NIWA
Taihoro Nukurangi

# Definition and calculation of freshwater quantity over-allocation

*Prepared for Ministry for the Environment*

*November 2016*

Prepared by:
D.J. Booker

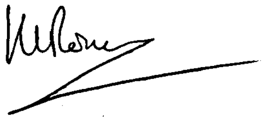
For any information regarding this report please contact:

Doug Booker
Scientist
Freshwater Ecology
+64-3-348 8987
Doug.Booker@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 147
Ruakaka 0116

Phone +64 9 432 5500

| | |
|---|---|
| NIWA CLIENT REPORT No: | 2017017CH |
| Report date: | November 2016 |
| NIWA Project: | MFE17xxx |

| Quality Assurance Statement | | |
|---|---|---|
|  | Reviewed by: | Helen Rouse |
| | Formatting checked by: | America Holdene |
|  | Approved for release by: | Charles Pearson |

© All rights reserved. This publication may not be reproduced or copied in any form without the permission of the copyright owner(s). Such permission is only to be given in accordance with the terms of the client's contract with NIWA. This copyright extends to all forms of copying and any storage of material in any kind of information retrieval system.

Whilst NIWA has used all reasonable endeavours to ensure that the information contained in this document is accurate, NIWA does not give any express or implied warranty as to the completeness of the information contained herein, or that it will be suitable for any purpose(s) other than those specifically contemplated during the Project or agreed by NIWA and the Client.

# Contents



## Tables



## Figures

## Executive summary

The National Policy Statement for Freshwater Management (NPS-FM) states that limits for the use of water resources should be set in regional plans to manage the potential cumulative impacts of abstraction. These limits must comprise at least a minimum flow (the flow below which all abstractions should cease) and a total allocation rate (the maximum rate of abstraction). Defining these limits is important for establishing a definitive level of environmental protection and clarifying availability of the water resource to users. Comparing these limits against water use from active consents and permitted activities characterises the status of water allocation on paper, including under-allocation or over-allocation. This is important because the NPS-FM provides direction to councils to reduce allocation of water in over-allocated catchments. However, there are considerable and practical difficulties in defining water resource use limits and subsequently calculating over-allocation because:

- over-allocation will vary through time and across river reaches even within the same catchment;
- the hydrological effects of permitted activities (legitimate abstractions that are not consented, but allowed by regional plans or the Resource Management Act) are unknown, yet these effects must be accounted for;
- variability in the way in which consent conditions are expressed complicates calculation of total allocation; and
- the effect of restrictions (consent conditions that dictate when abstraction must reduce or cease) should be incorporated when calculating over-allocation.

These complications mean that unless a methodology for calculating over-allocation is predefined, it is likely that regional and district councils will apply a variety of methods for determining over-allocation. This will create potential for disputes between abstractors and environmental advocates about over-allocation status, and thus cause difficulty for water managers. Despite these complications, there are possible methods for calculating over-allocation which could be applied uniformly across New Zealand and would address some of/all the issues outlined above. In this report, methods are outlined for the following:

- Expression of water resource use limits (minimum flows and total allocations) at control points, including methods for unscaling (per unit catchment area, or as percentages of flow statistics) to assess the relative magnitude of the limits across catchments in addition to being expressed in absolute units of flow. Minimum flows can be expressed as proportions of low flow statistics and as positions of the flow duration curve. Total allocations cannot be expressed as positions on the flow duration curve. The position of the management flow (minimum flow + total allocation) can be expressed as a position on the flow duration curve, but only when all abstractions are controlled by the same minimum flow. This is rarely the case as many abstractors have either different minimum flows or some will not have a minimum flow.
- Expression of allocation within catchments by plotting total upstream allocation against estimated naturalised median flow for each impacted reach across a catchment, whilst also expressing the size of each reach, the proportion of reaches in

the catchment influenced by consented takes, and the allocation status at the outlet to the sea.

- Expression of allocation between catchments by calculating the Weighted Allocation Impact (WAI). This is an index that integrates magnitude and spread of allocation across an entire catchment.

These methods could be used to calculate nationally consistent estimates of allocation status. WAI for all major catchments in New Zealand is calculated using consents active in February 2014. However, the calculations applied were complex in nature. This indicates that adoption of these methods (or similar methods) nationally would require the publication of clear explanations for methods of calculation, or availability of a common tool which could be used by all councils to apply the same methods.

# 1 Background

Pressures on water resources in New Zealand result from widely distributed abstractions for both irrigation and drinking purposes, as well as hydro-electric power generation from dams and diversions on some larger rivers. In comparison to other countries, New Zealand's climate and topography results in relatively short, steep rivers with high precipitation falling as both rainfall and snow, creating relatively flashy flow regimes with little capacity to store or manipulate flows. There is high demand for water use coupled with a lack of practical engineering solutions to strategically manipulate water resources.

The National Policy Statement for Freshwater Management (NPS-FM) requires regional councils to set limits on the maximum use of water resources in their regional plans and to establish methods to avoid over-allocation. The intention is that these limits would provide clarity regarding water availability for public, industrial, and agricultural uses whilst also ensuring protection of cultural and environmental values such as maintaining river ecosystem characteristics and functions.

In theory, setting limits for the use of a water resource would inform on the state of water availability for both present and potential users through some form of comparison between the limits and present allocation. This type of comparison would clarify which water bodies are under, fully, and over allocated. These are important tasks that would inform councils in their water allocation processes. However, no practical guidelines have currently been issued to regional and district councils describing how over-allocation should be calculated. For example, neither the mathematical form of this comparison, nor the temporal and spatial scale at which it should be applied have been clearly described. Lack of a mathematical definition of over-allocation and practical procedures for its calculation or communication may cause:

- wasted effort as each council devises its own definition, calculation and procedure;
- an inability to compare results across regions due to inconsistency in methods applied across councils;
- lack of consensus between water resource users and managers of in-stream values regarding allocation status; and/or
- potential for councils to be accused of choosing a method that deliberately favours exploitation of water resources over maintenance of in-stream values or *vice versa*.

This report describes several issues that would have to be considered and resolved when answering the question: "where limits have been set, which water bodies are under, fully, and over allocated?" Examples and summary statistics taken from work undertaken for the Ministry for the Environment (MfE) for environmental reporting purposes are given to demonstrate these issues. A potential solution for resolving these issues is then proposed.

# 2 Definition of water resource use limits, over-allocation and headroom

The NPS-FM requires councils to use regional water management plans (RWMPs) to establish freshwater objectives and enforceable water resource use limits in the form of both water quality and water quantity limits for all bodies of freshwater. The amendments to the NPS-FM (New Zealand Government 2014) attempt to clarify three key concepts relating to water quantity resource use limits (hereafter referred to as “limits”) to be set in RWMPs:

1. A freshwater objective is a statement of what will be achieved, or a desired environmental outcome in a freshwater management unit. These objectives may be expressed at different levels of detail or precision. For example, there may be regional freshwater objectives, but a detailed objective may relate to a part of a water body or catchment.

2. Limits and management methods (including rules) are set to ensure freshwater objectives are met.

3. A freshwater management unit is the water body, multiple water bodies or any part of a water body determined by the regional or district council as the appropriate scale for setting freshwater objectives and limits for freshwater accounting and management.

The NPS-FM implementation guide (MFE 2015) states that water quantity limits must account for the cumulative effects of all takes, whether by consented or permitted activities (some activities such as taking of water for domestic use, fire-fighting and stock drinking water do not currently require consents under Section 14 of the Resource Management Act). Consents are also often not required for certain purposes provided that rate of take does not exceed a specified threshold as specified within a rule of a regional plan. Accounting for cumulative effects raises the expectation that adverse cumulative effects will be avoided. Limits must be set in order to meet freshwater objectives and avoid over-allocation. Over-allocation is defined in the NPS-FM as the situation where the water resource either has been allocated to users beyond a limit or is being used to a point where a freshwater objective is no longer being met (MFE 2011).

It follows that under-allocation could be defined as the situation where the water resource either has been allocated to users below a limit or is being used in a manner that enables all freshwater objectives to be met. The former situation could be described as one with future headroom (more takes can be added without breaking the pre-defined limits). The latter situation could be described as one with collective headroom (i.e., abstractors are collectively operating in a manner that is consistent with the freshwater objectives that have been set, possibly by not utilising their consents fully and therefore not breaking water resource use limits such as minimum flows or total allocations). In this situation there is headroom for existing consents to be more fully utilised, or headroom to grant more consents whilst maintaining freshwater objectives (but only if existing consent holders continue to under-utilise their consents).

The NPS-FM states that, for flowing water, water quantity limits (i.e., environment flows as defined in MFE 2013) must comprise at least a minimum flow ($Q_{min}$) and a maximum allocation rate ($\Delta Q_{max}$). Figure 2-1 shows a graphical representation of $Q_{min}$ which specifies the flow below which no further water is to be taken, and $\Delta Q_{max}$ which specifies the maximum rate of abstraction summed across all upstream abstractors. When these water quantity limits are applied to a single location they have two consequences:

1. the rate of take at any point in time ($\Delta Q_t$) must never exceed $\Delta Q_{max}$; and
2. flow must not fall below $Q_{min}$ unless this occurs in the absence of abstractions (i.e., naturally).

One method for ensuring this second stipulation is to restrict $\Delta Q_t$ at lower flows. To do this the naturalised flow ($Q_t$), which is flow in the absence of any abstractions at time (t) must first be calculated. Restrictions would be required when $Q_t$ is higher than $Q_{min}$ and lower than $Q_{min} + \Delta Q_{max}$. This upper limit defines the management flow ($Q_{man} = Q_{min} + \Delta Q_{max}$). This is the $Q_t$ above which no restrictions are required to ensure $Q_{min}$ is exceeded. See Figure 2-1 for a graphical explanation. Restrictions should protect the minimum flow by ensuring that $\Delta Q_t$ will equal $Q_t$ minus $Q_{min}$. In this context the process of setting limits is interpreted as enforcing target values of $Q_{min}$ and $\Delta Q_{max}$ to ensure that limits are complied with. Target values of $Q_{min}$ and $\Delta Q_{max}$ are hereafter referred to as "the limits".

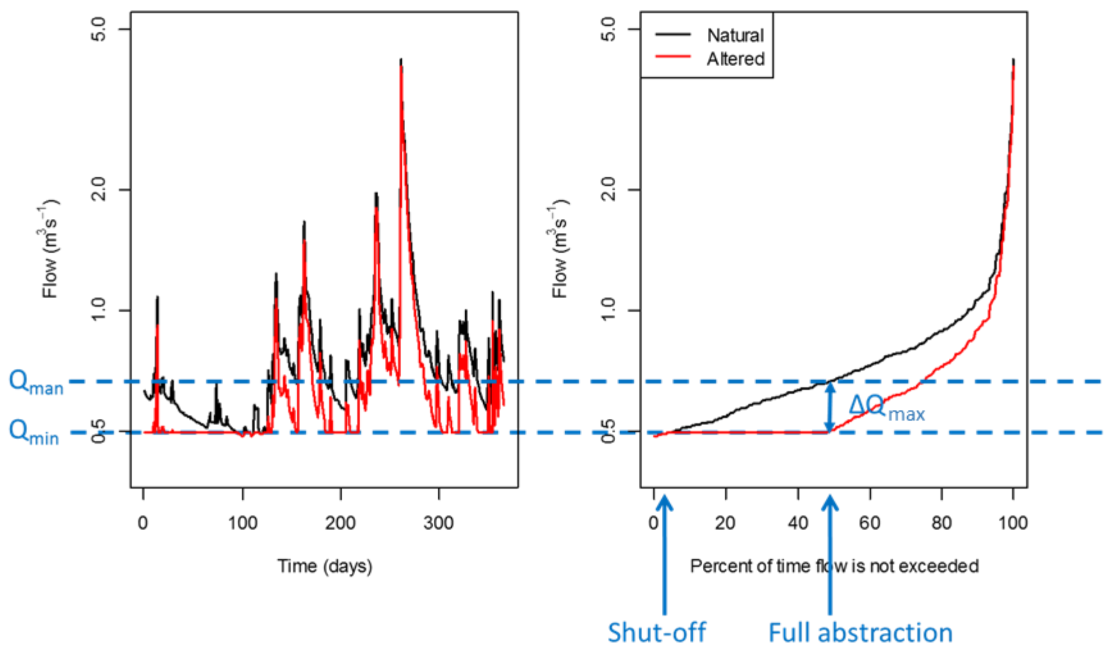



**Figure 2-1: Hypothetical example hydrograph (left) and flow duration curve (right) under natural and altered flow regimes.**

A change in either $Q_{min}$ or $\Delta Q_{max}$ involves a three-way trade-off between:

- minimising alteration of natural river flows, and therefore ensuring minimal impact on (but not necessarily optimisation for) in-stream values;
- ensuring reliability of water supply for longer periods of time; and
- allowing larger volumes of water to be abstracted.

