Whaitua Te Whanganui-a-Tara

Flow and Allocation Expert Panel Report:

Ecological health impacts of different river water abstraction regime scenarios for the Te Awa Kairangi, Wainuiomata and Orongorongo

Mike Thompson[1]

Dr Joanne Clapcott[2]

Dr Robin Holmes[2]

Dr Paul Franklin[3]

Dr Mark Heath[1]

[1] Greater Wellington Regional Council

[2] Cawthron Institute

[3] NIWA

Executive Summary

Background

Whaitua Te Whanganui-a-Tara Committee has been established to set freshwater objectives and limits for the Te Whanganui-a-Tara catchments. Part of the Committee's responsibility is to establish objectives and limits relating to the take and use of water from the larger public water supply rivers in the Whaitua.

This report describes the outputs of a Flow and Allocation Expert Panel (the Panel) commissioned to provide advice and opinion to the Whaitua Committee on the likely significance of the bio-physical effects of different water abstraction scenarios in the three water supply rivers; Te Awa Kairangi, Wainuiomata and Orongorongo rivers. The Panel's outputs are ecology-focused assessments that should be considered alongside other scientific, social, cultural, and economic information to help the Committee in their decision making.

Approach

The Panel assessment process included a fieldtrip and two workshops to consider flow and abstraction scenarios. It was supported by an in-depth hydrological assessment of various abstraction scenarios (Keenan 2020) and physical habitat-flow modelling for aquatic invertebrates, fish and algal communities (Holmes 2020). The assessment process also drew on pre-existing catchment information and Panel member's broader experience. Ultimately, the assessments of predicted ecological effects described in this report are based upon a mix of objective and subjective measures and present an environmentally conservative interpretation of risk with respect to the potential effects of the scenarios, especially where data are sparse.

The Panel focussed on attributes directly impacted by abstraction − flow and physical habitat – with attention also given to attributes where the response may be indirectly affected by abstraction – e.g. algae, water quality and recreational values – but still important to consider in the context of wider ecosystem effects. The ecological attributes assessed are generally aligned with those considered by the Water Quality and Ecology Panel (Greer 2020).

Bands that define the risk of ecological effect were applied to the various abstraction scenarios. The criteria to define bands of hydrological change and effect (under different scenarios) were sourced and adapted from widely referenced flow science literature. While the selection of the band thresholds was inherently subjective, the underlying principle was that the risk of ecological effect increases from weak to strong as aspects of a flow regime progressively depart from a naturalised river flow baseline (i.e. the flow regime in a river without any abstraction). A further aim of the assessment was to compare relative change between abstraction scenarios.

Te Awa Kairangi and Wainuiomata River catchments were split into sub-catchment units (Upper, Middle and Lower) for assessment. These sub-catchment units were based broadly on change points in river hydrology and channel morphology.

Several scenarios of water allocation and minimum flows were assessed for each sub-unit using a modelled naturalised flow regime as the baseline against which to measure the predicted change:

Scenario 0: Current use of water allocation (defined by actual abstraction records over the past 20 years)

Scenario 1: Maximum use of current water allocation (assuming full theoretical use under existing consents and plan policies)

Scenario 2: Increased abstraction in Te Awa Kairangi catchment (by reducing the Kaitoke minimum flow by one third and/or increasing Waiwhetu Aquifer groundwater abstraction)

Scenario 3: Reduced river abstraction (by increasing minimum flows by one third)

Several sub-scenarios were also explored and these are described in the report.

Assessments

Te Awa Kairangi (Hutt River) Assessment Unit

The **current use** of water from Te Awa Kairangi does not remove any of the fundamental components of the natural flow regime. Floods and fresh flows, including algae flushing flows, retain their natural frequency, timing, and size. Natural seasonal changes from high winter to low summer base flows still occur and there are no large-scale changes to mid-range flows as might occur on rivers subject to either very large diversions or damming. However, there are substantial changes during low base flows, typically in summer and autumn. Of most relevance to river ecology are the changes to the magnitude and duration of low flows, and especially those below or equivalent to mean annual low flow (MALF).

Figure E1 summarises the key assessment results of current use and the other scenarios relative to a naturalised baseline for ecological attributes. Natural flow alteration ranges from large to very large in the Upper River (Kaitoke Gorge) to more moderate through the Middle River (Upper Hutt) and increases again in the Lower River as the effects of groundwater abstraction become apparent. The effect of this alteration is that, overall, the current water use regime likely has moderate to strong negative impacts on ecosystem health in Te Awa Kairangi. Risks to ecosystem health are probably highest in the Lower River where groundwater losses are greatest between Taita Gorge and the tidal boundary.

When considering scenarios of **increased or decreased use** for the Upper and Middle river, shifts in the predicted ecosystem health effects are mostly minor and incrementally negative or positive compared to current use. Such shifts are unlikely to be measurably different to those already realised under the current regime; the important qualifier being that the ecological effects under the current regime are already considered to be strongly or moderately negative compared to naturalised state. In the Lower River, the shifts are more substantial, and especially so for the increased abstraction scenario that incorporates both a reduced Kaitoke minimum flow and higher groundwater pumping (see Scenario 2e in Figure E1).

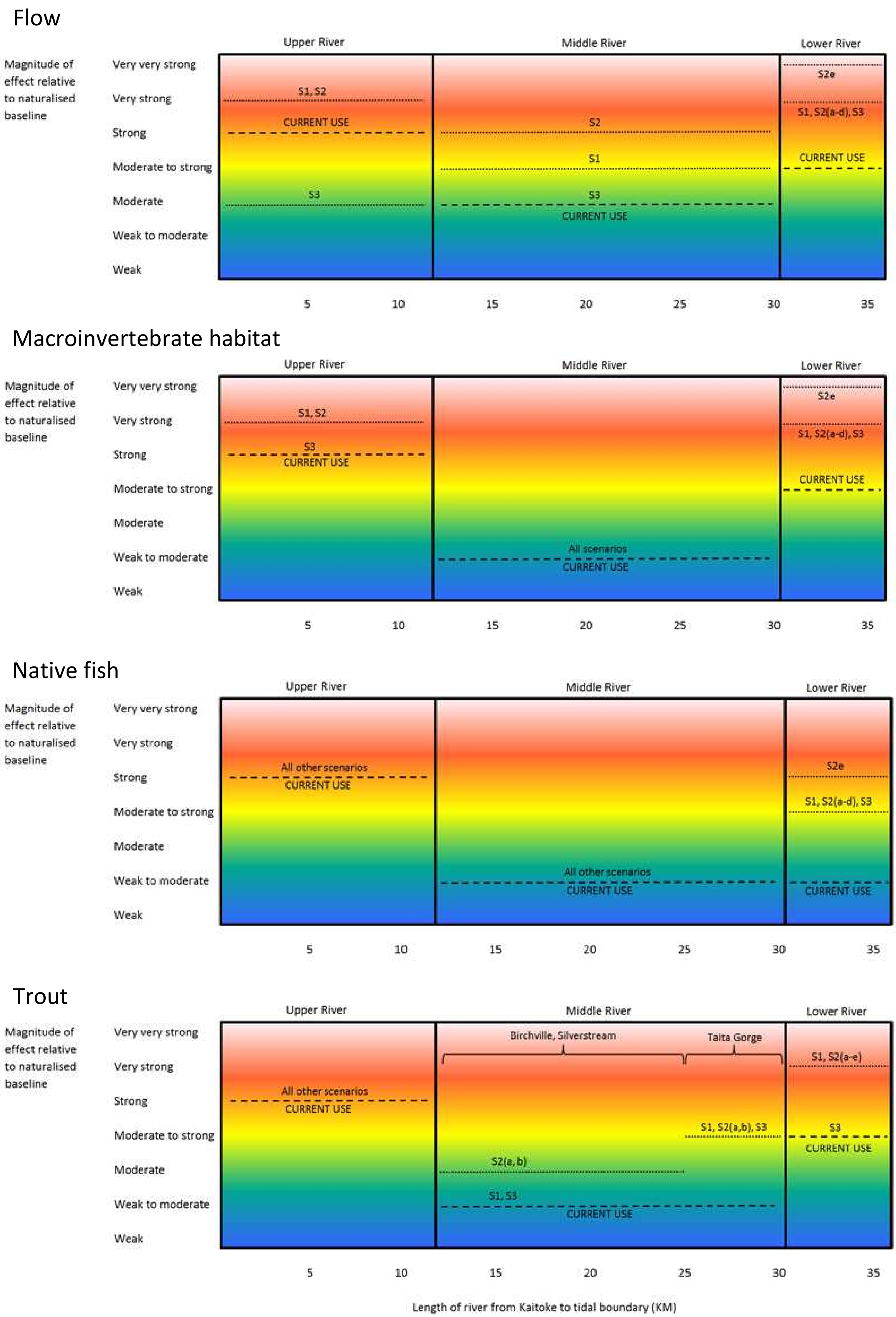


Figure E1. Expert panel assessments of scenarios for the ecological attributes of flow, macroinvertebrate habitat, native fish habitat and trout habitat in Te Awa Kairangi.

While the alternative allocation scenarios evaluated in this assessment are only expected to make incremental differences to ecological health relative to current state, and these changes may be barely measurable, it is important to note that this does not mean that the changes may not be ecologically significant. River biota are likely to be under significant stress during current low flow periods. This stress is a function of reduced space for organisms to live, greater competition for food resources, reduced dilution of pollutants, elevated water temperatures and depleted dissolved oxygen. Where the magnitude of low flows is reduced and/or the duration of low flow periods increases under scenarios of increased allocation, the stress on river biota is increased and is experienced for a longer period. This increases the likelihood of further degradation of ecological communities (e.g. reductions in abundance, impaired growth of organisms, proliferation of algae), but also reduces the resilience of these communities to other possible stressors (e.g. pollution events or floods) that may arise. Conversely, scenarios of reduced allocation will incrementally reduce the stress being experienced by river biota, making the community more resilient overall.

Wainuiomata River Assessment Unit

The **current use** of water from the Wainuiomata River does not remove any of the fundamental components of the natural flow regime. Floods and fresh flows (including algae flushing flows) retain a natural frequency, timing, and size. Natural seasonal changes from high winter to low summer base flows still occur and there are no large-scale manipulations of mid-high range flows, as might occur on rivers subject to either very large diversions or damming. However, as with Te Awa Kairangi, parts of the natural low-flow regime for the Wainuiomata River are substantially altered.

Figure E2 summarises the key assessment results of current use and the other scenarios relative to a naturalised baseline for ecological attributes. Flow alteration ranges from large in the Upper River to more moderate to weak in the Middle and Lower River (which makes up a large majority (~70%) of the river length below the abstraction). Like Te Awa Kairangi, the most ecologically relevant changes occur in the magnitude and duration of extreme low flows, and especially those below or equivalent to MALF. But, the alteration of mid-range flows is more substantial in the Wainuiomata compared with Te Awa Kairangi.

With respect to effects, some attribute changes are suggestive of minor effects (e.g. small changes in available native fish habitat space). This is consistent with observations of an apparently healthy brown trout population in the lower river. However, such individual attribute examples are not conclusive evidence for minor ecosystem health impacts in the more holistic sense. There is some evidence of moderate to large habitat loss for food producing macroinvertebrates which suggests that while space may not be a problem for fish, food availability may be. Overall, the Panel assessment for the majority of the Wainuiomata River under the current use regime is of moderate negative ecosystem health effects.

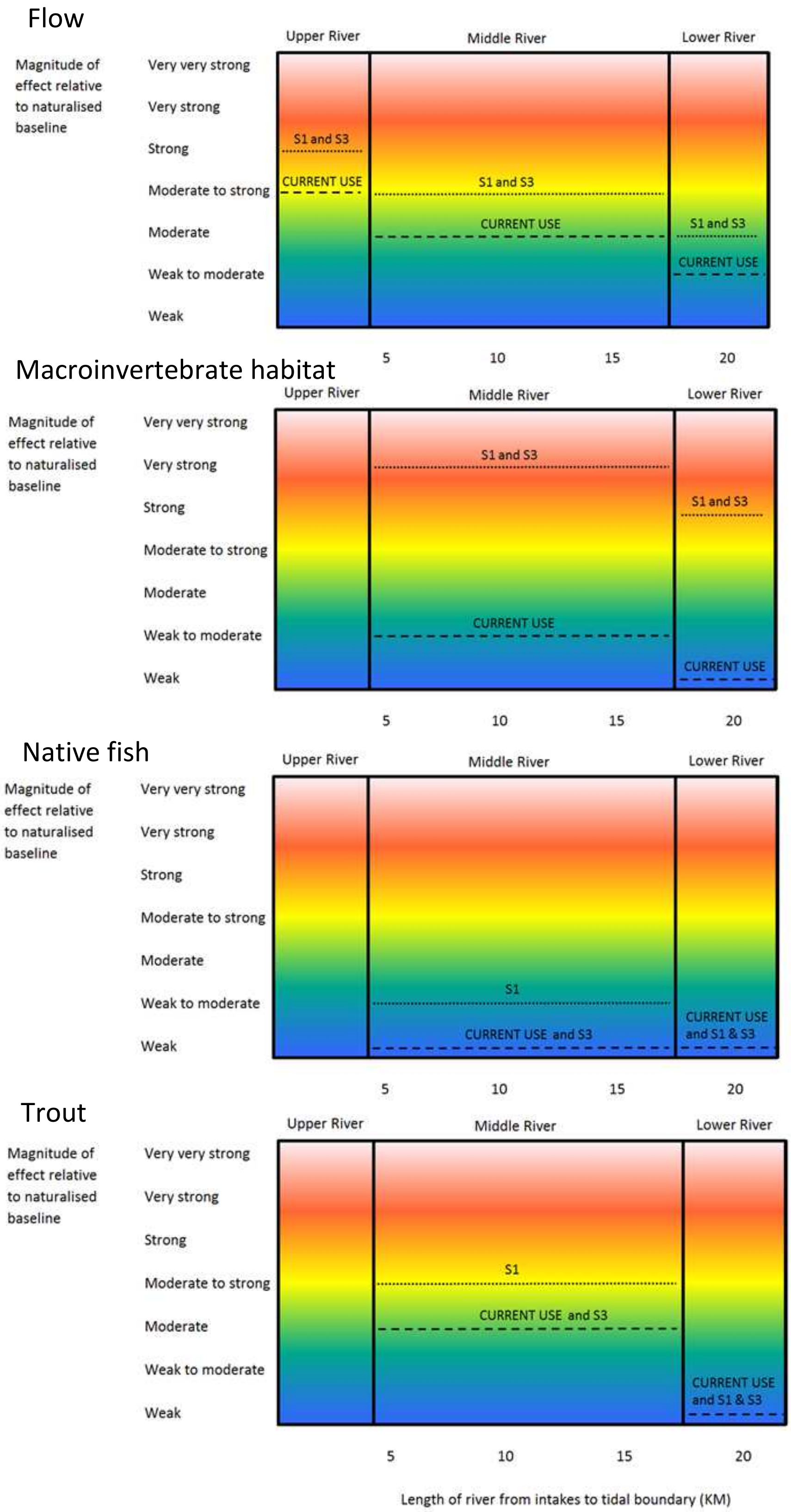


Figure E2. Expert panel assessments of scenarios for the ecological attributes of flow, macroinvertebrate habitat, trout habitat, and native fish habitat in the Wainuiomata River.
Note: Flow-habitat modelling was not undertaken for the Upper River segment due to a lack of available data.

