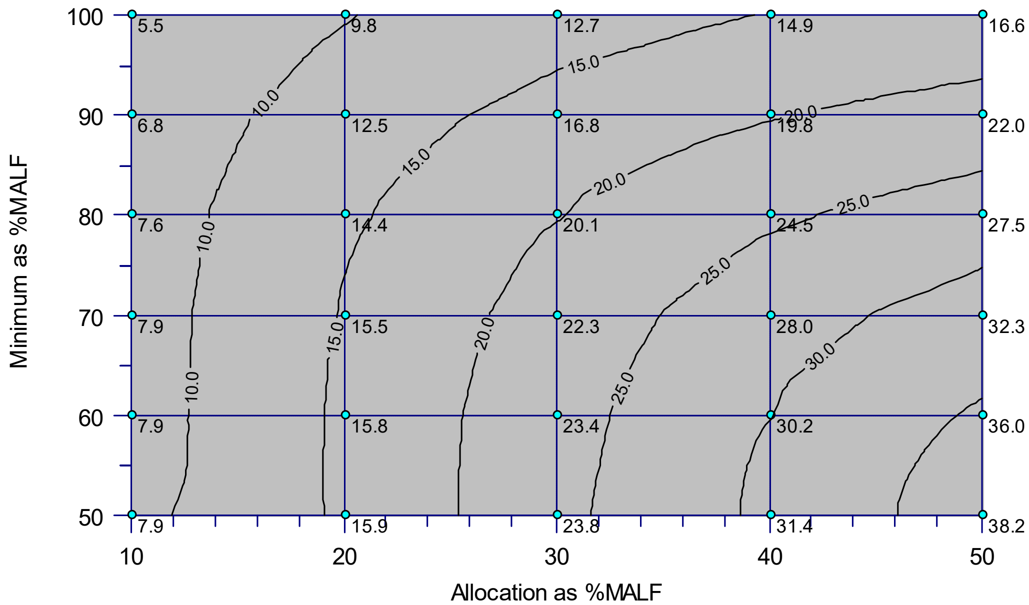

Figure A26: Contours of percent reduction in 30-day MALF from the Manganui River. Calculated values are shown at intersections of axes.

14.9 Waiongana Stream at SH3A

The instream habitat survey data for the Waiongana Stream is described in Jowett (1993).

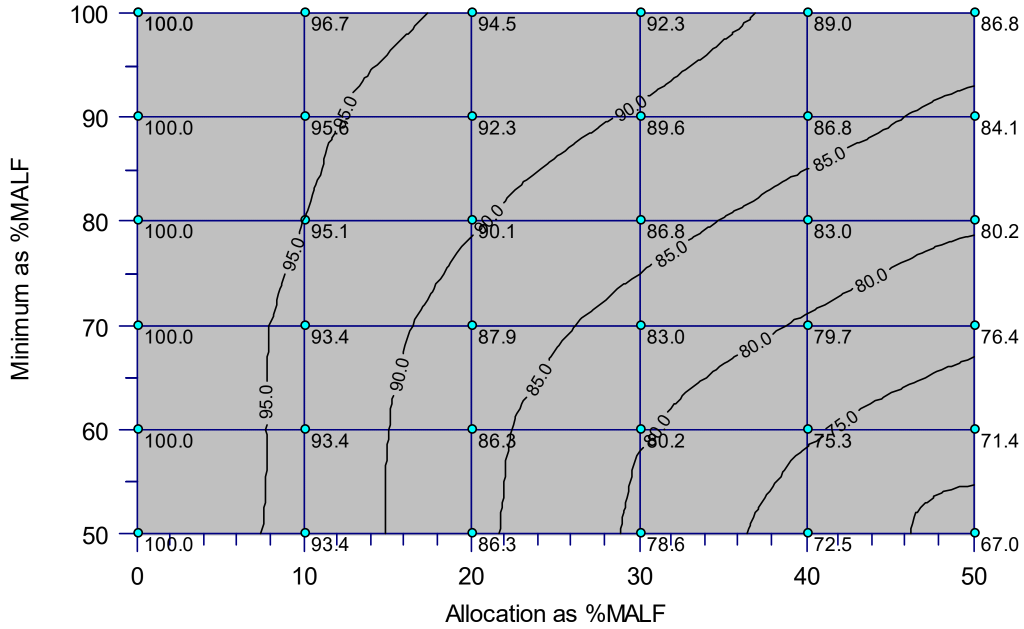

Figure A27: Contours of percent retention in density of high MCI invertebrate species for the Waiongana Stream. Calculated values are shown at intersections of axes.