A change to either of $Q_{min}$ or $\Delta Q_{max}$ necessitates a change in all of these points. Minimising alteration of natural river flows always comes at the expense of reduced reliability or allowing smaller volumes to be taken.

# 3 Are the limits protective of freshwater objectives?

The NPS-FM states that over-allocation can occur under either of two clauses. These clauses relate to whether the water resource:

- Clause A) has been allocated beyond a limit; or
- Clause B) is being used to a point where a freshwater objective is no longer being met.

From a management and policy perspective in the NPS-FM, allocation and over-allocation in relation to water quantity is treated separately from allocation and over-allocation managed in relation to water quality, but recognises that there are clear connections between the two. For the purposes of this report water quantity issues only are discussed in the following.

Let us assume that freshwater values (e.g., no excessive build-up of nuisance algae) have been agreed upon, and measureable objectives have been defined (e.g., mean chlorophyll *a* should not exceed 120 mg $m^{-2}$ on average for 11 out of 12 monthly surveys over the course of a year). Clause A would appear to implicitly assume that the limits are adequately protective of freshwater objectives, but that these rules are not being adhered to. Clause B would appear to assume that the limits are either not adequately protective of freshwater objectives, or that the resource is being used beyond the limit despite allocation being under the limit. Prior to calculating over-allocation, either case leads to the question; to what extent are the limits protective of freshwater objectives? This question may be impossible (or very expensive) to answer definitively due to various issues:

1. There are uncertainties in how much water is actually being taken due to:
   a. inaccuracies in measuring takes;
   b. non-recording of many small takes because permitted activities and permits that only allow water to be taken at a rate of less than 5 litres/second are not required to supply records of takes under the Resource Management (Measurement and Reporting of Water Takes) Regulations 2010; and
   c. inconsistencies in temporal resolution (15 minute, hourly, daily, monthly, annually) of take data.
2. There are uncertainties in relationships between time-series of takes and time-series of river flows because:
   a. estimating quantity and timing of stream flow depletion from groundwater takes is uncertain; and
   b. some abstracted water may augment river flows via unrecorded return flows (e.g., from a raceway that takes water from a river, but then partially flows back to a river) or seepage (e.g., as would occur through inefficient irrigation practices).
3. There are uncertainties in the relationships between river flows and freshwater attributes because, in addition to being influenced by river flows, ecological attributes (e.g., periphyton, macrophytes, invertebrates, fish, birds) may be influenced by:
   a. nutrients concentrations;
   b. sediment state and transport;

c. physical habitat and geomorphological template;

d. dissolved oxygen;

e. temperature;

f. other various pollutants;

g. traits or the presence of invasive species (didymo or trout); and

h. various biotic interactions, characteristics and processes such as trophic interactions (feeding and the food chain), resistance (ability not to change under stress) and resilience (ability to return to pre-stressed state).

4. Freshwater objectives may not be being met due to issues other than flow alteration because attributes can be stressed or influenced by:

   a. any factor stated in Points 3 a-f above; and

   b. naturally occurring low flows.

5. Both the frequency and duration of both low and high flow events can influence freshwater values.

6. There is natural spatial variability in flows and the states of freshwater values.

   a. The relative influence of a single take will diminish with distance downstream and as tributaries add more flow to the river.

   b. There may be critical locations such as spawning habitat or river mouth openings that more strongly influence a freshwater attribute than other locations.

   c. Some locations have naturally occurring low flows, and therefore naturally stressed ecological states.

7. There is spatial variation in freshwater values.

   a. Some attributes will be highly valued in some locations, but be less highly valued (or not relevant) in other locations. For example, several threatened native fish species are restricted to specific regions or catchments. Alternatively, some species considered culturally important for food gathering may be important in some locations, but not in others.

Regardless of these issues, it would be informative to assess the relative magnitude of the limits for all locations prior to an assessment of over-allocation. This could be achieved by expressing $Q_{min}$ and $\Delta Q_{max}$ in units that account for scale (size of river or catchment). For example, $Q_{min}$ and $\Delta Q_{max}$ could be expressed as proportions of the naturalised (i.e., not impacted by abstraction) 7-day Mean Annual Low Flow (MALF) or median flow ($Q_{50}$; the flow that is not exceeded 50% of the time). Alternatively, calculation of the proportion of the time that $Q_{min}$ and the management flow ($Q_{man} = Q_{min} + \Delta Q_{max}$) would be not exceeded under natural flow conditions would be informative and relatively simple to calculate. For example, a situation in which $Q_{min}$ and $Q_{man}$ would be not exceeded under natural flows for 40% and 50% of the time respectively would be very environmentally conservative. This situation would also provide low volumes of water with low reliability. This is because the flow would have to be moderately high before any abstractions were allowable, and total allocation would be relatively low compared to naturally occurring river flows. Conversely, a situation in which $Q_{min}$ and $Q_{man}$ would be not exceeded under natural flows for 2% and 50% of the time respectively would be very resource enabling (Figure 2-1). This situation would also provide high reliability of being able to abstract some, but not all allocated water. This is because the flow would have to be extremely low before restrictions were applied, and total allocation would be very high compared to naturally occurring river flows. This situation would also provide a low relatability of being able to abstract all allocated water.

Any of these methods requires reliable estimates of naturalised flows. Flow duration curves describe the proportion of time for which each flow is not exceeded for a particular location. Nationwide predictions of naturalised flow duration curves and various hydrological indices have been calculated and their uncertainties have been quantified (Booker and Snelder, 2012; Booker and Woods 2014; McMillan et al., 2016). For example, Figure 3-1 shows maps of MALF represented as absolute flow rates and as flow rates per unit catchment area. The figure shows that larger rivers generally have larger low flows, but that there is also considerable variation in low flows between rivers of the same catchment area across the country.

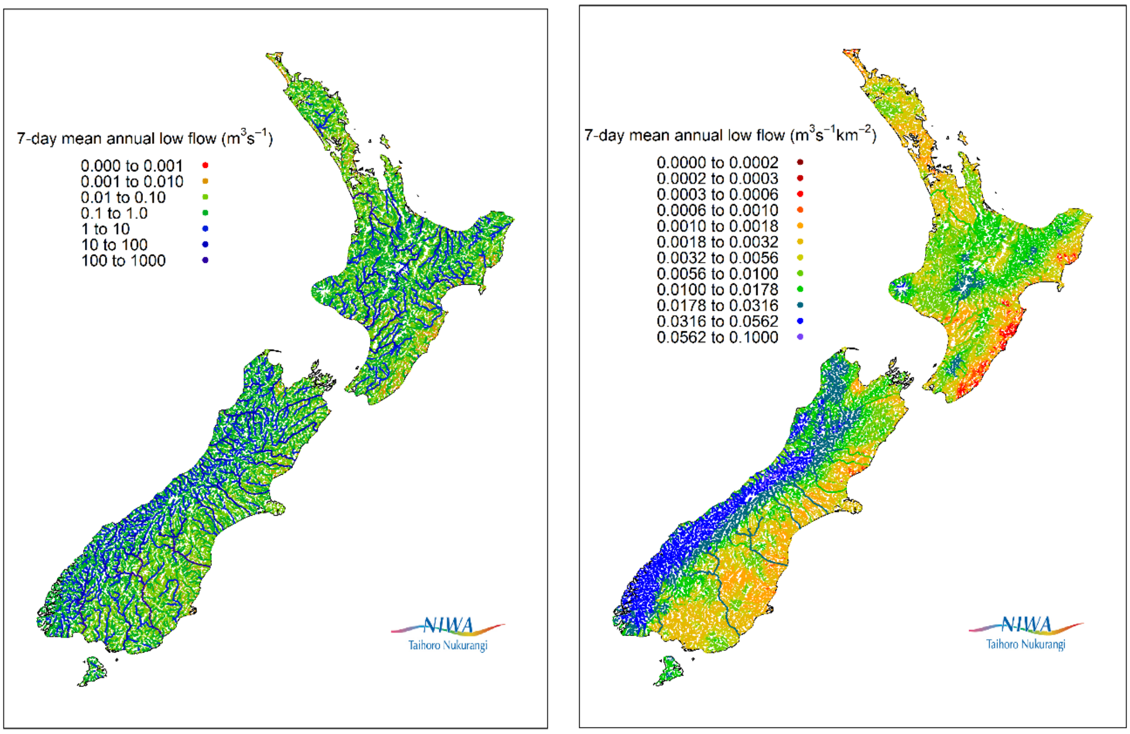



**Figure 3-1: Predicted mean annual low flows across New Zealand in absolute units (left) and standardised by catchment area (right).**

# 4 Complicating issues for quantifying over-allocation

There are several complicating issues that hamper simple assessments of: a) the utility of limits where they have been set; and b) to what extent over-allocation has occurred.

## 4.1 Spatial issues

If limits are set as proportions of hydrological indices (e.g., MALF or the flow that is exceeded 95 percent of the time) then the same limits may be set strategically (at multiple locations along a river, across a catchment or across a region). Although these limits are specified using spatially uniform rules, they will equate to different flow rates at each location in the river network due to natural variations in hydrology (Booker and Woods, 2014). However, spatially uniform limits will not lead to spatially uniform consequences across New Zealand for either in-stream values such as physical habitat for particular fish species or out-of-stream values such as reliability of water supply (Snelder et al., 2011). This is because flow-habitat relationships are not the same shape for all rivers (Booker, 2016), flow duration curves are not the same shape for all rivers (Booker and Snelder, 2012), and the position of MALF on the flow duration curve is not the same for all rivers.

Whilst the NPS-FM requires limits that account for the cumulative effects of multiple takes and therefore avoid over-allocation, little guidance is currently available on the spatial and temporal resolution at which these limits must be implemented in RWMPs. Furthermore, little guidance is available on the spatial and temporal resolution at which over-allocation must be assessed. For example "the geographical and temporal definition of over-allocation will relate to the detail of the freshwater objective for a particular freshwater body" (MFE, 2011, p24). Since limits are intended to enable freshwater objectives to be met, the spatial resolution at which limits are implemented might be expected to relate to the spatial resolution of freshwater objectives. However, the NPS-FM states that freshwater objectives can be set at a variety of scales and levels of detail, and may be narrative or numeric. The NPS-FM implementation guide states that "A freshwater management unit (FMU) should not be set at too large a scale, which may prevent the setting of freshwater objectives that are specific enough to be effective. Equally, an FMU should not be set at too small a scale, which may result in undue complexity and cost in the planning process or in the management of the FMU".

At the coarsest spatial resolution, limits may be implemented solely at the point where each catchment flows into the sea. This means that all upstream processes are integrated *en mass*. Alternatively, if limits are defined as proportions of hydrological indices (e.g., MALF as in the proposed National Environmental Standard for ecological flows and water levels; MFE, 2008), then the spatial resolution that limits could be applied at is only limited by the spatial resolution at which these hydrological indices can be observed or estimated. For example, estimates of MALF have been calculated for every reach in the New Zealand river network (Booker and Woods, 2014), which is comprised of 570,000 reaches with an average length of ~700 m. Individual limits could therefore, in theory, be implemented at every location throughout the river network. However, it is impractical to enforce limits at such a fine spatial resolution as this would require discharge to be continuously monitored at the location of each individual take. In practice it is far more likely that water resource limits implemented in RWMPs would be enforced using observed hydrological data from particular locations (e.g., hydrological gauging stations) towards the downstream end of a catchment in order to aggregate water resource use across that catchment. This is important because different implementation strategies (managing the number and allowable rate of takes, or allowing transfer of consents between different abstractors) may ensure that particular limits are met at a downstream monitoring point, but may not guarantee that these limits are complied with (or that freshwater objectives are being meet) elsewhere in the catchment. Conversely, a large take just upstream of the monitoring point might imply that no water is available across a catchment when in fact there is not abstraction upstream of the that take. These situations arise because the connected and hierarchical nature of river networks control how takes will combine to have cumulative effects (i.e. the sum of all takes accumulates in the downstream direction, but flow also naturally [usually, but not always] increases with distance downstream). As a result, the value of supplying a cubic metre of water per second may be the same for two abstractors in different locations within the same catchment, but the influence of a cubic metre of water per second for maintaining ecological values is highly influenced by the size and flow rate in the river that is being depleted. Consequently, once rules to define a minimum flow and an allocation rate have been established, differences in how these limits are implemented can lead to vastly different outcomes for both water users and the flow regime across a catchment (Booker et al., 2014).