Increased abstraction from the Wainuiomata River (within existing consent limits, i.e. Scenario 1) could cause significant negative ecosystem health effects. Of concern is the apparent sensitivity of macroinvertebrate habitat to further flow loss in the mid to low-flow range (Scenario 1 in Figure E2). While habitat availability for fish (native and trout) appears much less sensitive to increases in abstraction, the indirect impacts on fish from loss of macroinvertebrate food productivity are of more concern. The magnitude of extreme low flows (less than MALF) are not expected to further reduce under fully exercised consents as there is no more water availability at these times. However, any significant further abstraction from low to mid-flow range will bring the river into extreme low flow conditions more quickly and for a longer duration. This is expected to incrementally increase the potential for negative ecosystem health effects. In particular, the increased frequency and magnitude of low flows is likely to promote algal growth in the Upper and Middle rivers, and algal and macrophyte growth in the Lower River.

With respect to increasing the minimum flow at Manuka Track by a third (and thereby **reducing abstraction** at the lowest flows, i.e. Scenario 3), beneficial effects are likely to be modest in both magnitude and extent, quickly diminishing downstream.

Orongorongo River Assessment Unit

Data availability for the Orongorongo River was very limited compared with Te Awa Kairangi and Wainuiomata. Flow could only be naturalised for one location, 'Truss Bridge' directly downstream of the abstraction locations, and the subsequent record was not considered robust enough for further hydrological scenario modelling. No hydraulic-habitat surveys have been carried out in this river so inclusion in the flow-habitat analysis was not possible. Other water quality/ecological data were also very sparse. The Panel assessment for this river is, therefore, high level and based primarily on a conceptual understanding of the potential abstractive effects in this type of river environment. Accordingly, it is accompanied by a relatively low level of confidence.

Under **current use**, flows in the upper catchment are generally reduced by around 40–60%. Such reductions are of the same general order of magnitude as those in the upper reaches of Te Awa Kairangi due to the Kaitoke take and can reasonably be interpreted to occupy a similar band of hydrological change and ecological effect (i.e. 'large to very large'). Without downstream monitoring it is not possible to be certain how far the effects of the heavy flow alteration propagate, although it is expected to become more moderate through the middle and lower reaches. Habitat loss at low flows must be considered commensurate with the 'large to very large' low flow reductions until demonstrated otherwise. The wide and shallow channel in the alluvial valley will make this river particularly susceptible to the effects of abstraction with relatively steep reductions in physical space and hydraulic parameters likely to occur with declining flows and increased vulnerability to water temperature increases and bed drying.

Overall, there is uncertainty about the extent to which current allocation of water from the Orongorongo River alters some primary components of the natural flow regime. Floods and fresh flows (including algae flushing flows) retain a largely natural frequency, timing, and size. Natural seasonal changes from high winter to low summer base flows still occur and there are no large-scale flow manipulations (as might occur on rivers subject to either very large diversions or damming). However, as for Te Awa Kairangi and Wainuiomata rivers, mid to low flows in the Orongorongo River undergo large reductions. Also, the possibility that abstraction causes or aggravates flow cessation during extended dry periods in some lower river reaches has not been ruled out. Based on the broad principles relating to the susceptibility of the Orongorongo River ecosystem to abstraction described above, the overall Panel assessment is that ecosystem health is likely to be more negatively impacted than the Wainuiomata River under the current use regime.

Scenarios of **maximum use and lower abstraction** could not be modelled for the Orongorongo River. Logically, any further abstraction from low to mid-flow range will bring the river into extreme low flow conditions more quickly and for longer durations. This can reasonably be expected to increase aquatic stress and negative ecosystem health effects. Given the shallow channel morphology one might expect a greater risk of elevated water temperatures arising from further reducing flow compared to some of the other reaches considered in the Wainuiomata and Hutt rivers (which have different channel morphology). The potential for aggravation of river-bed drying is also of more concern in this catchment.

Overall, the lack of data to examine abstractive effects on the Orongorongo River combined with high natural catchment value warrants, in the Panel's view, an additional layer of caution in the interpretation of effect and change and should be more robustly evaluated.

Climate Change

The future is likely to bring progressively warmer baseline temperatures to Whaitua Te Whanganui-a-Tara, more 'hot' days, and longer durations of dry spells in summer and autumn (i.e. increased drought frequency and intensity). Reductions in mean annual low flow (MALF) of up to 20% in some parts of Te Awa Kairangi catchment by mid-century are predicted (and to a lesser extent in the Wainuiomata) with such reductions being more widespread through the Whaitua by the end of the century under a high emissions pathway. Mean catchment flows are unlikely to be significantly affected, although more subtle changes in hydrograph dynamics may well be masked by such averages.

Shifting to this new climate regime will be a gradual process and, to an extent, natural ecosystem adaptation and functional change over time to a 'shifting baseline' would be expected. Such gradual change will both disguise some of the real impacts but also mitigate some of the peak ecosystem stresses that might be more apparent with a quick shift. Even so, the Panel considers that, if realised, the effect of climate change would be to generally shift assessments of the current regime and scenarios further towards more negative ecosystem health outcomes.

It is not possible to draw detailed distinctions between the three water supply catchments in terms of ecosystem vulnerability to changing climate. At a conceptual level, although predicted climate-related reductions in low flows are more pronounced in Te Awa Kairangi, it is also likely to be more resilient than the Wainuiomata or Orongorongo, due to its headwater catchment size and nature of groundwater exchanges (that can dampen temperature responses).

Concluding remarks

The magnitude of hydrological change and ecological effect from abstraction is spatially variable within the water supply catchments and will be exacerbated by climate change. The Panel assessments provide some indication of this variability and associated ecological risk, but layering with other knowledge and values will be required to determine a favoured management response.

Further thoughts from the Panel regarding confidence, secondary minimum flows, change in abstraction regime, and non-ecological values are provided as concluding remarks to help inform decision making.

Modelling for this report shows that significant increases in abstraction in the low to mid-range flows could occur under existing public supply consents (in all rivers). It is acknowledged though that the likelihood of anything close to 'maximum use' occurring is very low for a range of reasons (the necessary additional demand is unlikely, additional storage is unavailable and WWL always need to operate with a substantial margin of unused water). The Committee may find it helpful to refine this element of potential risk through their discussions.

The scope of this report has been firmly constrained to consideration of ecosystem health effects. Nevertheless, some of the assessments can be interpreted in the context of other values. The premise is that an allocation regime set based on sustaining ecosystems will likely sustain other community values, since they are often heavily reliant on a healthy biological system. This premise does not of course apply as a rule and the Panel cautions against stretching assessments too far when trying to interpret for other values.

1. Introduction

1.1 Purpose of this document

This document provides a record of the advice from a Flow and Allocation Expert Panel (hereafter referred to as 'the Flow Panel') convened to assist the Whaitua Te Whanganui-a-Tara Committee in their decision making. The advice in this document represents the consensus view of the Flow Panel and is focused on the ecological health impacts of water abstraction from the main stems of the Te Awa Kairangi (Hutt), Wainuiomata and Orongorongo rivers.

1.2 Background

Whaitua Te Whanganui-a-Tara has been established to set freshwater objectives and limits for the Te Whanganui-a-Tara catchments, as part of Greater Wellington Regional Council's response to implementing the National Policy Statement for Freshwater Management (NPS-FM 2017).

The purpose of the Flow Panel is to provide expert advice and opinion on the likely significance of bio-physical responses to different water abstraction scenarios in three water supply rivers. The panel's outputs are intended to be ecology-focused assessments that should be considered alongside other scientific, social, cultural, and economic information to help the Whaitua Committee set freshwater objectives and limits.

1.3 How does abstraction affect river ecology?

There is a wide body of literature, national and international, providing conceptual and empirical evidence for flow regime being a primary determinant of river and stream ecological health. The key flow-ecology relationships have most recently been summarised in the context of Te Whanganui-a-Tara by Clapcott (2020). In her review, Clapcott (2020) describes how ecology is shaped by flows across the hydrograph (see Figure 1.1 for a further visual interpretation). Large floods shape the physical habitat template, forming channels, scouring pools, and transporting sediment downstream. Medium and small floods (i.e. freshes) shape the quality of in-stream habitat by displacing biota and fine sediment (e.g. flushing flows). Large to small floods also connect off-channel habitats and provide environmental triggers for fish migration. The receding hydrograph deposits sediment and biota as well as dispersing dissolved nutrients. Medium to low flows shape the quantity of in-stream habitat, determining the life supporting capacity of a river by providing continuous wetted habitat for key ecological processes, such as benthic productivity and in-channel connectivity.

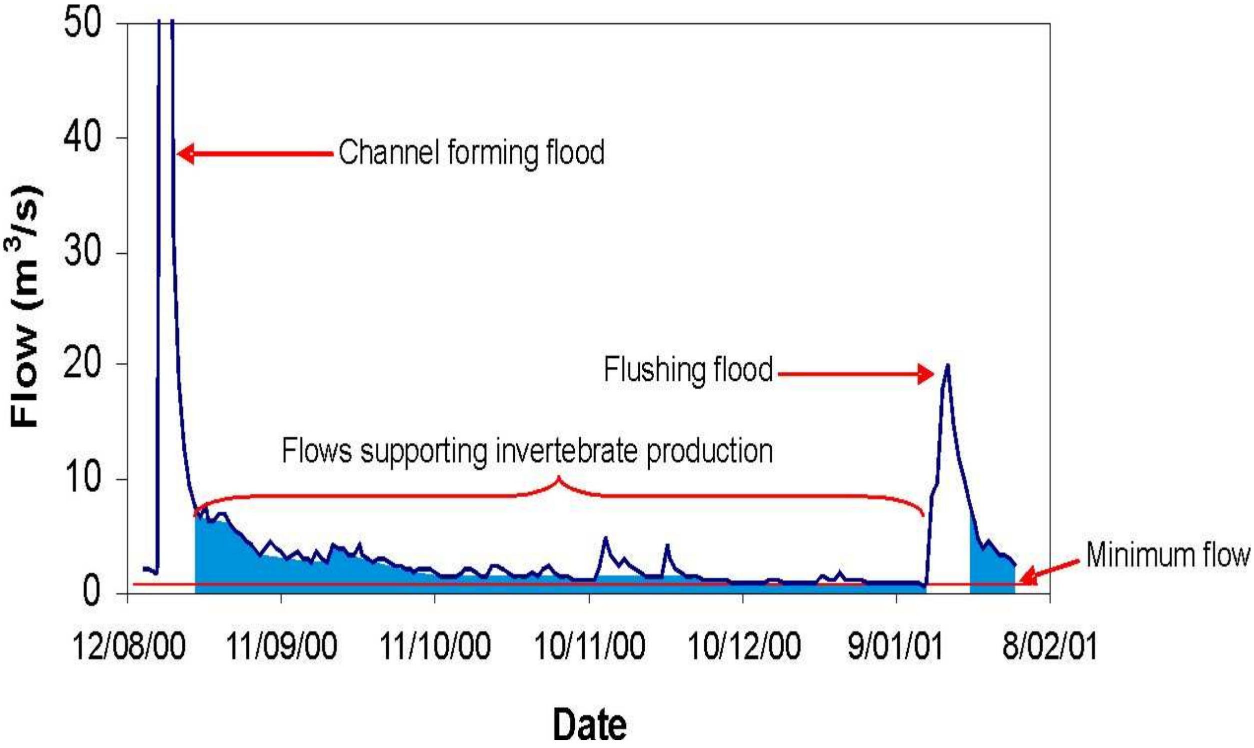


Figure 1.1. Primary functional components of the hydrograph (source: Beca 2008)

The extent to which any of the primary hydrograph components in Figure 1.1 are modified by water use depends on the type of abstraction and the water quantity limits that are in place. Dams and large diversions that have the capacity to store or divert large portions of river discharge have the potential to fundamentally change the entire flow regime, for example by removing flood events or completely altering the seasonality of flows. Run-of-river abstractions are much less likely to substantially change flood or fresh flows[1] but can significantly alter the magnitude and duration of mid to low range flows.