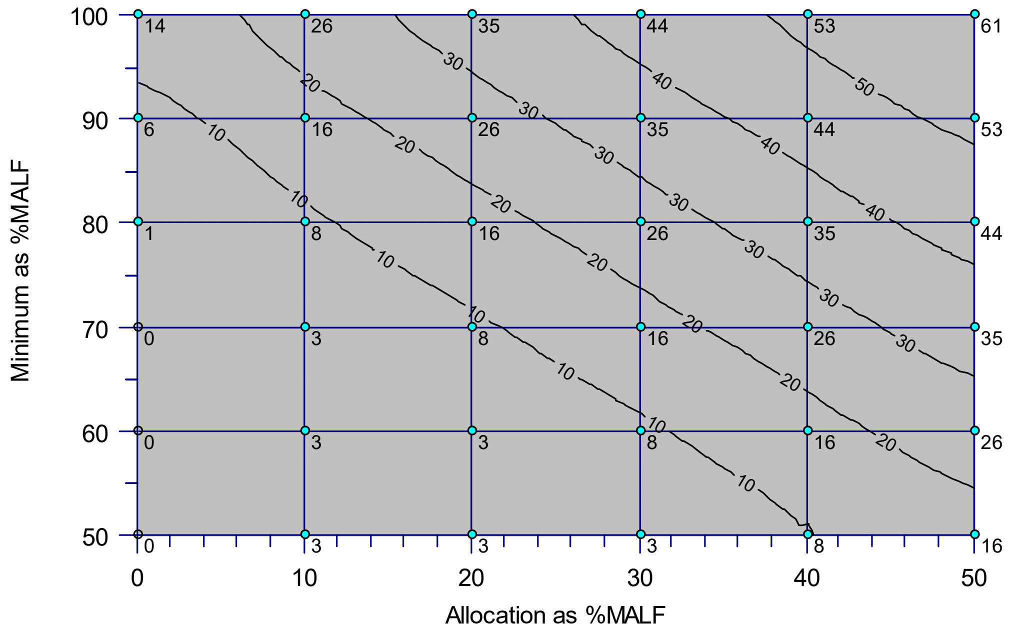

Figure A28: Contours of the average number of days per year of partial restrictions to abstraction from the Waiongana Stream. Calculated values are shown at intersections of axes.

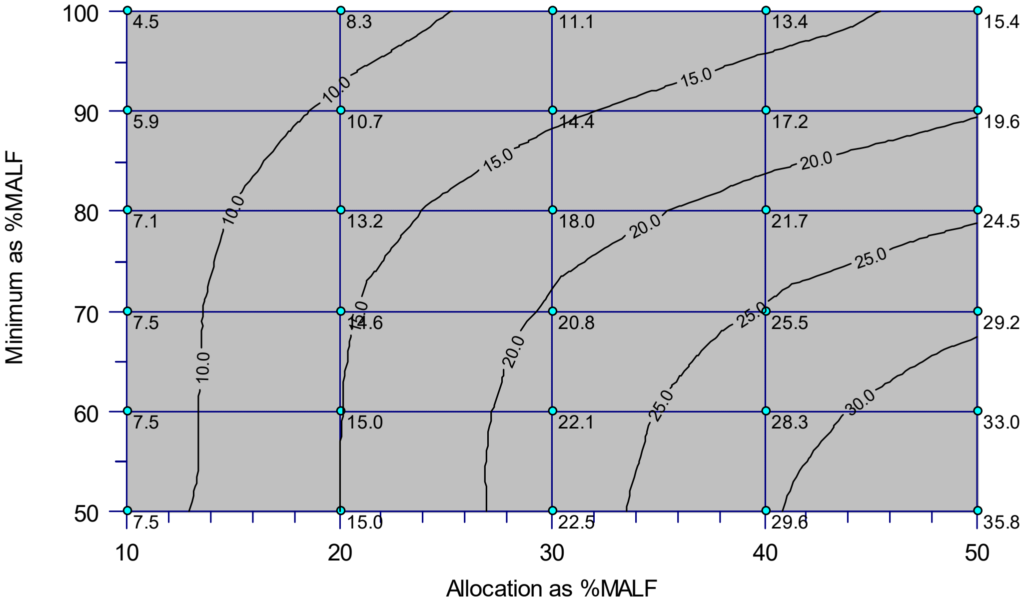

Figure A29: Contours of percent reduction in 30-day MALF from the Waiongana River. Calculated values are shown at intersections of axes.