## 4.2 Free format to consents

To date there has been no nationally consistent format which must be followed when specifying consent conditions. The format for specifying consent conditions has therefore varied between regions and through time within regions. This has led to a proliferation of the ways in which consents act to control abstractors. This freedom has allowed flexibility within the consenting process, however, it has also caused difficulties when quantifying total allocation or when calculating consent compliance. Some common issues are outlined below with examples from real consents:

1. Activities within consents
   a. Sometimes a separate consent is issued for each activity (e.g., drinking, irrigation, frost protection) for each abstraction.
   b. Sometimes one consent is issued with separate rates of take or other conditions for each activity for each abstraction. As an example, ECan’s consent number CRC950458.2 has two activities; activity number ACT064777 to take 3888 l/s for Irrigation, Pasture – mixed and activity number ACT065209 to take 6 l/s for Domestic Use.
   c. Sometimes one consent is issued with one rate of take covering all activities for each abstraction (e.g., "To take water from an unnamed tributary and use it for purposes of storage, irrigation and frost protection").
2. Records and locations of take within consents
   a. Sometimes a separate consent is issued for each location at which water is abstracted (e.g., "to take water from Warrens Creek at or about map reference O31:644-682 for the purpose of irrigating up to 60 hectares.").
   b. Sometimes a consent is issued which covers multiple locations from which water can be taken by the same abstractor (e.g., “to take water from Weilys Drain, Robertsons Drain and Murdochs Drain, at or about map references K37:984-813, K37:988-816 and K37:991-816 for irrigation of up to 120 hectares.”).
3. Multiple abstractors sharing the same location of take

a. Sometimes multiple abstractors (each with their own consent conditions) can all be abstracting from the same location (e.g., one groundwater bore or raceway supplies many users).

4. Constant versus seasonally varying consent conditions

   a. Some consents have a maximum rate of take that applies uniformly across the year.

   b. Some consents have seasonally varying maximum rates of take (e.g., different maximum rates of take or different minimum flows for each month of the year as is the case for some consents in the Hurunui catchment in Canterbury).

5. Consent duration

   a. Some consents have been issued with a fixed term (e.g., the majority of consents in the Bay of Plenty region expire 10 years from their issue date).

   b. Some consents have been issued with a common expiry date across catchments (e.g., many consents in the Christchurch/West Melton Zone in Canterbury are set to expire around 2032).

6. Some consents contain conditions which act to maintain minimum flows or limit total allocations. These are known as restrictions. Because consents have taken a free format, restrictions can come in many forms:

   a. Annual, monthly, weekly or daily volume is less than instantaneous rate (e.g., instantaneous rate of take can be 1 $m^3s^{-1}$, but daily allowable volume is less than 86,400 $m^3$ [the number of seconds in a day]).

   b. On or off depending on comparison between a "trigger condition" and monitoring data describing a control variable (e.g., no abstraction when Selwyn River at Coes Ford is flowing less than 1 $m^3s^{-1}$). Note that the control variable is typically river flow or groundwater level, but could be any continuously monitored variable (e.g., river water temperature or conductivity).

   c. Even days and odd days (e.g., no abstraction on even days of the month when the Ruamahanga River at Wardells Bridge is flowing less than 2.7 $m^3s^{-1}$).

   d. Sliding scale or ramping, also known as flow sharing (e.g., no abstraction when Selwyn River at Coes Ford is flowing less than 1 $m^3s^{-1}$, full abstraction when it is flowing more than 2 $m^3s^{-1}$, proportional abstraction between 1 and 2 $m^3s^{-1}$.

   e. Residual flows are often used to ensure minimum flows below dams or large diversions (e.g., take can be any amount as long as a flow of 10 $m^3s^{-1}$ is maintained below the dam).

   f. All the above conditions may vary in time for each abstractor (e.g., no abstraction when Selwyn River at Coes Ford is flowing less than 1 $m^3s^{-1}$ in January, no abstraction when Selwyn River at Coes Ford is flowing less than 0.9 $m^3s^{-1}$in February …).

   g. All the above conditions may vary between abstractors in the same catchment (e.g., no abstraction for Abstractor A when Selwyn River at Coes Ford is flowing less than 1

$m^3s^{-1}$; no abstraction for Abstractor B when Selwyn River at Coes Ford is flowing less than 2 $m^3s^{-1}$). Variations between abstractors can act to prioritise abstractions. Abstractors with the same triggers are sometimes referred to as being in the same band. A queuing system can be applied if each abstractor's minimum flow is defined as the sum of another user's minimum flow plus maximum instantaneous rate (management flow).

## 4.3 Consented allocation, restricted allocation, recorded take and actual take

Any analysis or debate relating to over-allocation versus headroom and whether freshwater objectives are being met could be applied to either of: the consented allocation; the restricted allocation; recorded takes; or actual takes. Over-allocation may have a different status and a different meaning in each case. The following proposed definitions could apply either to individual abstractors, or collectively when summed upstream of a location:

- Consented allocation = the maximum rate (or volume over a specified time) which can be abstracted regardless of restrictions that act to limit annual volume abstracted or maintain minimum flows. This is sometimes referred to as the "paper take".
- Restricted allocation = the maximum rate (or volume over a specified time) at which abstraction can occur after having taken into account any restrictions.
- Recorded takes = the recorded volume of water being taken (records may have different temporal resolutions: 15-minutely, daily, monthly etc.).
- Actual use = the volume of water being taken regardless of whether it is recorded or not.

Some consents have been issued, but are not being exercised (e.g., for back-up drinking water supplies or for potential future conversion from arable to dairy production). The vast majority of consents that have been issued are not fully exercised. This is because water demand is not constant through the year. There is anecdotal evidence that high water demand and strict restrictions (e.g., Canterbury) encourages use of off-stream storage so that water can be taken when available and used at a later date when restrictions are in place or when supply is limited. Conversely, there is little encouragement to utilise storage where supply is high and restrictions are infrequent (e.g., West Coast).

## 4.4 Temporal issues

There can be strong between-year changes in weather conditions. Warmer temperatures and reduced rainfall will increase water demand for out-of-stream use for irrigation, but these types of conditions will also tend to reduce river flows and groundwater levels. Caruso et al. (2016) demonstrated strong inter-annual variability in river flows for gauging sites across New Zealand. Consequently, neither water demand nor water supply are constant between years. To get a representative picture of long-term water requirements relative to allocation, one needs to look over the long-term with a view to characterising either the long-term mean, probability of high stress (e.g., the 1 in 5 dry year) or full probability distribution.

Between-year variations in weather conditions must be recognised when comparing consented allocation with recorded use. This is because less actual use than consented allocation would be expected in wetter years. Several councils are recognising the effect of temporal variation in water supply and water demand by issuing consents that supply sufficient water for “reasonable needs” (e.g., on average, eight years out of ten have at least 80% reliability). This means that in some years abstractors would be allocated more water than would be required for efficient irrigation, but in two dry years out of ten there would be a shortfall. This type of approach requires a working definition of “reasonable needs”.

It should also be recognised that the natural timing of low flows (Figure 4-1) does not always coincide with peak water supply demand, and that there is considerable spatial and inter-annual variability in patterns of natural low flows (Figure 4-2). For this reason seasonal or monthly flow duration curves may be informative (Booker and Snelder, 2012).

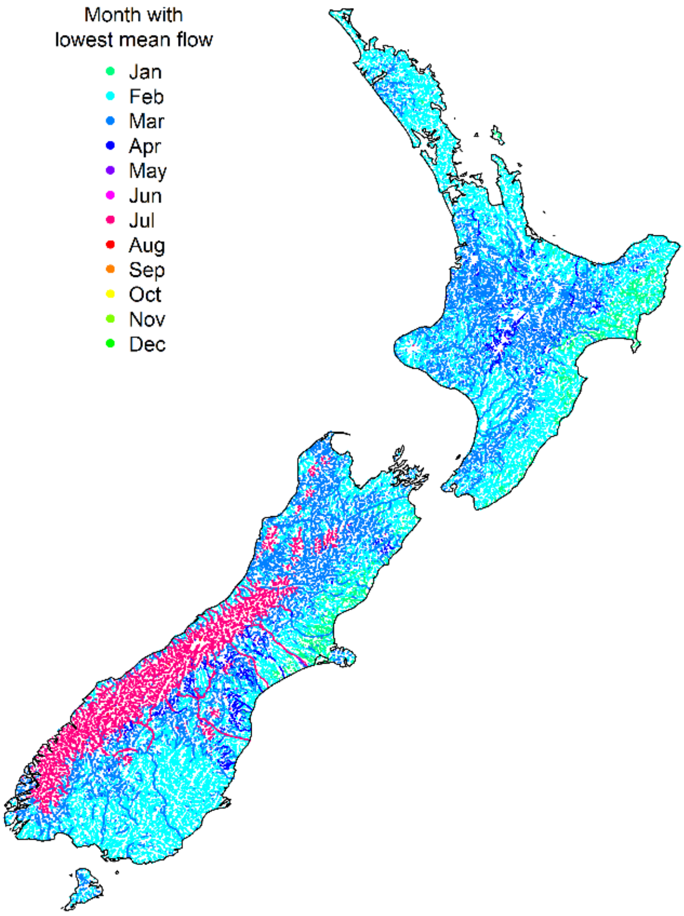



**Figure 4-1: Predicted month of lowest mean flow across New Zealand.**

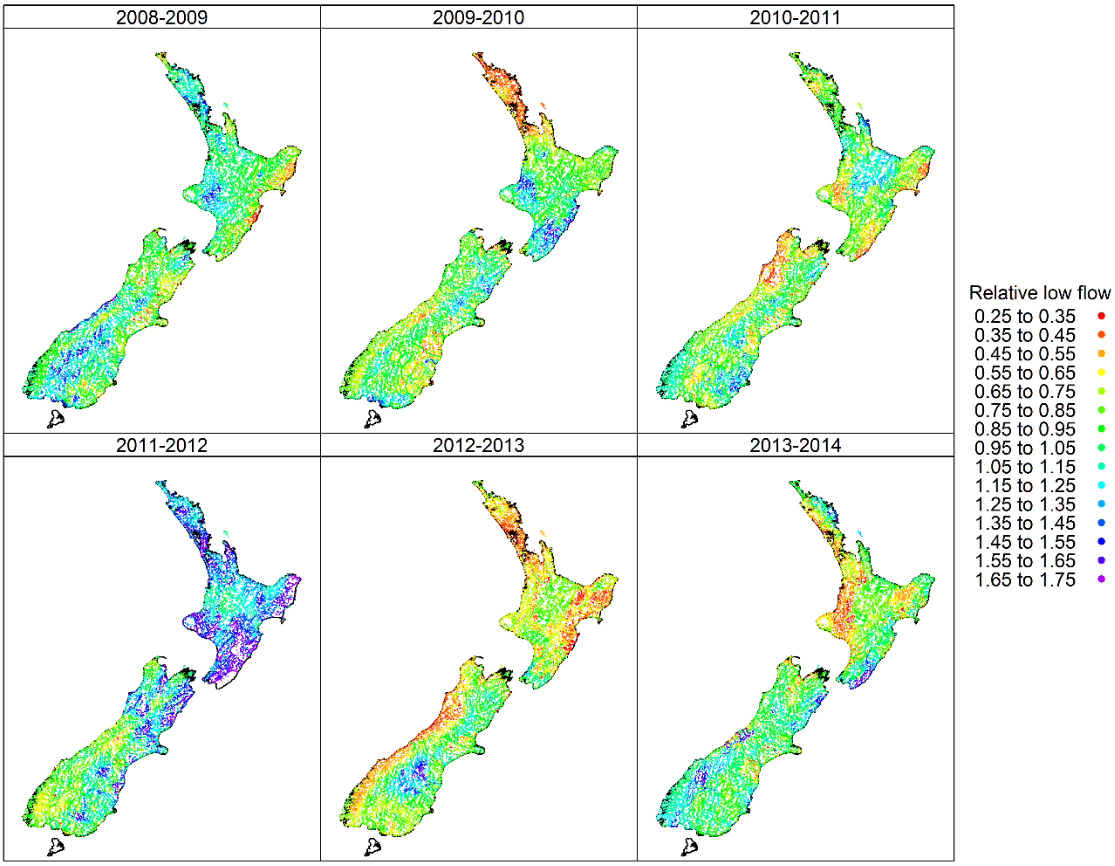



**Figure 4-2: Predicted low flow for hydrological years relative to the long-term mean as calculated from uncalibrated national TopNet model.**

## 4.5 Efficient irrigation

Ideally, each consent would not allow more water to be taken than would be required for efficient irrigation. However, specification of consent conditions to continuously allow for efficient irrigation is difficult because efficient irrigation will depend on weather conditions, area being irrigated, soil type and crop type.

## 4.6 Permitted and consented activities

The NPS-FM states that water quantity limits must account for the cumulative effects of all takes, whether by consented or permitted activities. Some regions tend to issue consents for activities such as stock water (37 and 34% of consents in the Horizons and Waikato regions respectively were recorded as having Stockwater as their primary use). This allows the effects of these activities to be explicitly included in assessments of over-allocation. Other regions tend to not issue consents for activities such as stock water (only 3 and 8% of consents in Wellington and Taranaki regions respectively were recorded as having Stockwater as their primary use). The effects of permitted activities have to be estimated. Methods for this estimation (e.g., number of cows multiplied by number of litres of water required for stock water estimates) have been applied in some regions, but they are uncertain and may not be transferable between regions. The importance of permitted activities will vary depending on the intensity of the activity and the size of rivers. For example, permitted activities such as stockwater takes could be important in locations with small rivers and high stocking density (e.g., Northland) in comparison to locations with large rivers and low stocking density (e.g., West Coast).