The primary result of reduced low flows is a reduction in the area of wetted habitat available to in-stream biota, i.e. there is less space in which animals can live. Further, as flow declines a greater proportion of the river becomes slower, which favours biota more suited to slow water environments. Low flows also affect the sources and exchange of material and energy in riverine ecosystems (Rolls et al. 2012). For example, lower flows mean there is less energy in the river to transport matter in the water column. This reduces food availability for filter-feeding invertebrates, lessens invertebrate drift and can subsequently impact drift-feeding fish (Hayes et al. 2019). Water quality will be affected by lowered flows because dilution of pollutants such as suspended sediments, nutrients and other contaminants is reduced. Slow-flow habitats are more likely to have low dissolved oxygen due to increased biological oxygen demand (from increased deposited organic material) and decreased reaeration. Both dissolved oxygen and temperature can be affected by increased groundwater interaction during low flows (Keery et al. 2007). Further, increased duration

[1] Although large run of river takes on small rivers and streams can reduce the frequency and capacity of flushing events.

of low flows (resulting from flow modification) can result in an increased duration of algal proliferation. Algal dynamics in turn change the habitat and food availability for benthic macroinvertebrates and fish. As such, low flow mediated changes in habitat conditions and water quality drive patterns of distribution and recruitment of biota (Rolls et al. 2012). Lastly, low flows can restrict the connectivity and diversity of in-stream and off-channel habitat, thereby increasing the importance of refugia and driving multi-scale patterns in biotic diversity (Rolls et al. 2012).

1.4 Panel process

The Terms of Reference for the Expert Panel are provided in Appendix 1.

Key dates for meetings and process were:

- 12 February 2020. **A fieldtrip** to familiarise Panel members with the river environments being assessed and visit some sites and reaches that are the subject of hydrology and habitat modelling.

- 25 February 2020. **Workshop** in Wellington attended by all Panel members. In this workshop, brief presentations about the Whaitua context and background to the technical work were given prior to the Panel making attribute assessments for Te Awa Kairangi. Assessment summaries were compiled on the whiteboard as the day proceeded.

- 29 April 2020. **Video conference** attended by all Panel members. Assessments for the Wainuiomata and Orongorongo rivers were completed with screen sharing by the meeting Chair used to summarise the consensus statements.

- 1 May to 10 July 2020. **Write up and review**. All assessments were compiled in a synthesis report (this report) by Mike Thompson. This report was circulated for review to all Panel members on three occasions at progressively more complete stages in order to both help develop the narrative around the assessments and confirm the level of consensus.

2. Assessment units, attributes, and abstraction scenarios

2.1 Assessment units

'Assessment unit' in this report describes the spatial extent of the water body for which attributes were assessed by the Flow Panel. For flow and allocation scenarios, three units were assessed; these are the main stem channels of each of Te Awa Kairangi, Wainuiomata and Orongorongo rivers. The extent of these units and sub-units within them is shown in Figures 2.1 and 2.2 along with the location of some key reporting reaches[2] for which flow and other data were examined. Assessments are provided later in this report for both reaches, sub-catchment units and overall assessment units.

Key features of the water supply river catchments are described more fully by Keenan (2020). Sub-catchment units defined in this report may not match exactly the sub-catchment descriptions in Keenan (2020) but are based on a combination of major hydrology or morphology transitions, as well as assessment data availability.

2.1.1 Hutt River

There are three sub-units of Te Awa Kairangi Assessment Unit and five associated reporting reaches for which hydrology and/or habitat data are available (Figure 2.1):

- The **Upper River** sub-unit extends for about 12 km between the Kaitoke abstraction and where the river emerges into Upper Hutt valley and is joined by the Mangaroa River. The reporting reach for this unit ('Kaitoke') is below the Pakuratahi River confluence directly downstream from the Kaitoke abstraction point; only flow data is available, not habitat.

- The **Middle River** sub-unit extends for almost 20 km from the upper to lower boundaries of Upper Hutt valley and comprises the three reporting reaches of 'Birchville' (upstream), 'Silverstream' (middle) and 'Taita Gorge' (downstream); and

- The **Lower River** sub-unit extends for about 6 km through Lower Hutt valley to the tidal zone downstream of Melling. The reporting reach is 'Avalon', located approximately in the middle of the groundwater depletion zone of the lower reaches.

[2] In this report the term 'reach' is used to describe a section of hydrologically and morphologically similar river channel that can hence be represented by a reporting site (such as a location for which hydrological modelling or habitat survey data are available).

Figure 2.1. Hutt River assessment unit (main river stem only assessed) showing sub-units and key locations (reaches) relating to flow measurements and/or flow and habitat modelling

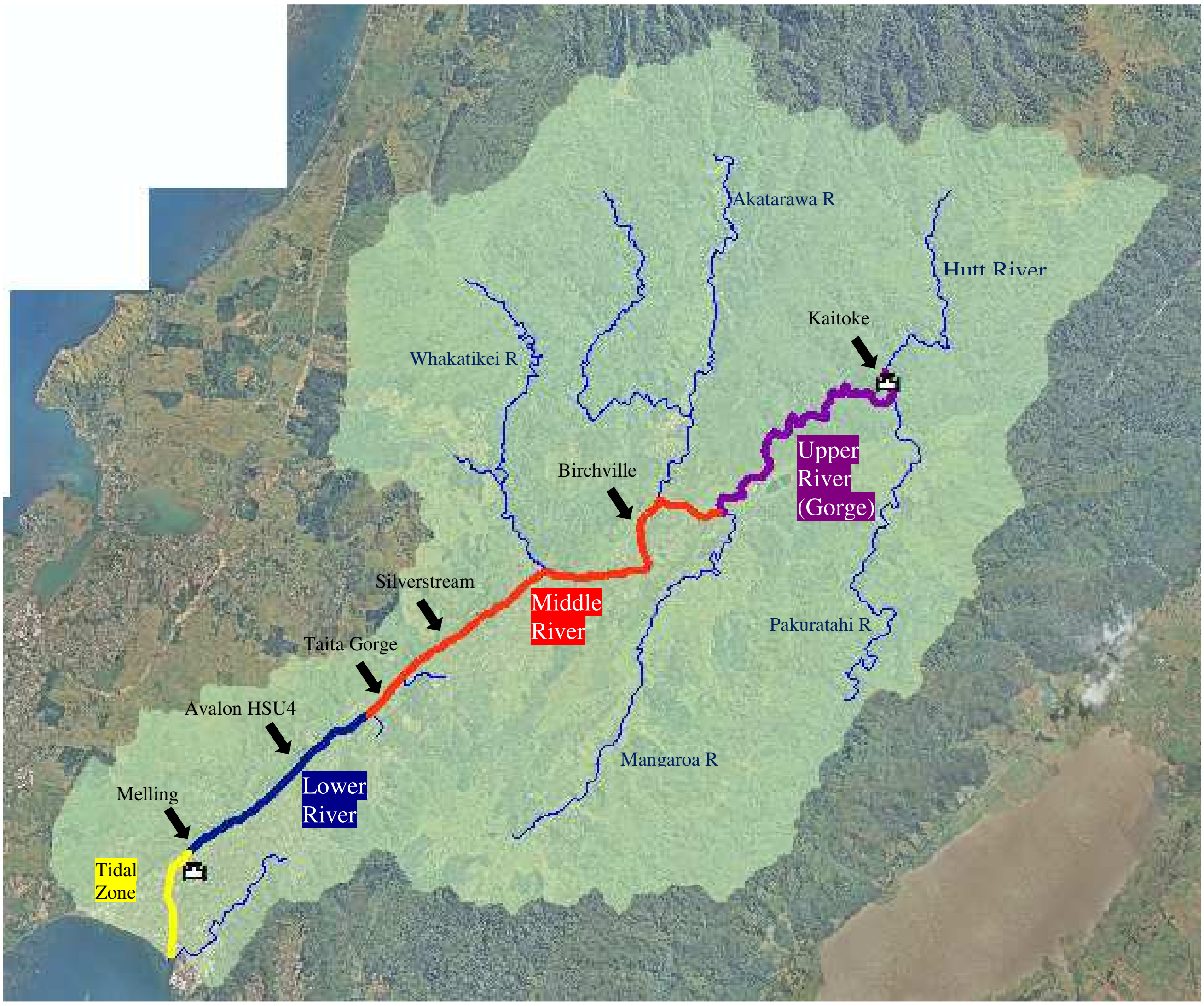
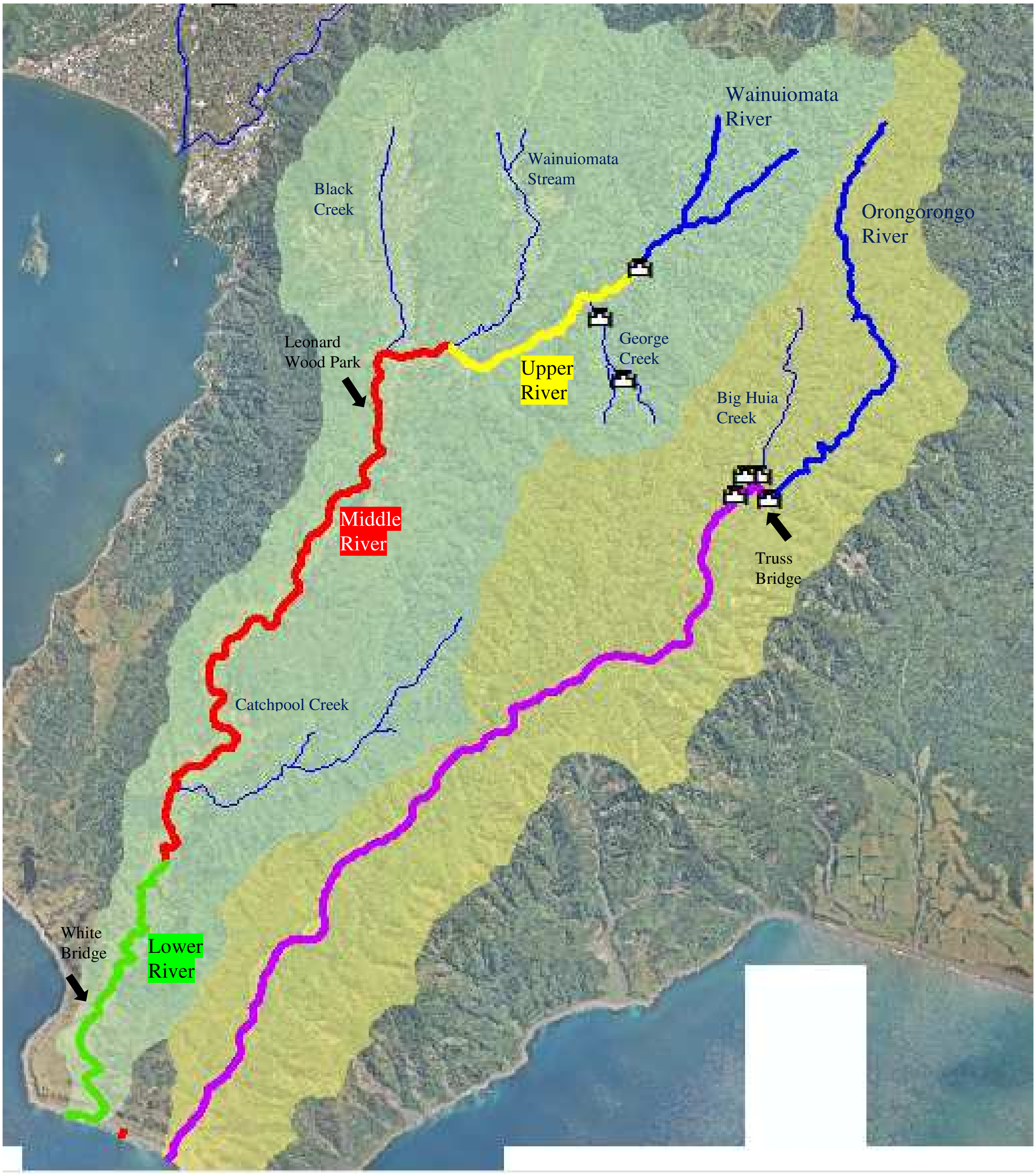


Figure 2.2. Wainuiomata and Orongorongo river assessment units (main river stems only assessed) showing sub-units and key locations (reaches) relating to flow measurements and/or flow and habitat modelling



2.1.2 Wainuiomata River

There are three sub-units of the Wainuiomata River Assessment Unit but only two associated reporting reaches for which hydrology and/or habitat data are available (Figure 2.2):

- The **Upper River** sub-unit extends for about 4 km between the abstraction intakes (on the main stem and George Creek) and where the river emerges from the valley and is joined by the Wainuiomata Stream. There is a GWRC hydrological monitoring site ('Manuka Track') upstream of the abstraction locations but no reporting reach for which naturalised flow or habitat data are available.

- The **Middle River** sub-unit extends for almost 15 km from the Wainuiomata Stream confluence, through part of Wainuiomata township and then south through mixed land use rural valley towards the coast. 'Leonard Wood Park' is the reporting reach for this segment which is characterised by shallow, gravel bed run-riffle-pool sequences.

- The **Lower River** segment occupying the final 3 km of the catchment to the south coast. This sub-unit is distinctly different from the Upper and Middle River, being macrophyte-dominated with deeper pools and much less run/riffle habitat. The reporting reach is 'White Bridge'.

2.1.3 Orongorongo River

The Orongorongo River Assessment Unit comprises a single channel unit extending from the abstraction location to the south coast, a distance of 30 km (Figure 2.2). There is a change in morphology from relatively steep gravel-bed river in the upper reaches to a mobile (sometimes braided) active channel on the wide alluvial floor of the Orongorongo Valley. Land use is consistently indigenous forest until the final 5 km where some low intensity farming occurs. There are no reporting reaches for this Assessment Unit and no current ability to model hydrology or habitat in the same way as for Te Awa Kairangi and Wainuiomata units.

2.2 Attributes

The attributes considered most relevant for assessing the ecological response to the different flow and allocation regime scenarios were;

- Tier 1 – Flow, Physical habitat

- Tier 2 – Water quality, Plant growth (algae)

- Tier 3 – Macroinvertebrates, Fish, Overall suitability for recreation

Appendix 2 provides information about these attributes and the parameters that were available for the Flow Panel assessments. Effects were considered primarily in the context of **ecosystem health**, as a fundamental tenant of the NPS-FM, but other values such as mahinga kai, amenity and recreation were brought into the assessment narratives where appropriate.

The attributes have been split into tiers based on how directly they are affected by changes in flow and allocation regime and how they in turn influence other attributes. This structure generally follows that taken by the Water Quality and Ecology (Ecology) Panel (Greer 2020). However, there is a key point of distinction between how the Flow and Ecology Panels went about their assessments; the attributes being considered by the Ecology Panel have attribute state bands prescribed by the NPS-FM whereas no such bands exist to guide the attribute assessments by the Flow Panel. Therefore, part of the Flow Panel's challenge was in how to convey the likely scale of change or movement from one attribute state to another without the guidance of nationally prescribed attribute state bands. The assessments represent the Panel's best judgements in this respect, supported as appropriate by documented science and national and international flow-setting frameworks. The effects of other non-abstraction stressors (e.g. especially water and habitat quality degradation from human land use) that accumulate together with abstractive effects were not a primary focus of the Panel assessments, although are considered by Clapcott (2020).

2.3 Defining change and effect

This section describes the key statistics and 'bands' of change and effect that the Panel used to develop their assessments and advice.

The Panel used a risk-based assessment framework because the response of ecosystems to flow alteration is highly complex and very rarely successfully measured (Hayes et al 2019). A risk-based banding system was developed to be broadly consistent with principles from the functional and natural flow paradigms − concepts, that are widely understood and well regarded (e.g. Beca 2007, Richter et al 2012 and Yarnell et al 2019) – and adapted to a local context.

2.3.1 Flow

Indicators of Hydrological Alteration (IHA) provided by Keenan (2020) were the primary source of material from which change in the flow attribute was assessed. IHA statistics were initially presented by Keenan (2020) in an early draft of her report (January 2020) using default IHA banding for 'low', 'moderate' and 'high' alteration. At their first meeting (25 February 2020), the Panel were of the view that the default bands, having been defined more than 20 years ago in a North American setting of highly modified rivers (often rivers with multiple dams / impoundments), were not sufficiently aligned with current NZ thinking about the risks of flow alteration, especially the effects of run-of-river abstraction at low flows. The Panel recommended that a revised version of the Keenan (2020) report adopt bands of alteration that better matched the Panel's interpretation of risk in the catchments of interest. This effectively resulted in a single 'band shift' where, for example, what was previously classified by Keenan (2020) as 'moderate' alteration became 'high'. This brings the flow assessment in line with similar processes undertaken in the Wellington region, e.g. see Hay (2017).

Table 2.1 summarises the final bands of flow change used by the Panel to characterise flow alteration under the different scenarios. The Panel chose to use intermediate categories between the main bands defined in Keenan (2020) to ensure the small shifts in some indicator statistics that signal incremental change between scenarios were made apparent. This was necessary to assess and rank impact for the many scenarios (and sub-scenario) options for future abstraction regimes.

Further indicators of change in extreme low flows (defined as being below the naturalised 7-day mean annual low flow) were added to the IHA standard list because they were considered useful indicators of ecologically stressful conditions that may result from the different abstraction scenarios. The two non-IHA indicators focused on the number of extreme low flow days per year and the maximum duration of extreme low flows. The interpretation of these statistics was guided by the criteria in Table 2.2. Visual inspection of the flow duration curve overlays (comparing scenarios) also helped the Panel interpret change and effect. These curves are provided in Appendix 4.

Table 2.1. Magnitude of flow alteration and accompanying effect; descriptors adopted by the Panel

Descriptors of change adopted by Panel	Corresponding category from Keenan (2020) based on IHA* approach (deviation from baseline)	Descriptors of theoretical effect adopted by Panel
No change	No or low alteration	No effect
Small		Weak
Small to moderate	Moderate alteration	Weak to moderate
Moderate		Moderate
Moderate to Large		Moderate to Strong
Large	Large alteration	Strong
Very large	Very Large alteration	Very Strong
Very very large		Very very Strong

* IHA, Indicators of Hydrological Alteration

The purpose of the Indicators of Hydrological Alteration (IHA) approach is to compare ecologically relevant flow statistics between flow / allocation regimes. Ecological effects of flow alteration are built into the IHA approach in a general sense by incorporating a selection of indicators for components of a flow regime that may be ecologically important. The bands of change (described previously) that are applied to the indicators further assist with interpretation by providing an assessment of the risk of negative ecological effects. For the purposes of a Tier 1 assessment of the flow attribute, the flow panel has assumed that the magnitude and direction of broad ecological effects will generally be commensurate with the classification of change itself. For example, a small negative change in flow is likely to lead to a small negative ecological effect. Conversely, a very large change in a flow attribute will correspond with a very large effect on ecology and so on. This thinking is reflected in the descriptions in Table 2.1. It is emphasised that this is a macro assessment of effects based on an expected average ecological response to flow change across river ecosystems. There is, however, no guarantee that the individual systems considered here will comply with this central tendency.

Table 2.2. Interpreting non-IHA results relating to change in frequency and duration of extreme low flows

Change	Change in number of extreme low flow[1] days per year	Change in maximum annual extreme continuous low flow[1] duration	Interpreted effect
No change or small	Less than 7 days	Less than 7 days	Generally commensurate with change category and noting that, for example, large changes in the number of low flow days are not always accompanied by large changes in maximum low flow duration (and vice versa). The most significant ecological risks are likely to occur when both number of days and duration are highly altered.
Moderate	7-20 days	7-20 days	
Large	20-40 days	20-40 days	
Very Large	More than 40 days	More than 40 days	

[1] Extreme low flow defined by the naturalised 7-day mean annual low flow (MALF)

Further consideration of ecological effect in relation to specific attributes (e.g. habitat, plant growth) occurred after the Tier 1 flow assessment and is described below.

2.3.2 Flow-habitat modelling

Habitat retention values for food producing habitat, fish, and a range of macroinvertebrates under different flow / allocation scenarios were assessed using the Area Weighted Suitability (%AWS) approach (Holmes 2020). Habitat retention values are reported for each scenario relative to the amount of habitat that would be available at the naturalised 7-day MALF and median flows; this approach is commonly used to set flows in New Zealand rivers based on an established ecological rationale. For algae, habitat suitability index (HIS) scores were used to assess changes in algal physical habitat preference under the different abstraction scenarios instead of %AWS (Holmes 2020). This is consistent with the approach undertaken by Heath et al. (2015) when assessing benthic cyanobacteria (*Microcoleus*) physical habitat preference in Te Awa Kairangi. These approaches also recognise that the impacts from the water supply abstraction regimes in these catchments are generally restricted to the low to middle parts of the flow regime because there are no substantial storage facilities—meaning that the schemes have little effect on the magnitude and duration of high flows (i.e. floods). Appendix 3 explains the rationale behind the flow-habitat modelling approach in greater detail.

Unlike National Objective Framework attributes that have band thresholds prescribed in national legislation (for interpreting magnitude of change and effect), no such prescriptions exist for in-stream physical habitat retention. The approach taken by Holmes (2020), therefore, is to band the percentage habitat retention reduction values (relative to naturalised flow statistics including the 7-

day MALF and median flows) that represent the likelihood of negative effects based on the standard proposed by Richter et al. (2012). These are summarised in Table 2.3.

Table 2.3. Interpreting bands of percentage habitat retention

Reduction in habitat retention relative to naturalised 7-day MALF	Descriptors of change	Interpretation of effect[1]
<10%	No change or small change	Very low risk of negative effect Minimum flows and allocation limits restricted to this level of alteration are considered highly conservative (precautionary) with respect to ecological protection
10 to 20%	Moderate	Moderate risk of negative effect Minimum flows and allocation limits restricted to this level of alteration are considered conservative with respect to ecological protection
20 to 30%	Large	Strong risk of negative effect; high likelihood of measurable changes in ecosystem structure and function Minimum flows and allocation limits set to this level of alteration are not conservative with respect to ecological protection
30 to 40%	Very large	Very strong risk of a significant negative effect Minimum flows and allocation limits set to this level of alteration could be considered difficult to justify in the context of the NPS-FM
>40%	Very very large	Very very strong risk of a significant negative effect

[1] See Section 2.5 for some discussion about assumptions involved in habitat modelling that have a bearing on the interpretation of effect

This standard was based on the 'natural flow' paradigm and is supported by an international review of flow setting approaches (Richter et al. 2012) based on retaining a percentage of natural flow. The difference in this case is that the bands are based on retaining a percentage of habitat. Richter et al.'s standard states that minimum flows and allocation limits that ensure natural flows are altered by no more than 10%[3] can be considered environmentally conservative (precautionary), in that the natural structure and function of riverine ecosystems will be maintained with minimal changes. Moderate levels of ecological protection will be provided when flow changes are limited to < 20% change (i.e. there may be some measurable changes in structure and minimal changes to ecosystem function). Higher levels of flow alteration will have increasing risk of adverse effects. While Richter et al.'s (2012) presumptive standard is based on flow alteration, its thresholds for guiding interpretation of

[3] Assessed by Richter et al (2012) as a change in *average daily flow*,irrespective of season or point on an flow duration curve.

ecological effects ought to be applicable to habitat alteration. In addition, the percent habitat reduction thresholds in this report are aligned with advice provided by Hay (2010) that was used to guide other GWRC water allocation planning (e.g. Thompson 2017 and Ruamāhanga Whaitua Committee 2018).

2.4 Scenarios

Firstly, the measured flows for Hutt River at Birchville, Hutt River at Taita Gorge and Wainuiomata River at Leonard Wood Park and the synthetic flows for the lower segment of Te Awa Kairangi were assessed against the naturalised flows[4], to provide an indication of the hydrological alteration caused by the current abstraction regime (referred to in this report as 'Scenario 0'). Several scenarios of water allocation and minimum flows were then assessed, again using the naturalised flows as the baseline against which to measure the anticipated change.

The scenarios were:

Scenario 0: Current use of water allocation (defined by actual abstraction records over the past 20 years)

Scenario 1: Maximum use of current water allocation, with two sub-scenarios for Te Awa Kairangi:

- **Hutt Scenario 1a:** maximum allowable river take (retaining a minimum flow at Kaitoke of 0.6 m^3/s) and groundwater abstraction at a constant rate of 100 ML/d, which equates to the Natural Resources Plan annual allocation limit for the aquifer of 36.6 Mm^3

- **Hutt Scenario 1b:** maximum allowable river take and seasonally variable groundwater abstraction peaking at 132 ML/d during January and February

Scenario 2: Increased abstraction in Te Awa Kairangi catchment, with the following sub-scenarios:

- **Scenario 2a** – Hutt River at Kaitoke minimum flow reduced to 0.4 m^3/s, year-round

- **Scenario 2b** – Hutt River at Kaitoke minimum flow reduced to 0.4 m^3/s, January to March only

- **Scenario 2c** – increased groundwater abstraction (seasonally variable, peaking at 143 ML/d in January and February)

- **Scenario 2d** – increased groundwater abstraction (maximum rate achievable while keeping water level at foreshore above 2 m)

- **Scenario 2e** – combination of Scenarios 2a and 2d, to represent an increase in groundwater abstraction and a decrease in minimum flow.

---

[4] 'Synthetic' flow in the lower reach refers to a modelled time series derived by adjusting Taita Gorge measured flow using the HAMv3 groundwater model inputs. 'Naturalised' flow refers to modelled time series in which abstractions have been added back in to simulate a natural flow record. Methods for synthesising and naturalising flows are described in detail in Keenan (2020).

Scenario 3: Reduced river abstraction during low flow conditions due to a 33% increase in minimum flow in Te Awa Kairangi and Wainuiomata rivers. For Te Awa Kairangi there are two sub-scenarios:

- **Scenario 3a** – increased minimum flow at Kaitoke and no change in groundwater abstraction
- **Scenario 3b** – increased minimum flow at Kaitoke and increased groundwater abstraction as in Scenario 2d (to offset the reduced surface water take at low flows).