## 4.7 Historical legacies

Consents do not allow the indefinite right to abstract. Each consent has a commencement and termination date (Figure 4-3). The duration of consents and timing or consent expiry dates has important implications for RWMPs and development of water management policies. This is because, unless all consents are reviewed, councils cannot influence existing consented activities. This has particular consequences when a council is seeking to claw-back consents in over allocated situations. In these situations a council may have to wait many years before total allocation can be reduced. This may lead to new applications being allocated less resource to compensate for older applications that have previously been allocated more resource. Importantly, consents needs a condition to specify under what circumstances it can be reviewed. If this condition is present then review are easier. Without such a condition, council have to fall back on general RMA duty to avoid adverse effects which may be harder to prove, therefore councils tend to let consents run to their full duration unless exception circumstances arise.

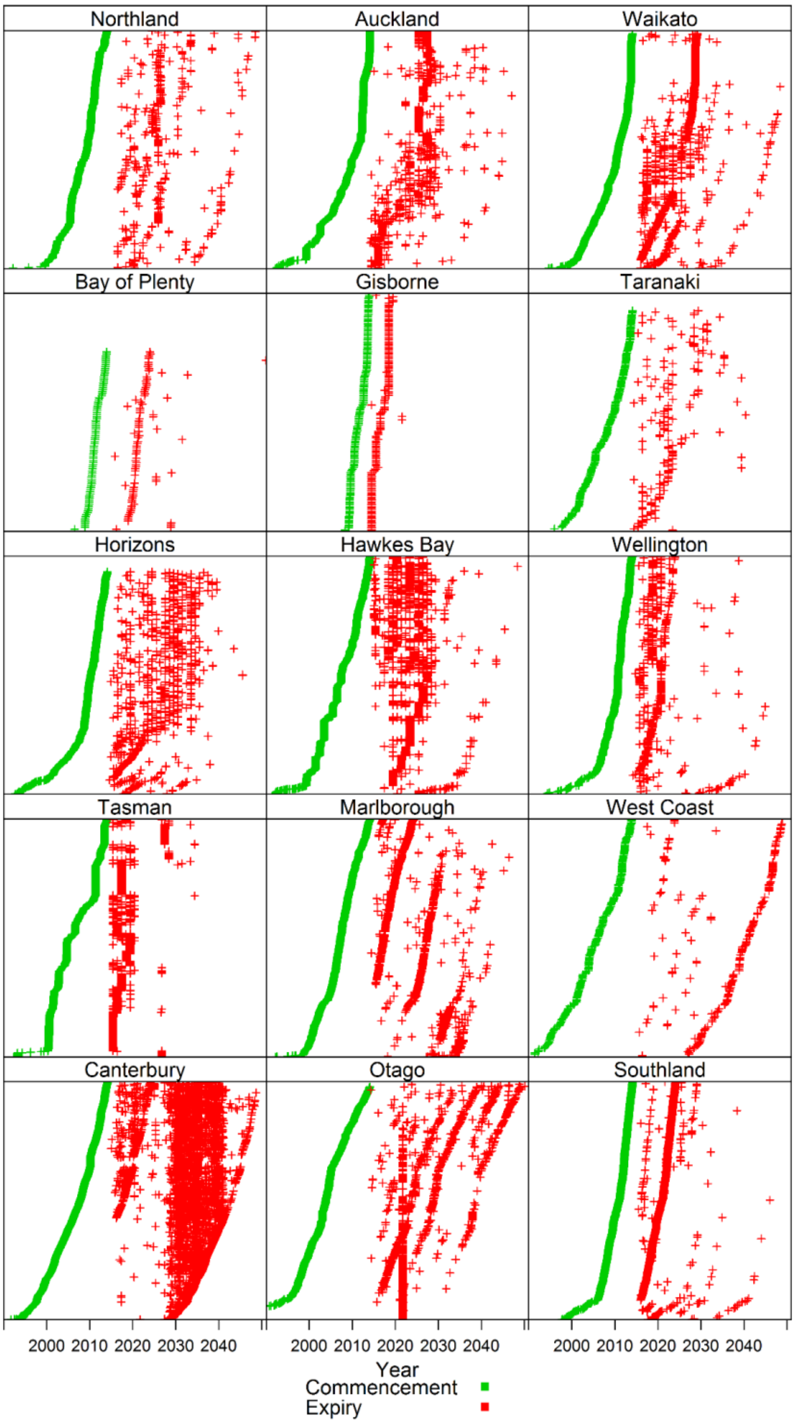



**Figure 4-3: Timings of all active (14/02/2014) consents by region.**

It should also be noted that more recent consents may include restrictions controlled by minimum river flows or groundwater levels. However, older consents may have not included similar conditions. This has led to the situation where a minimum flow (and total allocation) may be stated in a RWMP, but only a small proportion of consents are actually controlled by that minimum flow condition. For example, approximately 22% of ECan's consents are linked to conditions at a control site.

## 4.8 Stream flow depletion from groundwater abstraction

There are approximately twice as many groundwater consents across New Zealand than there are surface water consents, but approximately half of abstracted water is from groundwater. There are several important differences between groundwater and surface water abstractions that may influence calculation of over-allocation:

- Spatial influences
  - It is relatively easy to determine which (and to what extent) river reaches are depleted by a surface water take.
  - It is not very straightforward to determine which (and to what extent) river reaches are depleted by a groundwater take.
- Temporal effects
  - Rivers in New Zealand are typically short and relatively rapidly flowing. River flows therefore respond quickly to abstractions (the effects of abstraction can be seen at downstream gauges within hours). It is therefore sensible to manage abstractions on a daily basis according to river flows (this is typically how restrictions have been applied to surface water takes).
  - Groundwater levels in New Zealand are typically linked to seasonal or annual patterns in weather, river flows and groundwater abstraction. Groundwater levels therefore typically fall and rise more gradually than river flows. It may therefore not be sensible to manage groundwater abstraction on a daily basis because of long temporal lags between taking of groundwater and changes in groundwater levels.

## 4.9 Non-consumptive takes and discharges

Non-consumptive hydro-power schemes do not deplete river flows over the long-term, but they do have the ability to greatly alter river flows in the short-term. This is mainly through storage in reservoirs followed by release at a later time. In these cases changes in flow seasonality, low flow duration, frequency of flood flows and magnitude of flood flows are more informative for assessing environmental effects than mean annual flow change, or summed annual flow change. Some hydro-power schemes use diversions which result in river flows bypassing stretches of river within the same catchment. Often power schemes (those either with or without diversions) have consents that allow taking of very large volumes of water so that dams can be filled or electricity generated during times of flood (e.g., consents related to Manapouri power scheme in Southland or the Waitaki dams in Canterbury). Although these consented takes can be viewed as having considerable potential influence on flows, they can often only be exercised for limit periods of time when flows are high, and the volume of take are often limited by physical constraints such as dam volume capacity or power station capacity. For these reasons, it is not clear how non-consumptive hydro-power schemes should be considered when calculating over-allocation.

# 5 Options for expressing allocation

Having specified the many issues that complicate expression of allocation above, the following sections outline suggested methods that could be used to inform allocation status and quantify allocation at different scales.

## 5.1 Expression of limits at control points

In order to assess the relative magnitude of the limits across catchments, $Q_{min}$ and $\Delta Q_{max}$ must be expressed in units that account for scale in addition to being expressed in absolute units of flow. For example, units for minimum flows can be expressed as proportions of low flow statistics (Table 5-1). Table 5-1 shows how absolute values for minimum flows for the Selwyn River at Coes Ford (a relatively small hill-fed catchment with groundwater losses) are not comparable with those for the Waimakariri River at Old Highway Bridge (a relatively large mountain-fed catchment). Even taking account of scale issues by dividing minimum flows by catchment area does not provide a fair comparison since the Waimakariri catchment is wetter than the Selwyn catchment. Expressing minimum flows as a percentage of a low flow statistic (such as 7-day MALF) provides a metric of protection ecological values at low flows. A lower percentage of MALF provides less protection of low flows and a higher reliability of receiving some supply. Expressing minimum flows as position on the flow duration curve provides a metric of reliability of supply. A lower percentage of time not exceeded on the flow duration curve provides less protection of flow flows and higher relatability of receiving some supply. Expressing minimum flows in these ways does require estimates or observations of flow metrics and flow duration curves. There can be strong between-site differences in inter-annual patterns of the frequency and duration of low flows. For this reason minimum flows can be expressed as percentages of both MALF and the 1 in 5 year low flow (e.g., Table 5-1).

**Table 5-1: Examples of how minimum flows can be expressed.** Selwyn: area ≈ 854 $km^2$, 1 in 5 year low flow ≈ 0.56 m $s^{-1}$, MALF ≈ 1.03 m $s^{-1}$, median ≈ 3.23 m $s^{-1}$. Waimakariri: area ≈ 3105 $km^2$, 1 in 5 year low flow ≈ 32 m $s^{-1}$, MALF ≈ 42 m $s^{-1}$, median ≈ 98 m $s^{-1}$.

| Gauging Station | Band | Minimum flow | | | | | |
|---|---|---|---|---|---|---|---|
| | | Absolute value ($m^3$ $s^{-1}$) | Per unit area ($m^3$ $d^{-1}$ $km^{-2}$) | Percent 1 in 5 year low flow (%) | Percent MALF (%) | Percent Median (%) | Position on FDC (% of time not exceeded) |
| Selwyn at Coes Ford | | | | | | | |
| | A | 0.6 | 60.7 | 106.6 | 58.3 | 18.6 | 11 |
| | B | 0.7 | 70.8 | 124.3 | 68.0 | 21.7 | 12 |
| | C | 1.0 | 101.2 | 177.6 | 97.1 | 31.0 | 17 |
| Waimakariri at Old Highway Bridge | | | | | | | |
| | A | 41 | 1140.9 | 127.3 | 96.9 | 41.8 | 6 |
| | B | 63 | 1753.0 | 195.7 | 148.9 | 64.2 | 23 |
| | C | 105 | 2921.7 | 326.1 | 248.2 | 107.0 | 54 |

Total allocations could also be expressed per unit catchment area, or as percentages of flow statistics (Table 5-2). However, they cannot be expressed as positions on the flow duration curve. The position of the management flow (minimum flow + total allocation) can be expressed as a position on the flow duration curve, but only when all abstractions are controlled by the same minimum flow. This is rarely the case as many abstractors have either different minimum flows or some will not have a minimum flow. Table 5-2 shows that, for these control points, less water is allocated in the Selwyn than the Waimakariri. However, the Selwyn at Coes Ford is far more highly allocated (total allocation is equivalent to around two and half times the median flow) in comparison with the Waimakariri at Old Highway Bridge (total allocation is equivalent to around half the median flow).

**Table 5-2: Examples of how total allocations can be expressed.**

| Gauging Station | Source | Total allocation | | | |
|---|---|---|---|---|---|
| | | Absolute value ($m^3 s^{-1}$) | Per unit area ($m^3 d^{-1} km^{-2}$) | Percent MALF (%) | Percent Median (%) |
| Selwyn at Coes Ford | | | | | |
| | Total | 7.9 | 795.4 | 761.7 | 243.7 |
| | Surface water | 0.1 | 6.4 | 6.1 | 2 |
| | Groundwater | 7.8 | 789.0 | 755.6 | 241.8 |
| Waimakariri at Old Highway Bridge | | | | | |
| | Total | 51.4 | 1431.7 | 121.7 | 52.5 |
| | Surface water | 43.6 | 1213.7 | 103.1 | 44.5 |
| | Groundwater | 7.8 | 218.0 | 18.5 | 8 |

## 5.2 Expression of allocation within catchments

Patterns of allocation across a catchment can be expressed by comparing the total allocation upstream of each reach with an estimate of any hydrological index (e.g., the median flow) for each reach. This expression is achieved by plotting a metric of natural flow (e.g., the median flow) against a metric of potential flow impact of allocation (e.g., the sum of all upstream consented takes). Various flow indices could be used as the indicator of natural flow. Here the median flow is used as it represents the central tendency of flow availability, and because most flow restrictions occur below the median flow. Figure 5-1 illustrates the meaning of different positions when these two variables are plotted against each other. Reaches with low availability such as small rivers or those in dry locations, plot towards the left of the graph. Reaches with high availability such as larger rivers or wetter locations plot towards the right of the graph. Locations within the same catchment with accumulating flow will therefore plot from left to right as flows generally increase in the downstream direction (this will not always be the case as some rivers loss flow in some reaches). Reaches with large upstream consented abstractions plot towards the top of the graph. Reaches with small consented abstraction plot towards the bottom of the graph. Reaches with no upstream takes cannot appear on the graph. Therefore, high allocation status appears towards the top-left corner of the graph, whereas low allocation status appears towards the bottom-right of the graph. The size of each reach can be represented by wetted bed area at the median flow such that longer or wider reaches have larger symbols than narrower or shorter reaches. This type of graph does not necessarily include any comparison with a planned limit, such as a total allocation.

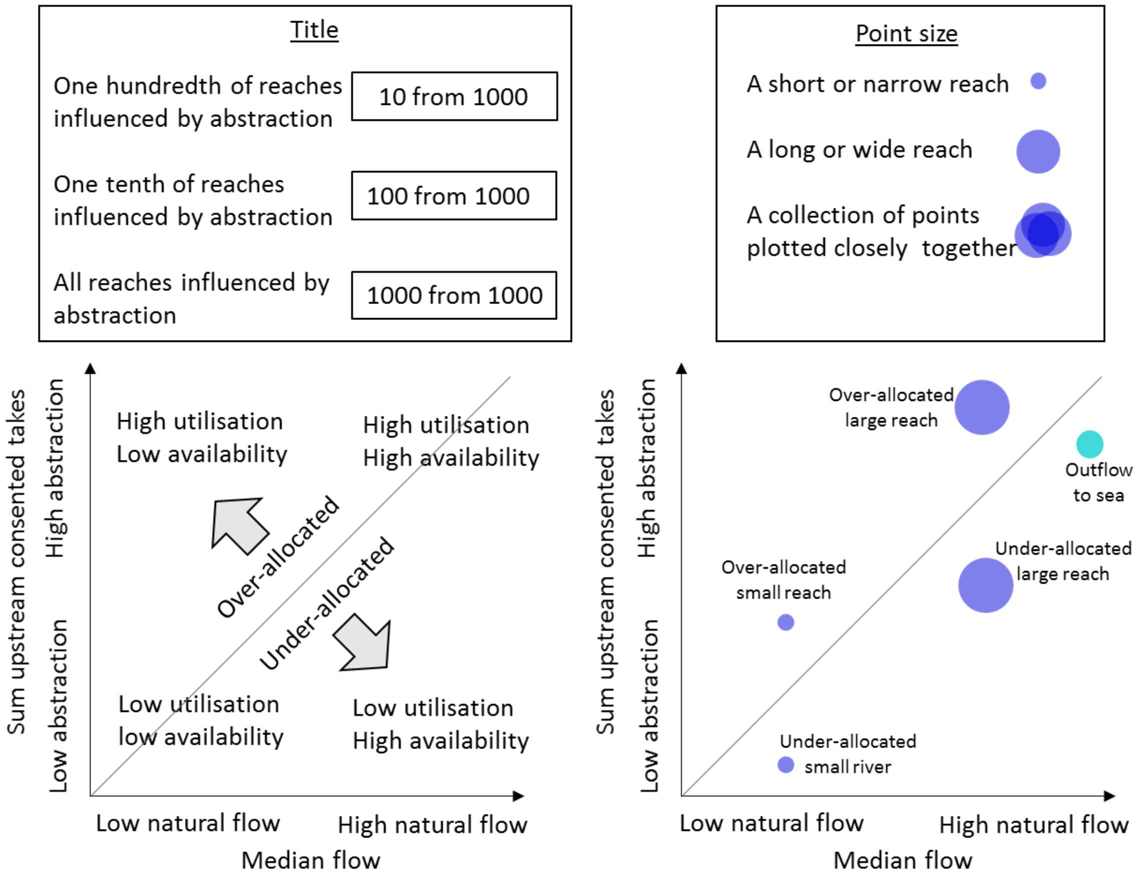



**Figure 5-1: Graphic explaining how allocation pressure across a catchment could be expressed.**

Figure 5-2 shows these types of graph for nine example catchments from the Canterbury region. Estimates of the naturalised median flow were calculated using the method of Booker and Woods (2014). Upstream total allocation was calculated for all current consents on 14/2/2014 for all sources (including groundwater) and all uses (including consumptive hydro-electric, but excluding non-consumptive hydro-electric). Wetted width was calculated using the method of Booker and Hicks (2013) which is an extension of the method of Booker (2010). Groundwater takes were assumed to deplete all river reaches within a 2 km radius (or the nearest reach if no reach was located within 2 km). For each groundwater take, the take was proportioned according to the estimated MALF's of the surrounding reaches multiplied by the inverse of distance between each reach centroid and the take. Thus greater stream depletion resulting from groundwater takes was estimated from reaches with greater flows and more nearby to groundwater takes in comparison with reaches that had less flows of were located further way from groundwater takes. See Booker et al. (2016) for further details.

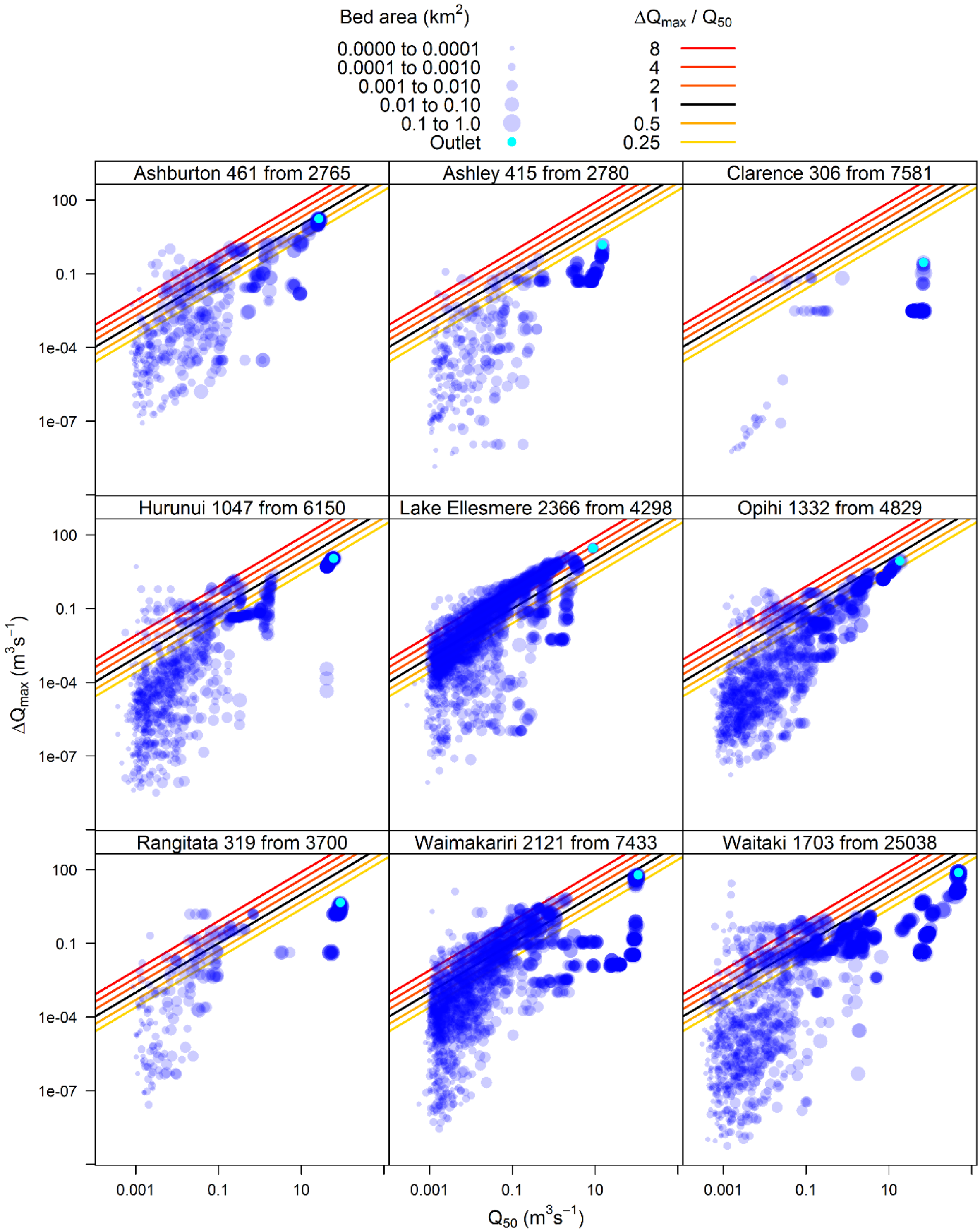



**Figure 5-2: Total allocation versus median flow for nine example catchments in Canterbury.** Each dot represents a reach. Size of dots represents the bed area at the median flow for each reach. Darker shades of blue appear when points are denser. Diagonal lines represent ratios of total allocation to median flow. Numbers in headings represent number of reaches impacted by abstraction and number of reaches in each catchment overall. Cyan symbols represent outlet to the sea.

Inspection of Figure 5-2 reveals the following patterns:

- The Ashburton has several reaches whose flows are impacted by upstream abstractions. The impact of total upstream abstractions on flows increases towards the coast for this catchment. This results in a relatively high total allocation at the outlet to the sea.
- The Ashley has many reaches whose flows are impacted by abstraction. However upstream total abstractions are relatively low compared to median flows in this catchment.
- The Clarence has very few of its reaches whose flows are impacted by abstraction. Its total allocation at the bottom of the catchment is very low compared to its median flow. However, there are still a very small number of reaches which could be considered to be highly allocated.
- The Hurunui has many reaches whose flows are impacted by upstream abstractions. Although total upstream abstractions are high in some places, the majority of the impact is moderate in proportion to the median flow.
- Many reaches of the rivers that flow into Lake Ellesmere/Te Waihora are highly allocated. This includes their collective outlet, which has a total allocation of around three times the median flow. Many reaches have an upstream total allocation that is very high; up to eight times the median flow. The high number of reaches with high allocation indicates the influence of widespread cumulative effects of abstraction.
- The Opihi has many reaches whose flows are impacted by upstream abstractions. The impact of total upstream abstractions increases towards the coast for this catchment, but remains relatively low for most reaches including the outlet to the sea.
- The Rangitata has relatively few reaches whose flows are impacted by upstream abstractions compared to other catchments. However, there are a small number of large takes towards the rivers outlet to the sea for this catchment.
- The Waimakariri has many reaches in the upper catchment whose flows are unimpacted by abstraction. Its total allocation at the bottom of the catchment is also relatively low compared with its median flow. However, many reaches of this catchment whose flows are highly allocated at around twice to four times the median flow. This is due to relatively large abstractions from smaller tributaries.
- The Waitaki has many reaches in the upper catchment whose flows are unimpacted by abstraction. Its total allocation at the bottom of the catchment is relatively low compared with its median flow. However, a few reaches of this catchment are highly allocated. This is due to large potential flow alterations resulting from diversions for hydro-electric uses and relatively large abstraction from smaller tributaries.

Figures similar to those shown in Figure 5-2 are useful for the following reasons:

- The proportion of reaches that are impacted is quantified.
- The magnitude of the potential effect of full abstraction is quantified for all reaches.

- Differences between total allocation at the outlet to the sea can be compared with total allocations across all reaches.
- Impacts of abstraction are weighted by wetted area of each reach. This up-weights longer and larger (wider) reaches, and down-weights shorter and smaller (narrower) reaches. This is done to avoid the assumption that each river reach is equally important regardless of length or wetted width.
- The same graphs could be plotted for groundwater or surface water abstractions separately.
- Provided data are available, the same graphs could be plotted for actual recorded takes. This could be done for each day of the year, or for the sum of actual takes over a year or over a specified period (e.g., for each month of the year or an entire year).
- The same graphs could be plotted for groundwater consents, surface water consents, or both together.
- The centroid of the points could provide a summary for the catchment overall.
- Where available, observed values from gauging stations could be added to the plots.

However, the disadvantages of figures similar to those shown in Figure 5-2 are as follows:

- Ungauged site estimates must be used to express allocation across all impacted reaches. These estimates can have considerable uncertainties.
- A flow statistic (e.g., the median flow) must be chosen against which total upstream allocation can be compared.
- The location of reaches are not expressed.
- They are most useful when an FMU is defined by a single catchment that flows to the sea, rather than a collection of smaller catchments that have multiple outlets to the sea.

The above comments have demonstrated how graphs similar to Figure 5-2 can be used to inform on over-allocation, both at the outlet of a catchment and across an entire catchment.

## 5.3 Expression of allocation between catchments

Whilst graphs similar to Figure 5-2 show the pattern of allocation across catchments, they do not provide the regional or national view that may be helpful to councils and MfE by quantifying allocation status for each catchment or zone. Figure 5-2 are a function of: a) number of reaches whose flows are impacted by abstraction; b) the wetted bed area of the reaches influenced by abstraction; and c) the upstream allocation compared with the median flow at each reach. The three elements incorporated into Figure 5-2 could be combined in various ways to provide an overall indication of allocation for each catchment. The following equation combines these three elements to calculate the Weighted Allocation Impact (WAI) for each catchment.

i = each reach influenced by an upstream take

$j$ = each reach in the catchment

$W$ = Wetted Bed Area

$\Delta Q$ = upstream accumulated consented rate of take

**Equation 5-1: Weighted Allocation Impact.**

$$WAI = \sum(W_i \Delta Q_i / Q_{50}) / \sum W_j$$

High values of WAI indicate greater allocation. Lower values of WAI indicate lower allocation. Lower values of WAI are only possible if there are very small allocations influencing a few reaches. Medium values of WAI can be caused either by: a) more widespread influence of allocations of lesser magnitude; or b) more localised influences of greater magnitude allocations. Very high values of WAI can only be caused by greater magnitudes of allocation across many reaches. Low values of WAI indicate under-allocation whereas high values indicate over-allocation. The following describes some allocation scenarios and their resulting WAI values, noting that the scenarios related to the natural median flow because this is the flow index applied in Equation 5-1.