Note that the two sub-scenarios 1a and 1b were required because of the various ways the proposed Natural Resource Plan annual groundwater allocation limits could be translated into realistic weekly abstraction rates in the Hutt Aquifer Model.

As mentioned previously, the aim of these scenarios is to assess the effect of allocation policies on the hydrological regime, not the effect of individual takes under various operating regimes. It is acknowledged that actual abstraction is likely to vary significantly seasonally and from year to year.

2.5 Assumptions and limitations

There are some assumptions and limitations that are particularly important when considering the advice provided in this report. In no particular order –

- Large scale abstraction for public supply has been a feature of Te Awa Kairangi, Wainuiomata and Orongorongo river catchments for well over 100 years. There is a school of thought that the current use regime should be considered the ecological baseline against which any future changes in abstraction should be compared. The flow panel have a different view. Assessment of change and impact relative to current regime is clearly important to understand but, if done in isolation from a naturalised state comparison, there is a danger of understating the full consequence of further incremental shifts in flow regime. The more 'honest' assessment of change should primarily involve comparing all scenario outcomes with the modelled naturalised flow regime. This approach has been adopted in both the background technical reports and this assessment report.
- Confidence in the assessments varies depending upon the attribute being considered and the quality and quantity of data available. This is discussed more fully in the next section. Here it is simply noted that the lower the confidence is in the outcome, the more important it is to take a conservative or precautionary interpretation of effects.
- This report does not consider any objectives or policies, existing or historical, relating to the management of the water supply rivers; for example, the notion of the upper reaches of the rivers being managed for water supply and the middle and lower reaches for other values (as described by Hudson 2010). This report focuses on the ecological implications of flow alteration, irrespective of management objectives.
- The 'maximum use' scenario (Scenario 2) is a significant simplification of how further abstraction may occur under existing policy and consent settings and could be misleading without careful interpretation. Wellington Water are of the view that the long-term average

water take for public supply is likely to remain significantly below permitted allocation amounts because source redundancy is needed to mitigate risks associated with network outages and other operational constraints. This apparent under-utilisation is a fundamental aspect of water supply risk management and will continue to feature in water takes in the future (Blyth 2020). In a sense, the maximum use scenario tested in this report is very unlikely to eventuate (certainly not in its fullest extent and assuming no significant transfer of WWL water to other users). However, it remains a useful scenario to include as it highlights where in the hydrograph additional water *could* be taken (and the likely impact of this) should operational and management constraints allow it and focuses attention on flow response sensitivity in this area. Since scenarios 1, 2 and 3 also contain the same maximum use assumptions, comparison of *relative change* between them remains valid.

- Similarly, the full extent of additional groundwater pumping simulated under scenario 2c could not occur under existing consents. This is because the saline intrusion trigger at the Petone foreshore (2 m a.m.s.l.) is predicted to be the primary constraint. Nevertheless, for the same reasons as just described, testing the higher groundwater pumping rates provides useful information of river flow sensitivity.

- The habitat suitability curves used to assess changes in instream physical habitat suitability for native fish have largely been generated from data collected in wade-able gravel-bottom streams and their transferability to larger rivers has not been evaluated.

- Assessments in this report rely heavily (although not exclusively) on flow alteration and 1-D habitat modelling. While both techniques provide robust information and have an established history for determining allocation in New Zealand, they do not capture all that is important for interpreting ecological health outcomes. For example, the habitat techniques probably understate risks of flow alteration for drift feeding fish (see Hayes et al 2018) and overall impacts of flow alteration on habitat quality beyond that defined by physical space, depth, velocity and substrate type. Interpreting risks relating to habitat loss are usually also hampered by uncertainty about whether habitat at low flows presents a major ecosystem limitation when river carrying capacity is unknown. Nevertheless, these limitations are common to most flow management decision making processes and are addressed mostly in the statements of confidence that accompany the assessments (discussed more in the next section).

2.6 Confidence in assessments

Each set of assessments of the magnitude of change and its associated ecological effect is accompanied by a statement about the Panel's confidence (low, moderate, high) in the assessments. These statements are intended to capture a general sentiment to assist with the Committee decision making, rather than being quantitative measures of uncertainty. The confidence statement amalgamates many elements of the assessment process from the rigour of the data and methods used (including availability of relevant data) to the knowledge and expertise of the Panel members.

Table 2.4 was used by the Panel members to recognise the interaction between change and effect when considering their overall confidence and to help ensure some consistency in approach.

Table 2.4. Determining confidence in assessments

		Confidence in data and modelling to support predictions of change and effect		
		Low	**Moderate**	**High**
Confidence in predicted magnitude of effect	**Low**	Low	Low	Moderate
	Moderate	Low	Moderate	Moderate
	High	Moderate	Moderate	High

Statements of 'high' confidence have been reserved only for the situation in which the Panel is highly confident about both the predicted magnitude of change and the effect it would result in. High confidence in either change or effect, but not both, can only result in a 'moderate' overall confidence, and a combination of low and moderate confidence will fall to 'low' overall.

In general terms, confidence in the predictions of flow change is high. This is due to having high quality, long term actual water use data that account for ~95% of the total catchment abstraction and allow for relatively accurate flow naturalisation to be achieved (demonstrated by good results when comparing modelled versus observed data). Uncertainties in the flow data and assumptions do remain, however, and in parts of the catchments where model validation cannot be achieved, for example, confidence in predictions of flow change is more moderate than high.

Assessment of the ecosystem effects of flow change, especially those that are more indirect, are generally accompanied by lower confidence than the change itself. As noted earlier, the response of ecosystems to flow alteration in multi-stressor environments is highly complex. This is particularly the case for higher trophic level organisms that are normally more mobile and can, on one hand, seek refuge from a location-specific stress but on the other, be subject to multiple and spatially variable stresses.

More is known about some components of the ecosystem than others. Trout (and other salmonid) responses to flow have a long history of study in New Zealand and overseas and subsequently relatively well-developed habitat suitability curves. The same cannot be said for many species of native fish. The contraction and recovery of benthic macroinvertebrate communities during extreme low flows is reasonably well understood, but the consequence for fish grazing and/or drift feeding is harder to predict. Similarly, the effect of flow change on communities, including macroinvertebrates, at other parts of the hydrograph are not well understood. *Microcoleus* Sp. (formerly *Phormidium*), commonly referred to as toxic algae, responses to flow and habitat alteration in Te Awa Kairangi have been extensively studied (Heath et al, 2012 and 2015). However, there is a paucity of information on how other periphyton types respond to shifts in flow regime over low to mid-range flows.

2.7 Structure of the following report sections

The following three sections of this report each provide a synthesis of the assessments of individual flow related attributes for different sub-units of Te Awa Kairangi, Wainuiomata and Orongorongo rivers, respectively. The syntheses take a largely narrative form supported by figures to help compare predicted outcomes between abstraction scenarios.

Assessments have drawn on a range of material and expertise and relied particularly on two reports:

- Scenario flow modelling and Indicators of Hydrological Alteration analysis reported by Keenan (2020);
- Hydraulic-habitat model re-analysis for key macroinvertebrate, algae (periphyton) and fish species and life stages reported by Holmes (2020).

Each section begins with a summary of attribute changes and effects expected under the current abstraction regime (relative to a naturalised baseline state) and then moves onto comparing scenarios of higher and lower abstraction against both current and naturalised state.

3. Summary - Hutt River Assessment Unit

3.1 Current Use

3.1.1 Attribute change from naturalised state

Assessment results are summarised in Tables A5.1 to A5.4 in Appendix 5.

The current allocation of water from Te Awa Kairangi does not remove any of the fundamental components of the natural flow regime. Floods and fresh flows, including algae flushing flows, retain their natural frequency, timing, and size. Natural seasonal changes from high winter to low summer base flows still occur and there are no large-scale changes to mid-range flows as might occur on rivers subject to either very large diversions or damming. However, there are substantial changes during low base flows, typically in summer and autumn. Of most relevance to ecological effects are the changes to the magnitude and duration of low flows, and especially those below or equivalent to mean annual low flow (MALF).

Due to the location of primary abstractions (surface take at Kaitoke and groundwater take in Lower Hutt) and natural flow inputs from tributary rivers in between, the degree of low flow alteration is spatially variable along the course of the river (Figure 3.1).

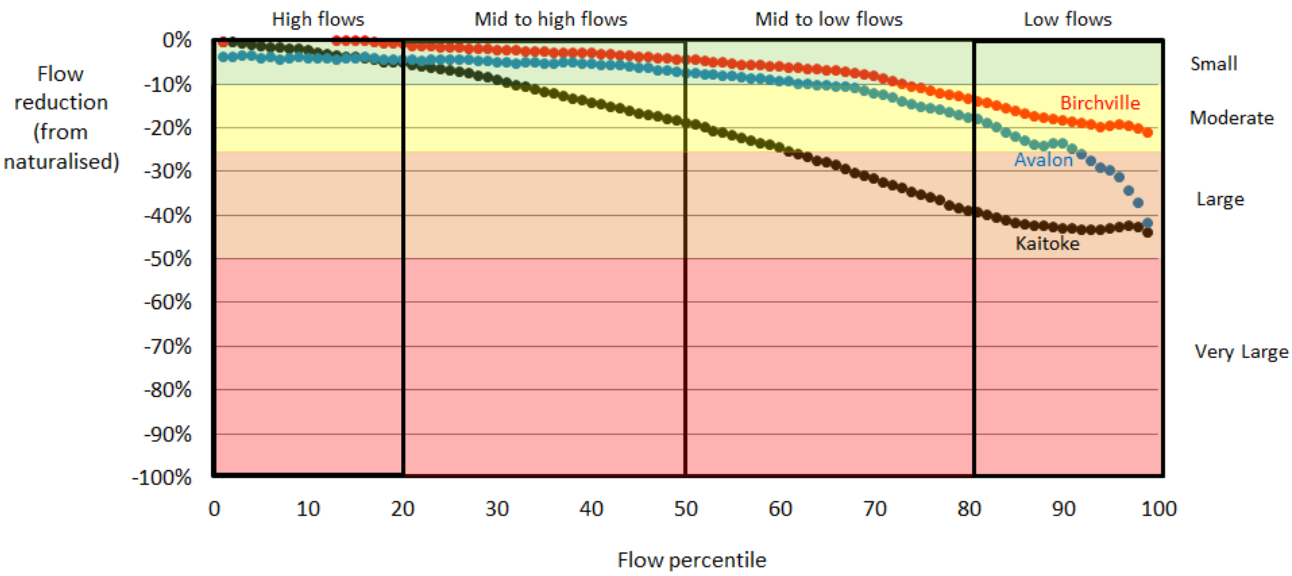


Figure 3.1. Comparison of the reduction from naturalised flow regime at Kaitoke (Upper River), Birchville (Middle River) and Avalon (Lower River) caused by current abstraction. Flow percentile bands (vertical black lines) show that greatest proportional reductions occur at low flows at all sites. Flow reduction categories are based on the hydrological alteration categories in Table 2.1 and progress from small (green shaded panel) to very large (red).

Upper River

The Upper River flows for about 12 km through the gorge between Kaitoke and the Mangaroa River confluence and undergoes the largest flow alteration; Figure 3.1 shows that low flows in the Upper River are altered, on average, by up to 40% compared to the naturalised regime. This is more than twice the alteration that occurs lower in the catchment (except for extreme low flows in the lowest reaches). The full effects of the surface take at Kaitoke at low flows are strongest in the Upper River with little attenuation from the only tributary, the Pakuratahi River. All indicators of hydrological change considered here suggest an increase in the frequency, magnitude, and duration of low flows that equate to large or very large departures from the natural regime.

Impacts of flow alteration on algae, habitat availability for food productivity, benthic macroinvertebrates and fish cannot be reliably assessed in the Upper River due to a lack of data. It is hypothesised that physical habitat may be less sensitive to flow reductions in the gorge sections of the Upper River than lower in the catchment due to marked differences in channel geometry, with the channel being generally deeper and narrower. However, in the absence of more complete data, the most reasonable (i.e., precautionary) approach is to assume that reductions in habitat availability at low flows in the Upper River are commensurate with the scale of low flow alteration and, therefore, are best described as large to very large. Algal physical habitat quality is the sole exception, with only negligible changes expected for this aspect of ecology.

With respect to water quality, again there are insufficient data to confidently assess change. Conceptually, and supported by experience in similar gravel bed river systems, flows are likely to remain well-oxygenated through the gorge even when heavily drawn down by abstraction. Monitoring immediately upstream of the Kaitoke take and downstream of the gorge (Te Marua) suggests maximum summer temperatures commonly lie around or below 20 °C in the Upper River, with an approximate 3-5 °C increase from upstream to downstream. However, flow-temperature modelling has not been done so change under the current use regime cannot be quantified.

One possible consequence of reduced flow due to abstraction is a reduction in the nutrient dilution capacity of the river. A desktop assessment found modest to large increases in dissolved inorganic nitrogen (DIN) concentrations downstream of the Pakuratahi River confluence during low flows associated with water abstraction, possibly due to reduced dilution (Heath and Greenfield 2016). The increase in DIN concentrations was hypothesised by the authors to facilitate toxic algae (*Microcoleus*) growth in the lower segments of this reach.

Middle River

The Middle River extends for just under 20 km between the Mangaroa River confluence and Taita Gorge and currently undergoes much lower levels of hydrological alteration than the Upper River (Figure 3.1). Although there is some loss to groundwater in the upper reaches, natural base flows effectively double through the Middle River with contributions from the Mangaroa, Akatarawa and Whakatikei rivers and a return flow (and net gain) of groundwater. The effect of the direct surface take at Kaitoke on the flow regime diminishes accordingly. Nevertheless, indicators of hydrological change suggest negative shifts in extreme low flows (magnitude and duration) that still equate to moderate departures from the naturalised baseline (Figure 3.1).

Reductions in physical habitat, as defined by percent Area Weighted Suitability (AWS) analysis, are small for food producing and benthic macroinvertebrates, and small to moderate for native fish and trout. Changes in algal physical habitat quality are small for all four algal types; availability may increase or reduce depending on algal type. Water quality shifts resulting from current use cannot be fully quantified due to a lack of data. However, nutrient concentrations are expected to be higher under the current use scenario during water abstraction (at Kaitoke) because of the reduced capacity for the river to dilute more nutrient rich waters downstream. Continuous dissolved oxygen monitoring (Wellington Water 2018) at three sites in the Middle River suggests any shift in dissolved oxygen profile caused by the abstraction regime (among other stressors) is unlikely to be very large. Maximum water temperatures are between 4 and 11 $^{\circ}$C higher in the middle reaches compared with Kaitoke, peaking at 25 to 30 $^{\circ}$C. This will be driven to a large extent by the longer channel retention time, and increased exposure to direct solar radiation with channel widening and lack of shade from topography and vegetation. The relatively high peak temperatures in the mid and lower river exceed preferred water temperatures for most native biota and will interact with low-flow periods to create stressful conditions for in-stream biota.

<u>Lower River</u>

The Lower River extends for about 6 km through Lower Hutt between Taita Gorge and the tidal boundary downstream of Melling Bridge. It currently undergoes higher levels of hydrological alteration than the Middle River, although not as high as the Upper River until the most extreme low flows are reached (Figure 3.1). While much of the impact from the Upper River catchment take has been attenuated, there are natural flow losses to groundwater in the Lower River and significant further flow losses caused by abstraction from the Waiwhetu aquifer. Indicators of hydrological change suggest an increased occurrence and magnitude of extreme low flows that equate to moderate to large departures from the naturalised baseline. Reductions in physical habitat, as defined by percent Area Weighted Suitability (AWS) analysis, indicate moderate to large reductions in food producing and benthic macroinvertebrates and trout, but a small to moderate reduction in in-stream physical habitat for native fish. Only small changes in the quality of algal physical habitat from the naturalised baseline are predicted for the Lower River. However, increases in the frequency and magnitude of low flow days (i.e. algal accrual period) under current use has likely resulted in increased algal growth and biomass during low flows; the narrative above for water quality in the Middle River applies to the Lower River also.

3.1.2 Effects realised under current use

Effects associated with the changes described in the previous section are summarised in table form in Appendix 3 and visually in Figure 3.2(a-d). The overall pattern is one of strong to moderate predicted effects on ecological and flow attributes in the Upper and Lower rivers, and weak to moderate effects in the Middle River. Whether the effects have been realised cannot be determined with high confidence, but the following points were made by the Flow Panel:

- Modified low flows in Te Awa Kairangi are not sufficiently extreme to cause localised extirpation of fish. The concern is more about fish abundance than diversity of species. Whether fish abundance has been materially affected by the current abstractions depends to a large extent on whether habitat at low flows strongly limits the carrying capacity of the river for fish. Frequent flooding in Te Awa Kairangi likely causes substantial mortality for fish and implies that fish populations may be maintained below carrying capacity during most years, therefore, fish abundance may be less sensitive to changes in extreme low flows in comparison with rivers with more stable flow regimes (e.g. spring-fed rivers). On the other hand, if the river fish populations approach carrying capacity at times, for example after two or three relatively stable flow years with no large floods, then the effect of prolonged low flows on habitat loss due to abstraction will be more detrimental. Furthermore, relatively high water temperatures that have been observed in some parts of the river could have the effect of increasing the sensitivity of the ecological communities to habitat constraints arising from reduced flows.

- Repeat summer trout surveys on Te Awa Kairangi suggest abundance of adults is driven more by the cyclical patterns of floods than dry spells. Recruitment and survival of adult brown trout has been described as "good" by Fish & Game (Pilkington 2016) outside of flood prone periods. Based on these surveys, relative abundance varies between reaches over time but there is a generally consistent pattern of lower trout numbers in the reaches with highest habitat losses at low flows (predicted by the flow habitat modelling) (Kaitoke, Avalon) compared with higher trout numbers in the Middle River reaches that are less affected by flow alteration. However, other factors could be driving these patterns in trout abundance, such as juvenile displacement and recruitment following high flows, and water temperature refugia associated with groundwater upwelling. No systematic longitudinal monitoring exists for native fish so abundance patterns (spatially and with time) are unknown.

- The relationship between change in instream physical habitat and effects on benthic macroinvertebrates is more linear and certain than for fish. As habitat diminishes so too will numbers of resident macroinvertebrates, and in a roughly proportionate manner. Consequently, large reductions in the magnitude of low flows can be expected to have strong negative impacts on macroinvertebrate communities. However, the flow-on effect of this for higher trophic levels (i.e. fish) is less clear. Since fish are mobile the effect of diminishing benthic macroinvertebrate food supply in some reaches may be offset by feeding opportunities elsewhere. It is also thought that, when considering macroinvertebrates as a food source to sustain higher trophic levels (especially drift feeding fish and river birds), changes in mid-range flows may be more consequential than alterations to low flows (Hayes et al 2019). This is because macroinvertebrates can rapidly colonise recently inundated habitat (in the order of weeks). Under the current use regime, reductions in mid-range flows are very minor and hence effects on macroinvertebrate productivity are expected to be minimal.

- Macroinvertebrate monitoring data collected to date are not useful for assessing effects of water abstraction. This is because the methods used have focussed on collecting invertebrates from riffle flow habitats only and metrics calculated from these data are designed to indicate organic enrichment and sediment pollution (i.e. Macroinvertebrate Community Index (MCI)). Flow effects on invertebrates are more likely to be detected by i) sampling flow-sensitive environments (e.g. edge waters) or conducting area-weighted full habitat sampling, ii) using metrics designed to detect flow effects (e.g. LIFENZ; Greenwood et al. 2016) or iii) by focussing on community or population biomass, or iv) investigating aquatic invertebrate drift-flow relationships.

- Algal physical habitat quality has remained relatively unchanged under current water use in all three Hutt River sub-units compared to naturalised flows. Of the four algal types, three; diatoms, *Microcoleus* and short filamentous have marginally reduced physical habitat quality while long filamentous algae marginally increased. The change in the frequency and duration of low flows (i.e. accrual period) in the Lower River is of far greater concern than the small changes in physical habitat quality. An increase in accrual period allows algal communities further time to acquire resources (such as nutrients) needed to grow, expand and colonise the available habitat.

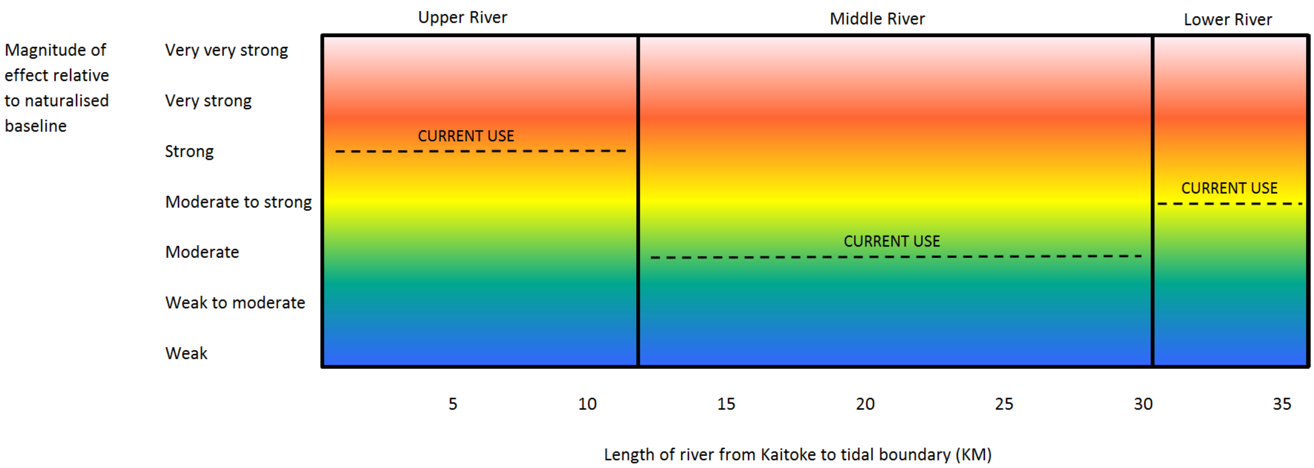
- An important result from the flow habitat modelling was that toxic algae *(Microcoleus)* physical habitat quality reduces at low flows in Te Awa Kairangi. This is consistent with earlier *Microcoleus* habitat suitability investigations undertaken by Heath et al (2015) and Heath and Greenfield (2016). Reduced physical habitat quality at lower flows is hypothesised by Dr Heath to be the result of decreased nutrient mass transfer, i.e. there is not enough nutrients passing-by quickly enough at low flows. This result highlights the important role that 'resources' such as amount of light, temperature and nutrients play in regulating *Microcoleus* growth in Te Awa Kairangi

- While the Upper River segment undergoes the greatest degree of flow alteration it is also the least impacted by other stressors which occur downstream. The channel and riparian margins are almost entirely unmodified by land use or flood management works and the bedrock containment of the relatively narrow channel sustains water depth. Steep terrain and shading vegetation reduce solar radiation exposure and water temperatures remain relatively low through summer. It is reasonable to think that these factors combined will help offset the effects of the abstraction. Almost the opposite is true for the Lower River at the Avalon reach. Here, the extent of flow alteration is lower than in the Upper River, but any low flow effects will be accentuated by channel exposure and significantly higher summer water temperatures.

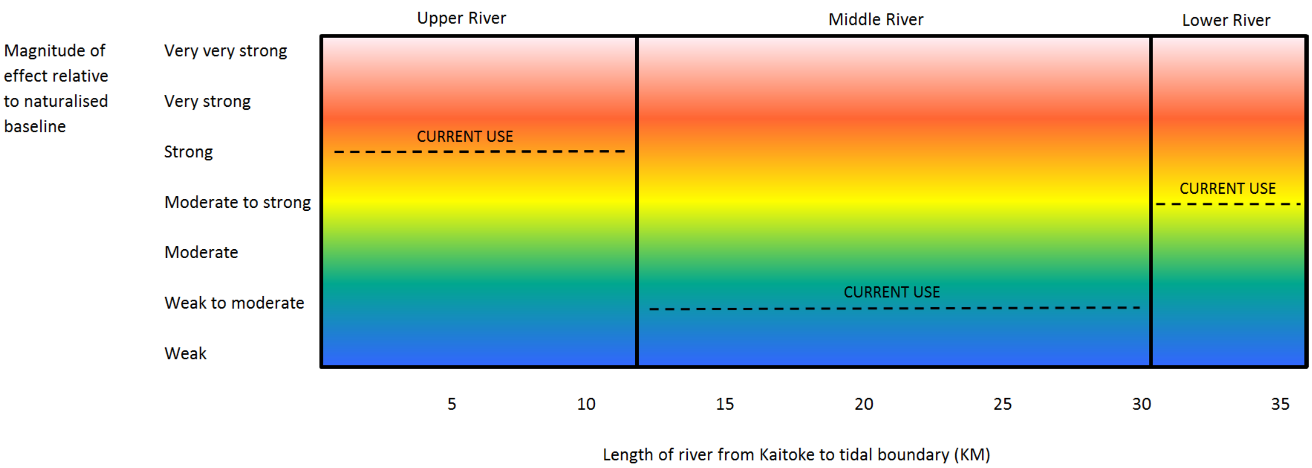
In summary, it is not possible to be confident or unequivocal about what ecological effects of flow changes have been realised under the current use regime in Te Awa Kairangi due to a lack of data. While some indicators (e.g. mid-range flow alteration) and attribute observations (e.g. trout abundance patterns) are suggestive of minor effects, more significant effects, especially relating to low flow alteration, cannot be ruled out. Clapcott (2020) notes that the data needed to be more conclusive about overall ecosystem health impacts simply are not available and there are obviously no pre-abstraction conditions to refer to.

In the absence of fuller evidence to the contrary it is necessary to take a precautionary view of likely effects. This means applying a minimum operator principle (i.e. defining overall effect by the attribute or river segment/reach that is most limited by abstraction) and relying on available modelled flow alteration and habitat change statistics with relatively conservative interpretations with respect to the risk that these alterations are negatively affecting ecology. Under this approach, the most reasonable assessment for Te Awa Kairangi is that the current water use regime likely has moderate to strong negative impacts on ecosystem health. Risks to ecosystem health are probably highest in the Lower River where groundwater losses are greatest between Taita Gorge and the tidal boundary. However, it should be noted that the length of river in question here is relatively short, making up about 15% of total river length below Kaitoke.