- If half the reaches in a catchment have the median flow allocated, then a WAI of 0.5 would be calculated.
- If all reaches in a catchment have half the median flow allocated, then a WAI of 0.5 would be calculated.
- If all reaches in a catchment have the median flow allocated, then a WAI of one would be calculated.
- If half the reaches in a catchment have twice median flow allocated, then a WAI of one would be calculated.
- If all reaches in a catchment have twice flow allocated, then a WAI of two would be calculated.

Figure 5-3 to Figure 5-9 shows WAI calculated for every catchment across each region of New Zealand. The effects of all non-hydropower water take consents is shown separately for groundwater and surface water consents. WAI could be calculated for any grouping of reaches such as FMUs designated by councils. In this analysis catchments refer to groups of reaches as defined by the 1956 Soil Conservation and Rivers Control Council's "Catchments of New Zealand" (Soil Conservation and Rivers Control Council, 1956). Catchment names including "xxx to yyy" refer to adjacent groups of small rivers that each flow to the sea. For example, a few small rivers located south of Lake Ellesemere/Te Waihora and north or the Rakaia River are grouped into the "Lake Ellesmere to Rakaia" catchment in Canterbury.

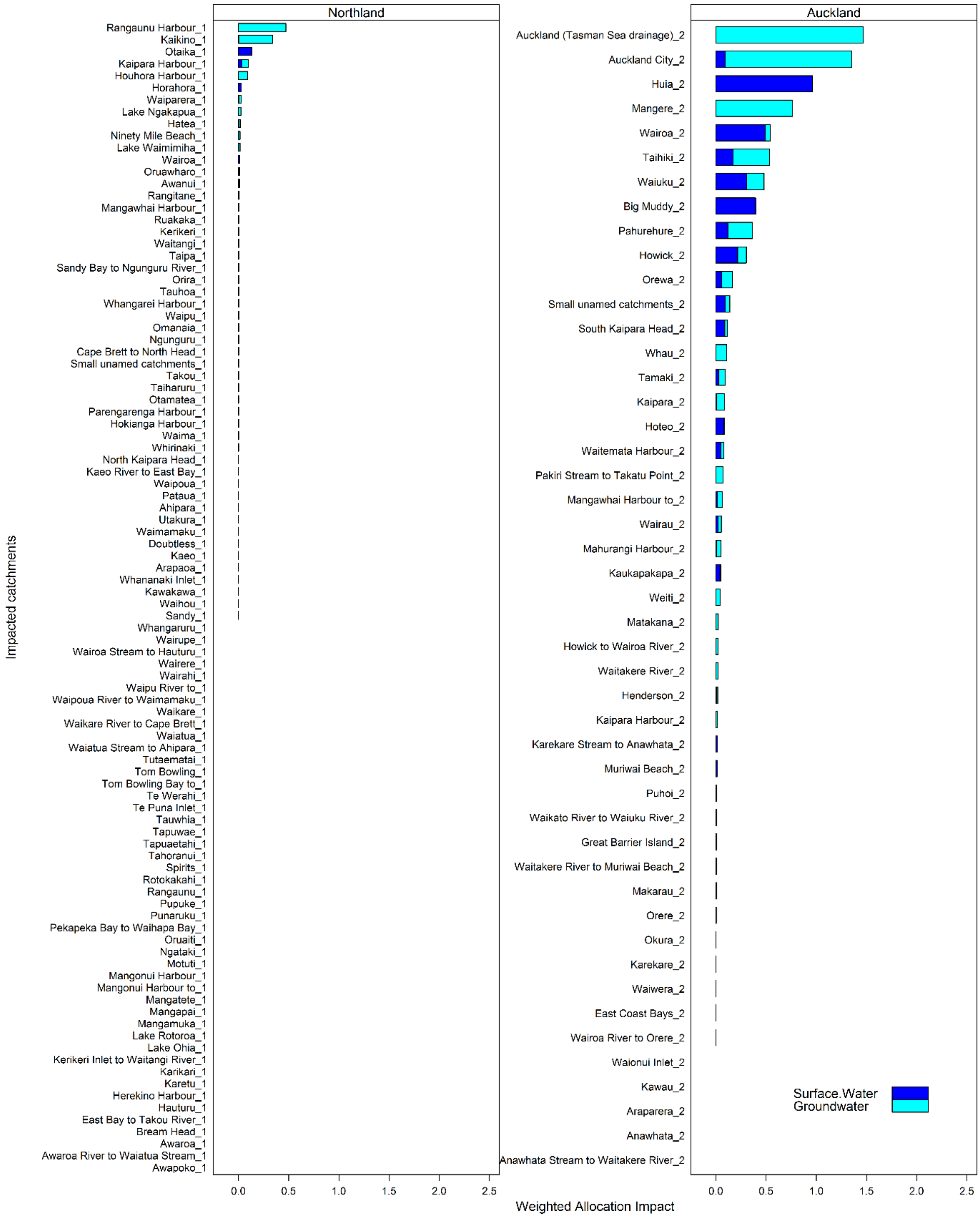



**Figure 5-3: Weighted Allocation Impact (WAI) for catchments containing water take consents in the Northland and Auckland regions.**

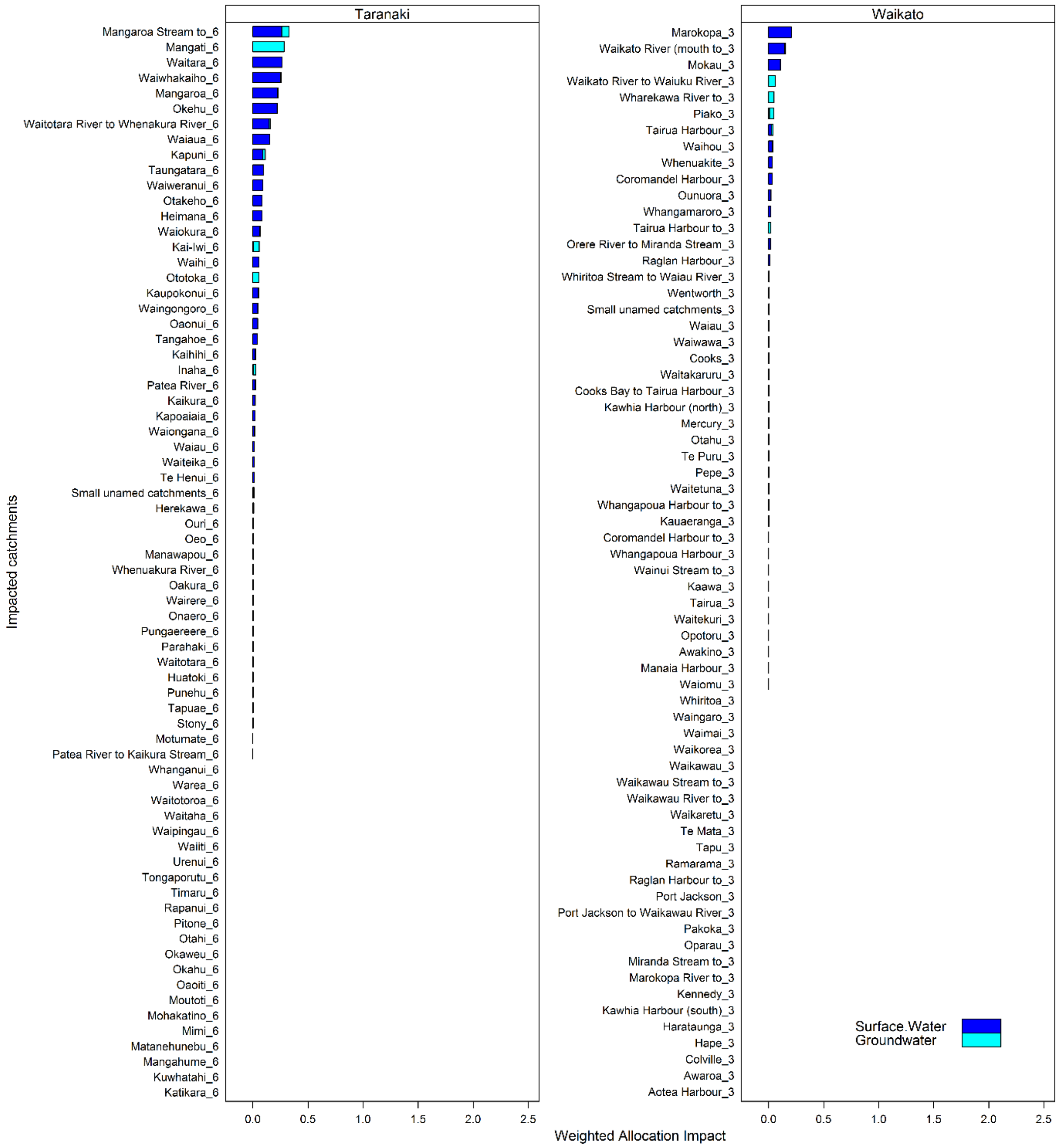



**Figure 5-4: Weighted Allocation Impact (WAI) for catchments containing water take consents in the Waikato and Taranaki regions.**

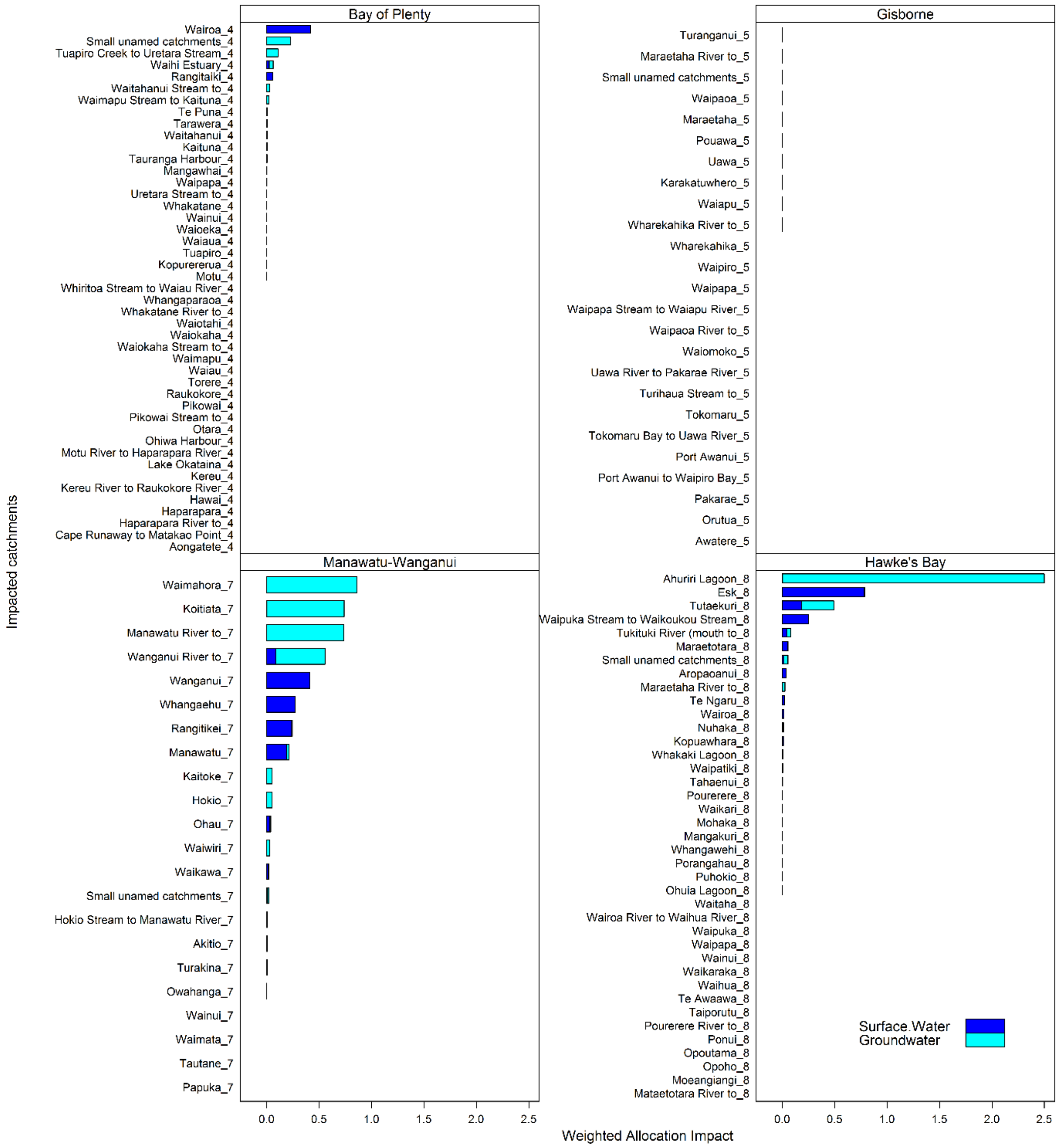



**Figure 5-5: Weighted Allocation Impact (WAI) for catchments containing water take consents in the Bay of Plenty, Gisborne, Manawatu-Wanganui and Hawke's Bay regions.**

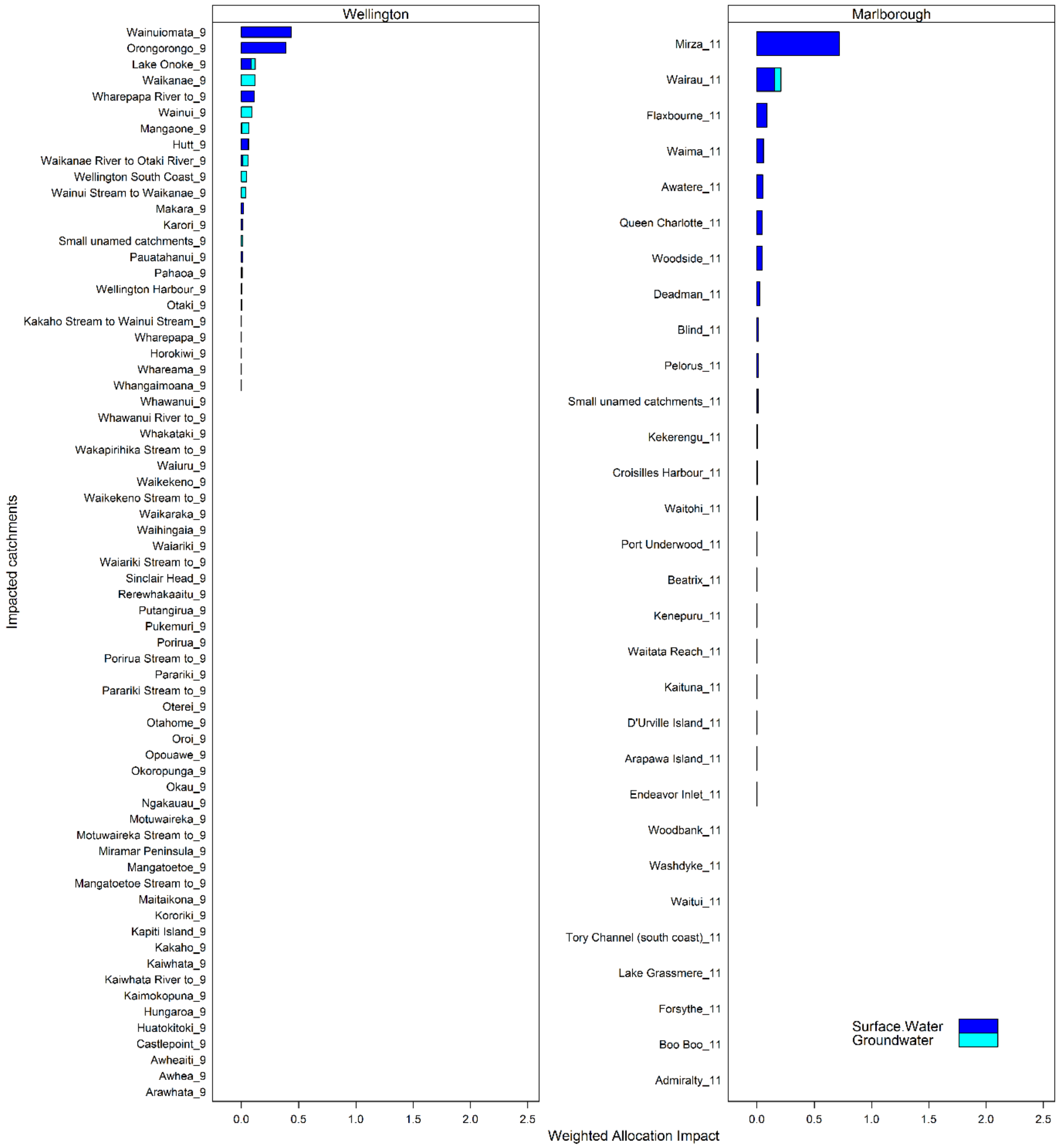



**Figure 5-6: Weighted Allocation Impact (WAI) for catchments containing water take consents in the Wellington and Marlborough regions.**