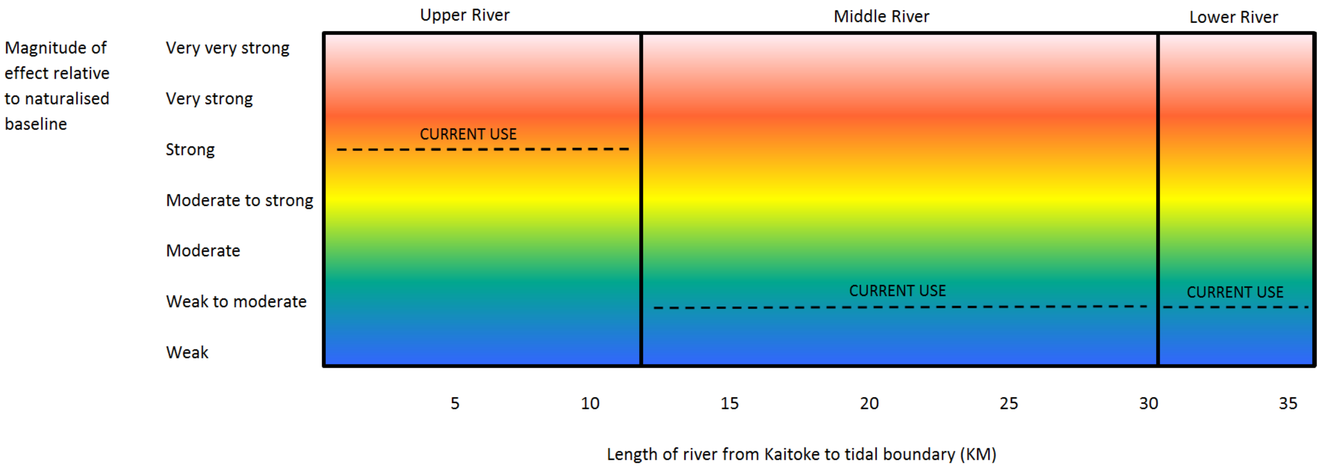
(a) Attribute: Flow



(b) Attribute: Macroinvertebrate habitat



(c) Attribute: Native fish habitat



(d) Attribute: Trout habitat

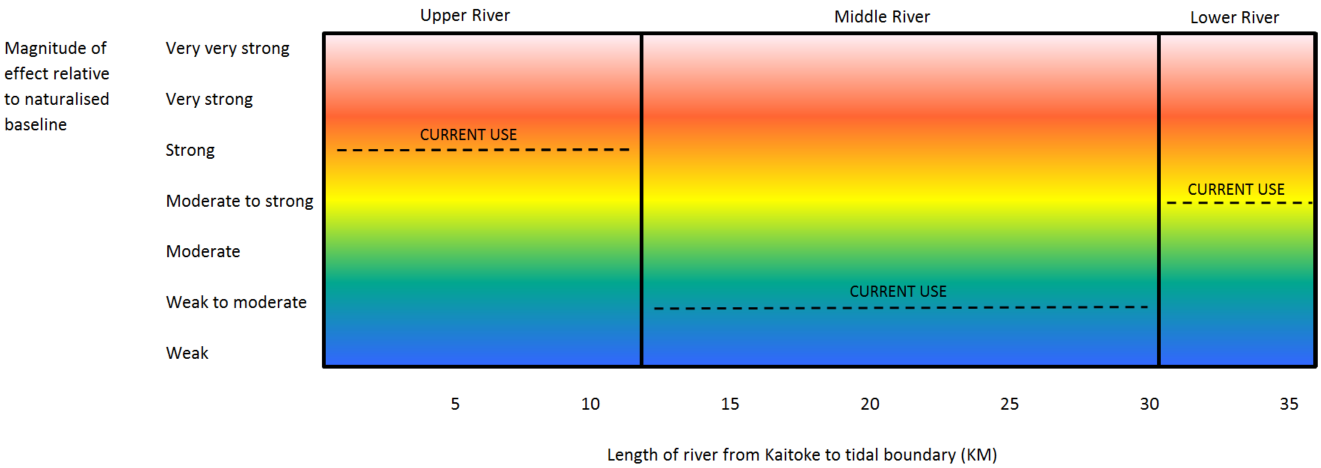


Figure 3.2. Assessment of predicted effects under current use (Scenario 0) for the attributes in Appendix 5. On the horizontal axis, the three sub-units (Upper, Middle, Lower) are sized according to the approximate length of river in each. This allows a sense of the physical 'extent' of river to which the change and effect predictions apply.

3.2 Scenarios of higher and lower abstraction

3.2.1 Attribute change from current use and naturalised state

The relative scale of hydrological alteration from naturalised flow predicted for the abstraction scenarios in the three river sub-units is shown in Figure 3.3. It illustrates the potential for quite different outcomes in different parts of the catchment.

For the Upper River (Figure 3.3a), compared with the large shift that has already taken place from naturalised to current state, further flow alterations relating to the various abstraction scenarios are generally modest. Nevertheless, both negative and positive band shifts compared to alteration under the current regime (which is 'large' overall) are possible in the low flow range. In the Middle and Lower rivers, the reverse is true (Figure 3.3b and 3.3c); the hydrological shift that has already occurred in these segments is more modest than in the Upper River and the predicted further shift (almost all of which is negative) is relatively large.

When taking a closer look at the scenarios the following points are of note:

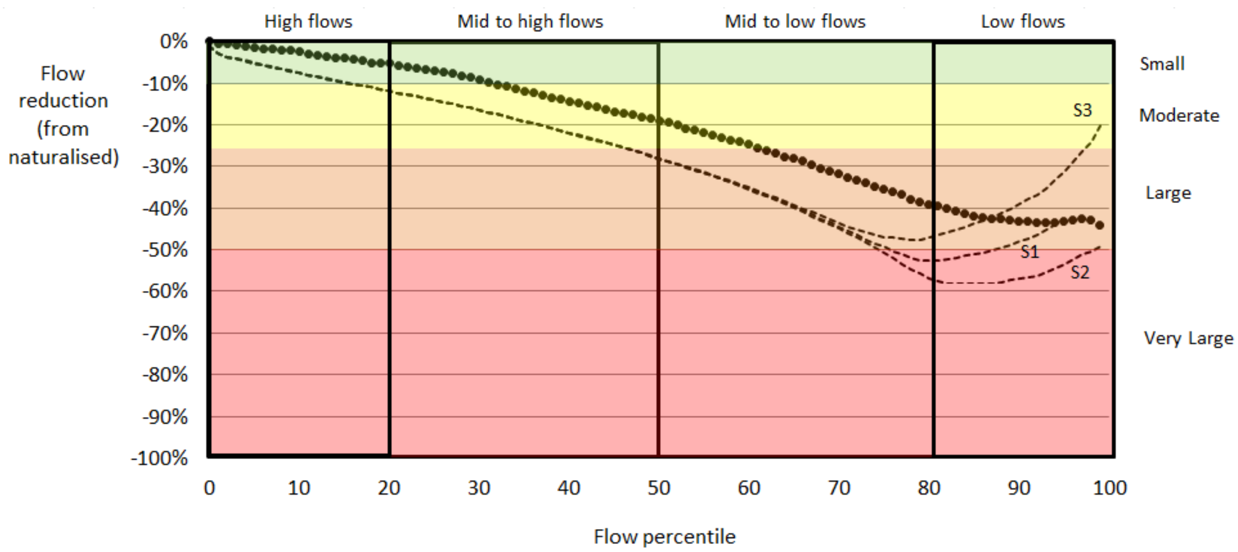
- A large change across the hydrograph first appears in Scenario 1 in which all available water that can be taken (under current consent and regional plan rules) is taken[5]. The key change under this maximum use scenario is that greater volumes of water are abstracted through the mid to low-flow range where, currently, demand does not require it. This manifests as both a reduction in mid-range flows and an increase in the length of low flow durations (although the magnitude of extreme low flows is not substantially reduced as water use at these times is generally already maximised).

- Subsequent flow changes under the increased (Scenario 2) and decreased (Scenario 3) abstraction scenarios incorporate the same changes from Scenario 1, but differ primarily in the impacts on the low flow range where the effects of lower and higher minimum flows at Kaitoke become more apparent (as well as groundwater pumping in the Lower River). The effect on the flow regime of increasing or reducing the Kaitoke minimum flow by 200 L/sec (Scenarios 2 and 3) does not effectively propagate beyond the Upper River and is not appreciably different from the existing level of flow regime alteration under current use. However, when a reduced minimum flow is combined with an increased groundwater take (Scenario 2e), greater and more prolonged low flow periods are likely in the Lower River segment (Figure 3.3c).

---

[5] The likely practical and/or operational constraints to this actually occuring are acknowledged and discussed further in the 'Assumtions and limitations' section.

(a) Kaitoke (Upper River)



Note: The final part of the Scenario 1 (S1) trace between percentiles 96 and 100 has been removed from Figure 3.3 (a) as it presented a misleading picture of how extreme low flows are expected to compare with Current Use. This was due primarily to inclusion of data in Current Use of abstraction below 600 L/sec in 2013 while earthquake strengthening the Te Marua storage lakes. This anomaly is not expected to have unduly affected the interpretation of results between scenarios in the Upper River

(b) Birchville (Middle River)

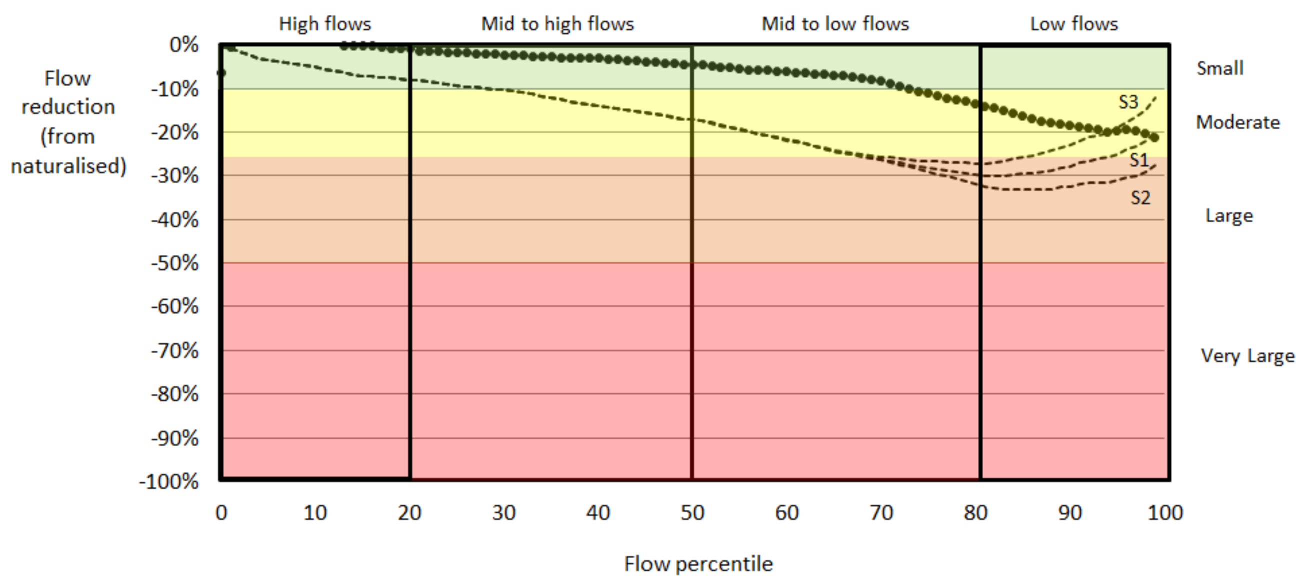


Figure 3.3. Comparison of the reduction from naturalised flow regime for different abstraction scenarios for Kaitoke and Birchville. Flow percentile bands (vertical black lines) show that greatest proportional reductions compared to naturalised flows occur at low flows at all sites. Compared to current use, the other scenarios have a significantly larger impact on mid-range flows. Reductions categories (labels on the right) are based on the hydrological alteration categories in Table 2.1 and progress from small (green panel shading) to very large (red). Current abstraction (Scenario 0) is shown by the solid black dots, and other scenarios are labelled on the figure.

(c) Avalon (Lower River)

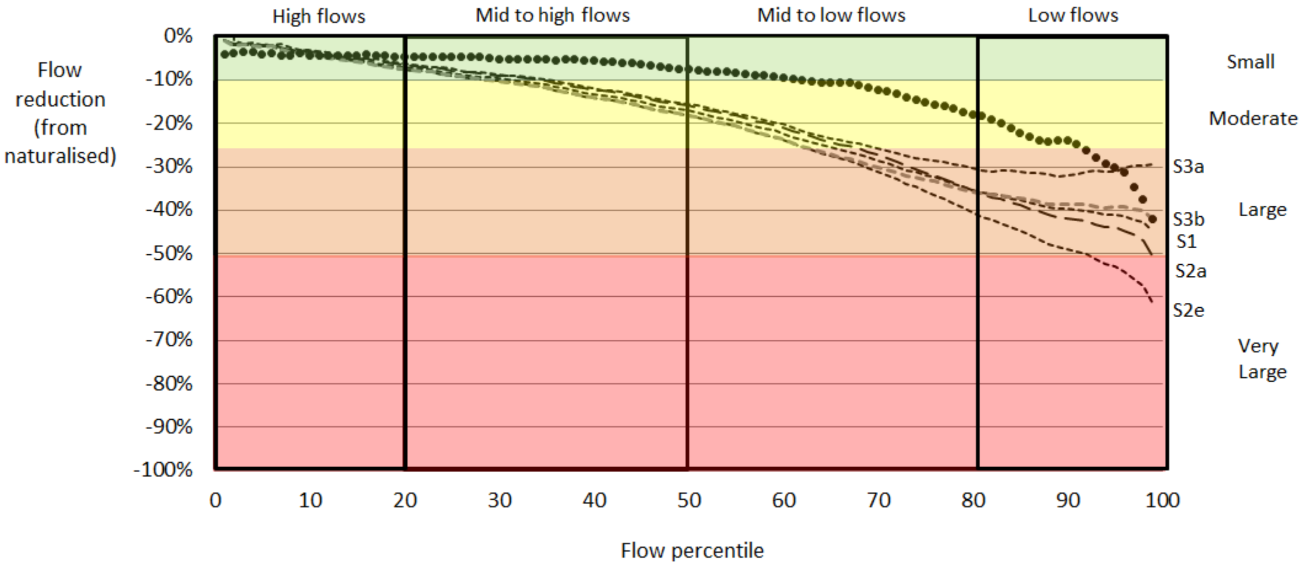


Figure 3.3 cont. Comparison of the reduction from naturalised flow regime for different abstraction scenarios for Avalon (Lower River). Flow percentile bands (vertical black lines) show that greatest proportional reductions compared to naturalised flows occur at low flows at all sites. Compared to current use, the other scenarios have a significantly larger impact on mid-range flows. Reductions categories (labels on the right) are based on the hydrological alteration categories in Table 2.1 and progress from small (green panel shading) to very large (red). Current abstraction (Scenario 0) is shown by the solid black dots, and other scenarios are labelled on the figure.