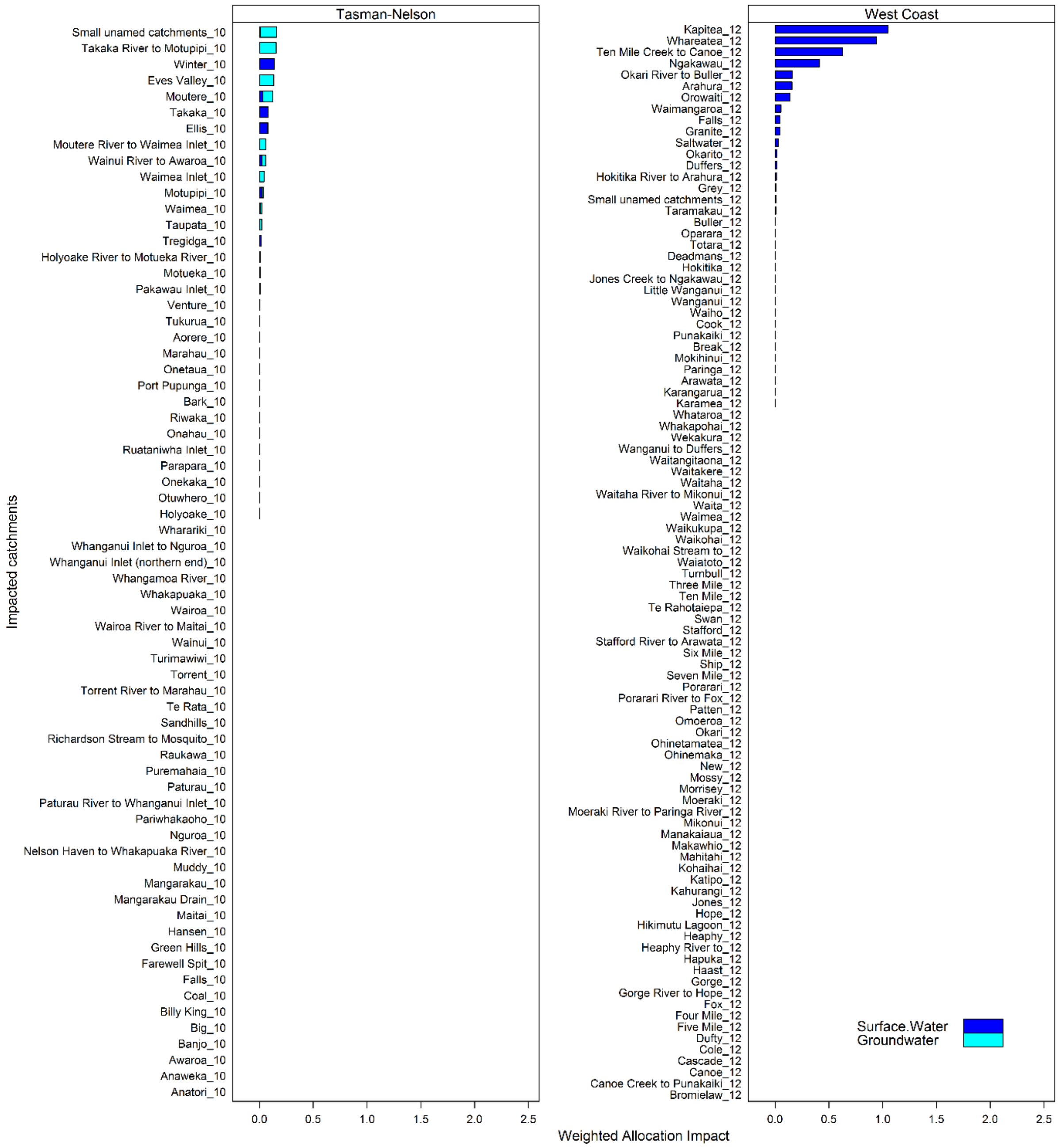



**Figure 5-7: Weighted Allocation Impact (WAI) for catchments in the Tasman-Nelson and West Coast regions.**

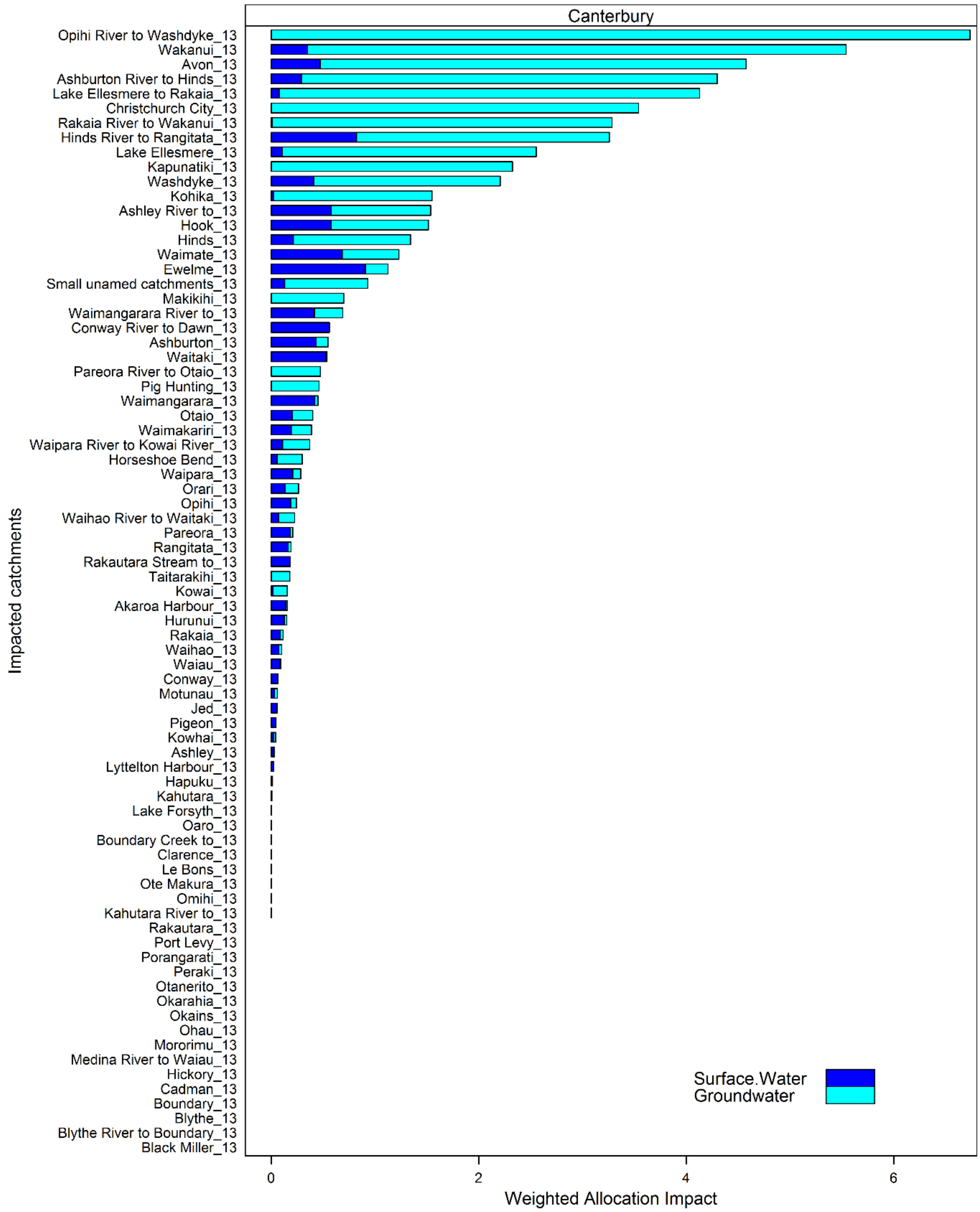



**Figure 5-8: Weighted Allocation Impact (WAI) for catchments in the Canterbury region.**

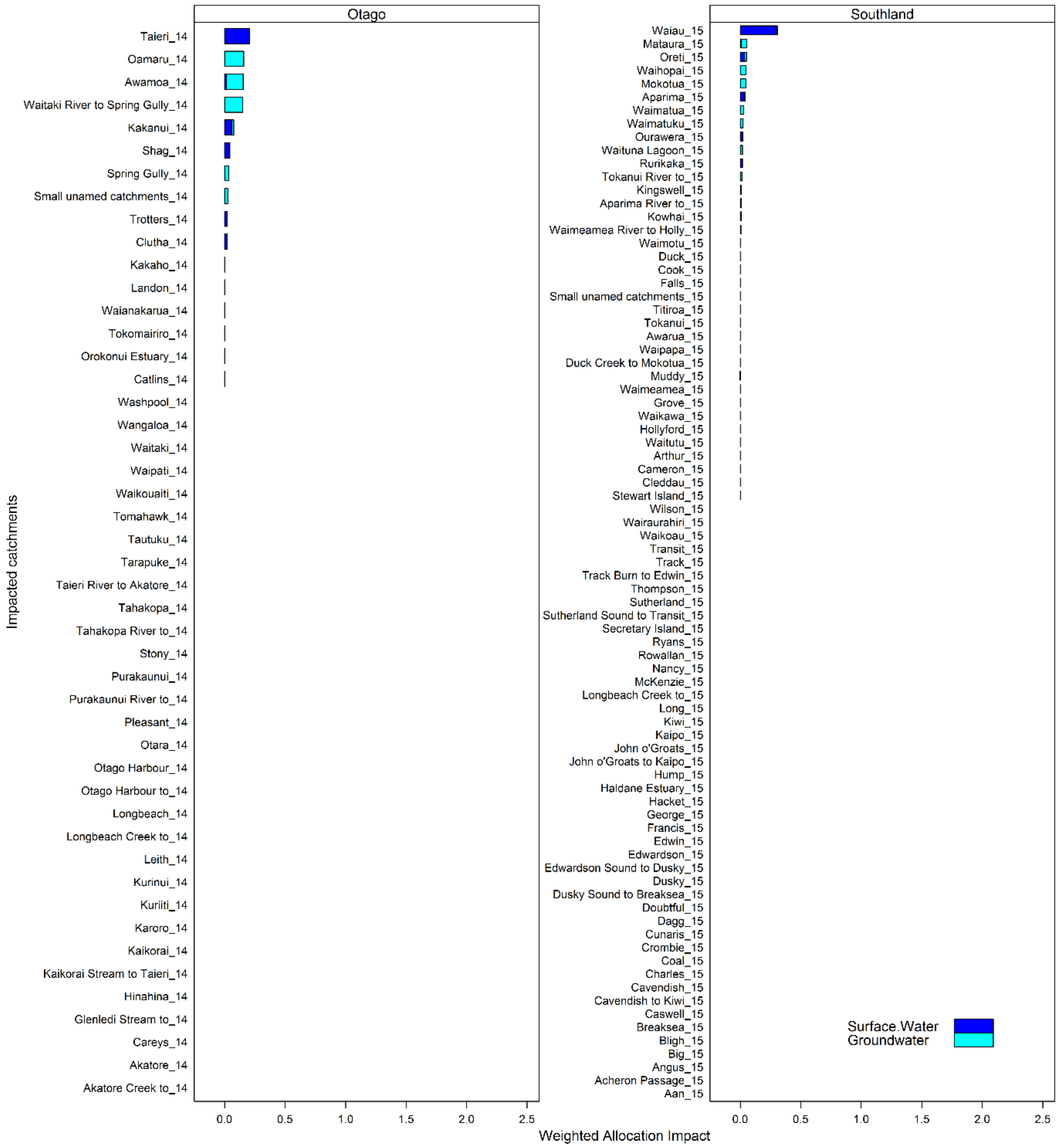



**Figure 5-9: Weighted Allocation Impact (WAI) for catchments containing water take consents in the Otago and Southland regions.**

The figures show relatively low levels of WAI across some regions such as the Tasman-Nelson and Southland regions. Some regions have many catchments with low WAI, but a few catchments with higher WAI (e.g., Marlborough, Wellington, Hawke's Bay). There are variable levels of WAI across the Auckland region, and some very high WAI allocations for many catchments in Canterbury. The highest of these WAI values are for small catchments where large proportions of the consented takes are from groundwater rather than surface water. It should be noted that there is considerable uncertainty about calculating which reaches may be being depleted in small low-lying catchments with alluvial geologies, thus this highlights one disadvantage of the methods applied which assumes that all groundwater takes result in streamflow depletion.

It should be noted that WAI integrates across reaches within a catchment. This means that the highest WAI values are calculated for catchments where takes are high in relation to natural flows and whose impacts are widespread across all reaches (e.g., the Avon river in Christchurch). Catchments with large proportions of their catchment that are not influenced by upstream takes can have lower values of WAI, even if their hydrology (in the downstream reaches) can be strongly influenced by takes (e.g., the Hurunui and Rakaia rivers).

Figure 5-3 to Figure 5-9 shows some variability between catchments relating to how groundwater and surface water takes influence WAI. The three catchments with highest WAI in Hawke's Bay (Ahuriri Lagoon, Esk and Tutaekuri) are dominated by groundwater takes, surface water takes and a mixture of both respectively.

Here WAI has been calculated for maximum consented instantaneous rate of take for all non-hydro-power groundwater and surface water takes. Providing appropriate data are available, similar methods could be applied to restricted takes, observed takes, all takes including estimates of permitted activities, or all takes including hydro-power.

It should be noted that WAI as defined here is not influenced by minimum flows. A catchment with high rates of take, but also high minimum flows will have the same WAI as catchments a catchment with the same rate of take but lower minimum flows. It should be noted that some consents in Canterbury have very high minimum flows, but no account of this is made in the WAI calculation. Therefore, WAI represents potential hydrological impact in the absence of flow restrictions.

As mentioned in preceding sections, calculation of over-allocation may need to consider:

- Paper takes versus actual takes;
- Temporal variability;
- Spatial variability;
- Difference in temporal and spatial dynamics between groundwater and surface water.

Figure 5-10 shows how over-allocation on paper (for example WAI) could be compared with over-allocation in reality. Temporal aspects could be incorporated by calculating the proportion of time (number of days in a year) in each quadrant of Figure 5-10. Spatial aspects could be incorporated by calculating the number of reaches (weighted by river length and/or size) in each quadrant, although this would assume a method for unscaling $\Delta Q_{max}$. Both temporal and spatial aspects could be incorporated by calculating the proportion and number of reaches in each quadrant.

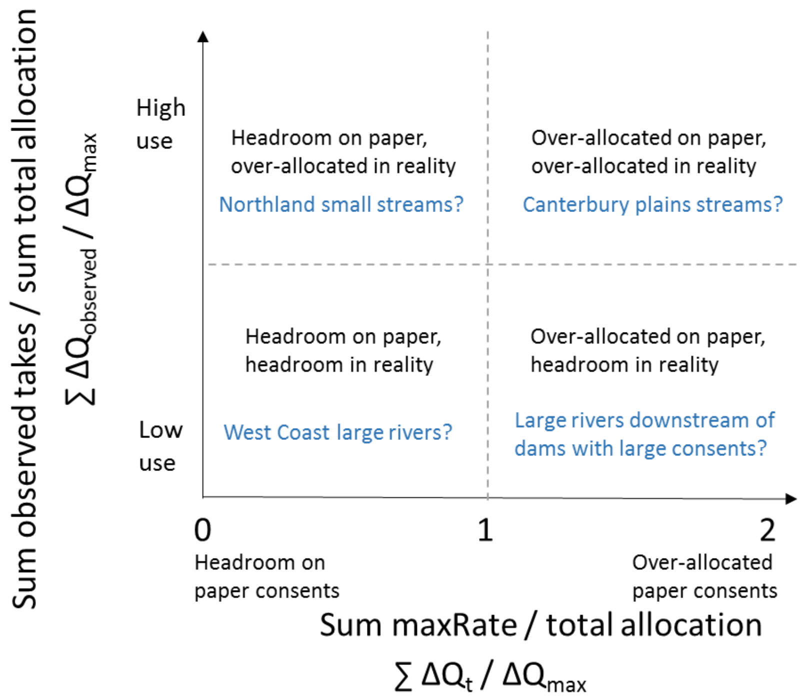



**Figure 5-10: Consented allocation versus observed use.**

# 6 Conclusion

The NPS-FM states that management of the potential cumulative impacts of abstraction on several aspects of the hydrograph can be achieved by setting limits defined by two properties; a minimum flow and an allocation rate. Defining these limits is important for establishing a definitive level of environmental protection and clarifying availability of the water resource to users. Characterising the status of over-allocation depends on a comparison between these limits and existing consents. However, there are considerable and practical difficulties in defining the limits and subsequently calculating over-allocation because:

a) the degree to which freshwater attributes will be degraded under pre-defined limits is uncertain;

b) it must be recognised that over-allocation will vary through time and across river reaches even within the same catchment;

c) the hydrological effects of permitted activities are unknown, yet these effects must be accounted for;

d) inconsistency in consent conditions complicate calculation of total allocation;

e) the effect of restrictions should be incorporated when calculating of over-allocation; and

f) plans and consents are static, but the environment and optimal allocation are dynamic.

These complications demonstrate that unless a specified methodology for calculating over-allocation is predefined, it is likely that councils will apply a variety of methods for determining over-allocation. This will lead to disputes between abstractors and environmental managers about over-allocation status. Despite these complications there are possible methods for calculating over-allocation which could be applied uniformly across New Zealand. In this report, methods are outlined for the following:

- **Expression of limits (minimum flows and total allocations) at control points**, including methods for unscaling to compare between catchments.
- **Expression of allocation within catchments** by plotting total upstream allocation against estimated naturalised median flow for each impacted reach across a catchment, whilst also expressing the size of each reach and the proportion of reaches in the catchment influenced by consented takes.
- **Expression of allocation between catchments** by calculating the Weighted Allocation Impact (WAI). This is an index that integrates magnitude and spread of allocation across an entire catchment.

These methods could be used to calculate nationally consistent estimates of allocation status. However, the calculations applied were complex in nature. This indicates that adoption of these methods (or similar methods) nationally would require the publication of clear explanations for methods of calculation or availability of a common tool which could be used by all councils.

# 7 Acknowledgements

This work built upon previous development of water allocation indicators for environmental reporting purposes for MfE and research undertaken as part of NIWA's SSIF funded Sustainable Water Allocation Programme (SWAP).

# 8 References


Booker, D.J. (2010) Predicting width in any river at any discharge. Earth Surface Processes and Landforms. 35, 828-841.

Booker, D.J. (2016) Generalised models of riverine fish hydraulic habitat. The Journal of Ecohydraulics, 1, 31-49. DOI: 10.1080/24705357.2016.1229141.

Booker, D.J. Franklin, P.A., Diettrich, J.C., Rouse, H.L. (2014) Implementing limits on water resource use: same rules, different outcomes. Journal of Hydrology (NZ). 53, 129-151.

Booker, D.J., Hicks, D.M. (2013) Estimating wetted width and fish habitat areas across New Zealand's rivers. Report to Department of Conservation, CHC2013-075, 33pp.

Booker, D.J.; Snelder, T.H. (2012) Comparing methods for estimating flow duration curves at ungauged sites. Journal of Hydrology 434–435: 78–94.

Booker, D.J., Whitehead, A.L, Henderson, R.D., Yang, J. (2016) National environmental indicators for water allocation. NIWA client report to Ministry for the Environment. 46p.

Booker, D.J.; Woods, R.A. (2014) Comparing and combining physically-based and empirically-based approaches for estimating the hydrology of ungauged catchments. Journal of Hydrology DOI: 10.1016/j.jhydrol.2013.11.007.

McMillan, H.K. Booker, D.J. Cattoëna, C. (2016) Validation of a national hydrological model. Journal of Hydrology. DOI: 10.1016/j.jhydrol.2016.07.043.

MFE (1998) Flow guidelines for instream values. Wellington, New Zealand. Ministry for the Environment. ME 270 (Volume A) and ME271 (Volume B). 146 and 215p.

MFE (2008) Proposed national environmental standard on ecological flows and water levels: discussion document. Wellington, New Zealand. New Zealand Ministry for the Environment. ME 868, 61p.

MFE (2011) National Policy Statement for Freshwater Management 2011: implementation guide. Wellington, New Zealand. Ministry for the Environment. ME 1077, 50p.

MFE (2013) Proposed amendments to the National Policy Statement for Freshwater Management 2011: a discussion document. Wellington, New Zealand. Ministry for the Environment. ME 1130, 76p.

Ministry for the Environment (2015) A Guide to the National Policy Statement for Freshwater Management 2014. Wellington: Ministry for the Environment. 96p.

New Zealand Government (2011) National Policy Statement for Freshwater Management 2011. Wellington, New Zealand. New Zealand Government. 11p.

New Zealand Government (2014) National Policy Statement for Freshwater Management 2014. New Zealand Government, Wellington, July 2014. 34p.

Snelder, T.H., Booker, D.J., Lamouroux, N. 2011: A method to assess and define environmental flow rules for large jurisdictional regions. Journal of the American Water Resources Association 47: 828–840. DOI: 10.1111⁄j.1752-1688.2011.00556.x

Soil Conservation and River Control Council (1956) River and stream catchments of New Zealand. Dec 1956.