Shifts in habitat availability are of the same order and pattern as flow alteration; that is, incrementally different to those under the current use regime. Points to note here are:

- The Middle River seems largely insensitive to the range of scenarios tested, with consistently small to moderate changes in algae, food producing, macroinvertebrate and fish habitat. In this part of the river, only trout habitat at the Taita Gorge reach seemed more sensitive with a fairly significant loss (relative to MALF) occurring under the maximum use (Scenario 1) and increased/decreased abstraction scenarios (Scenarios 2 & 3) relative to current use.

- Loss of habitat in the Lower River is more notable across all indicator species and life stages (moving from moderate-large to very large in some cases) except for algae, which is largely unaffected. The loss of habitat signals that this part of the river may be especially sensitive to even a modest increase in abstraction.

- In the absence of quantitative data on habitat in the upper segment, predictions about how sensitive this part of the river is to further changes in abstraction regime cannot be made with confidence. A precautionary view is that changes would be greater than for the Middle River because of proximity to the point of alteration, but perhaps not as great as for the Lower

River because Upper River channel morphology may dampen the relative response of habitat quality and quantity to flow change.

3.2.2 Effects on attributes

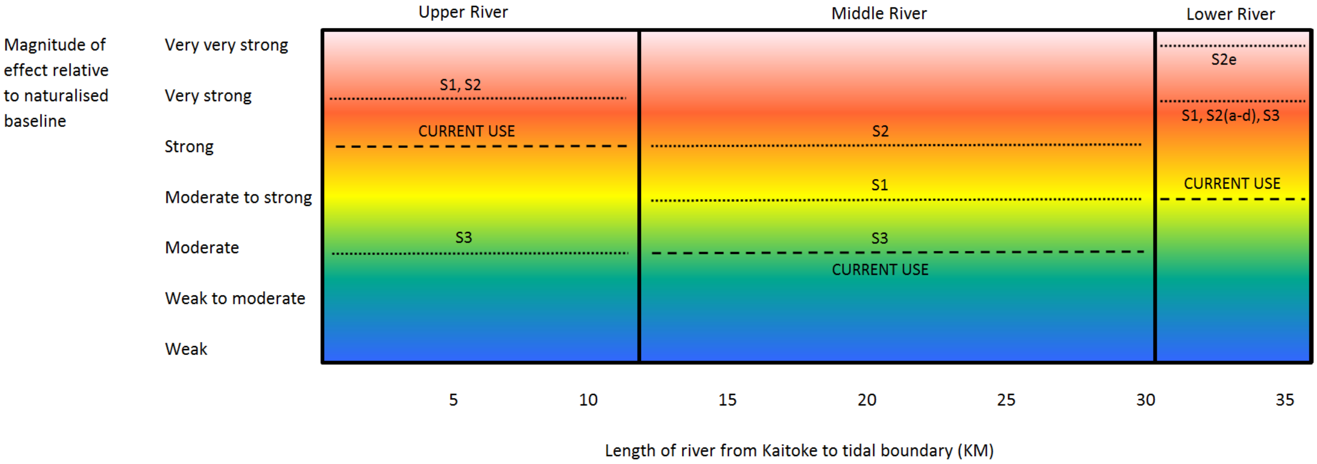
Effects associated with the changes described in the previous section are summarised in table form in Appendix 5 and visually in Figure 3.4. The overall pattern is one of highest probable sensitivity to further abstraction in the Lower River, followed by the Upper and Middle rivers, respectively.

For the Upper and Middle river, shifts in the predicted ecosystem health effects associated with the various scenarios are, by and large, minor and incrementally negative or positive compared to current use. Such small shifts are unlikely to be distinctly (measurably) different to those already realised under the current regime; the important qualifier being that the ecological effects under the current regime is already considered to be strongly negative compared to naturalised state for the Upper River segment. In the Lower River, the shifts are more substantial, and especially so for the increased abstraction scenario that incorporates both a reduced Kaitoke minimum flow and higher groundwater pumping (Scenario 2e).

With respect to Scenario 3, in which the minimum flow at Kaitoke is increased (thereby reducing abstraction at the lowest flows), beneficial effects are likely to be modest in both magnitude and extent. The largest potential benefit would occur for the Upper River (based on flow statistics), but without habitat modelling data this cannot be quantified with respect to potential effect on macroinvertebrates and fish. The potential benefit arising from the higher minimum flow quickly diminishes downstream and is not strongly apparent in the flow or habitat results for the lowest reaches where groundwater loss exerts more control.

Under higher use scenarios, average daily summer flows in all sub-units will reduce and low flows of a given magnitude will occur more often and last longer. Under such conditions, algae has a longer accrual period to acquire resources and occupy available habitat, macroinvertebrate production and, therefore, feeding opportunities for fish (and river birds) decrease, while physical habitat constraints at low flows add further stress to aquatic life. While some ecosystem components can be relatively resilient to repeated stress events – macroinvertebrates for example can recover relatively rapidly, within months, from flow-limiting events – effects on higher trophic level species may accumulate over long time frames. Ultimately, it can only be concluded that the risk of detrimental effects on ecosystem health (as described in Section 2.1) will increase with greater abstraction and that the risks compound particularly in the Lower River reaches where some of the predicted flow and habitat losses become very large. It is important to reiterate that the current regime already represents a large alteration in which effects must be considered moderate to strongly negative. Effects from further abstraction cannot be viewed in isolation from this current state.

(a) Attribute: Flow



(b) Attribute: Macroinvertebrate habitat

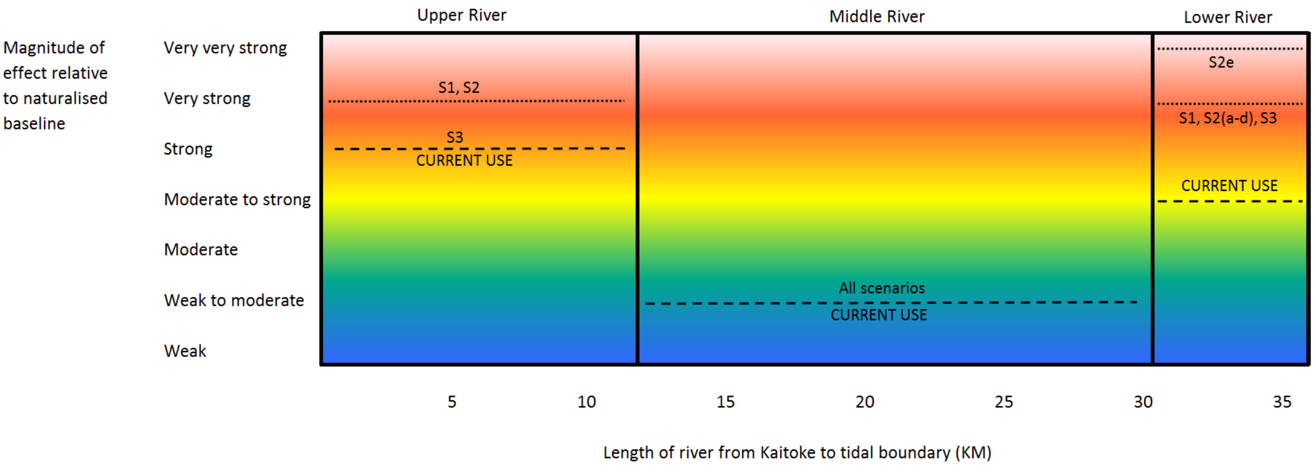
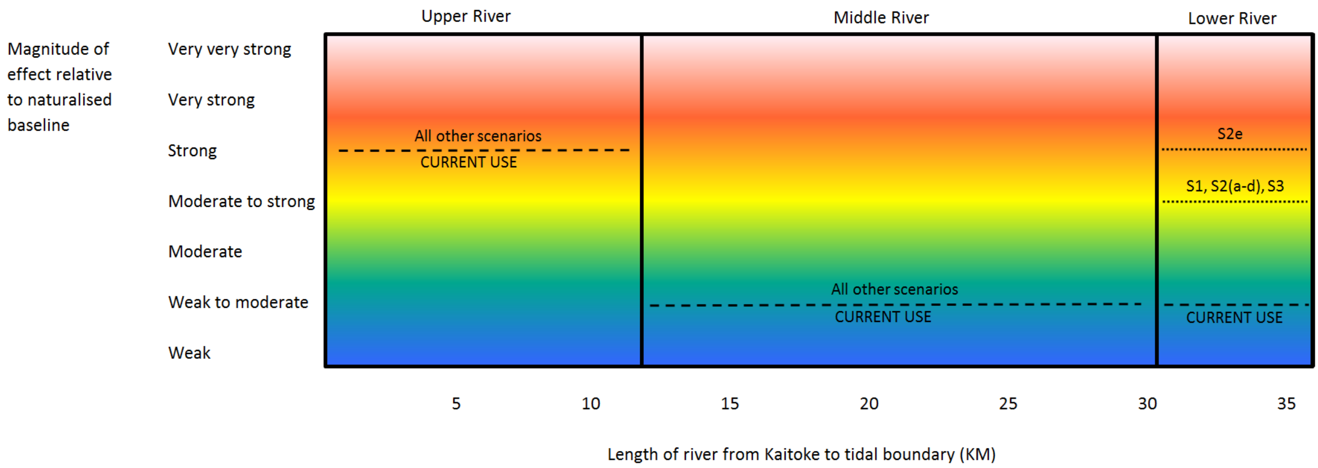


Figure 3.4. Assessment of predicted effects under higher abstraction (Scenarios 1 and 2) and lower abstraction (Scenario 3) regimes for the primary attributes in Appendix 5. Current use regime (Scenario 0) from Figure 3.1 is included for comparative purposes.

(c) Attribute: Native fish habitat



(d) Attribute: Trout habitat

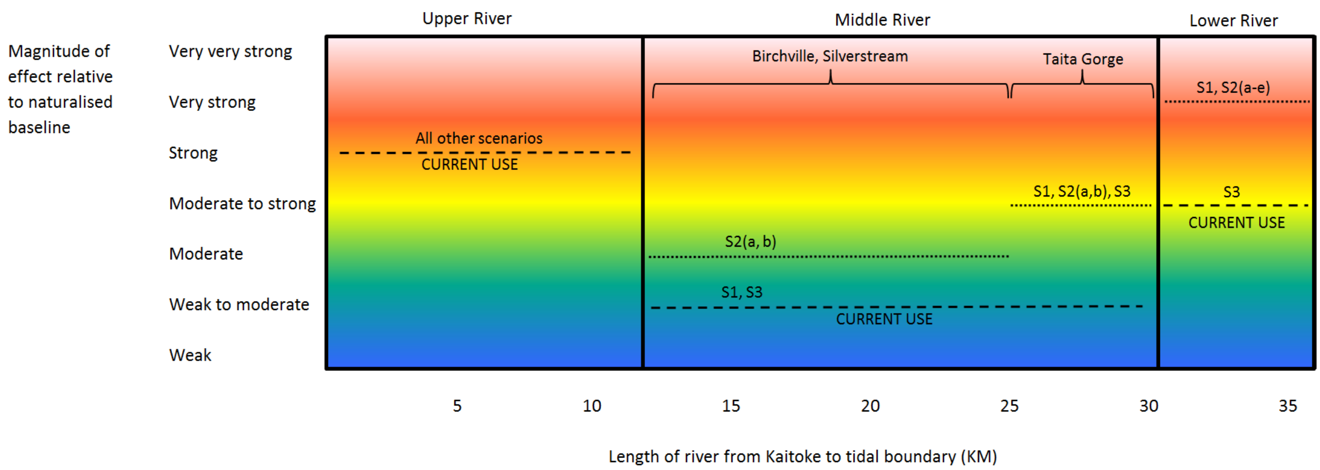


Figure 3.4 cont. Assessment of predicted effects under higher abstraction (Scenarios 1 and 2) and lower abstraction (Scenario 3) regimes for the primary attributes in Appendix 5. Current use regime (Scenario 0) from Figure 3.1 is included for comparative purposes.

Effects of taking groundwater versus surface water

Under Scenario 2 (relating to increased abstraction) there are several sub-scenarios (Scenario 2a-e) designed to look at how the Lower River responds depending on whether the additional water volume is sourced from the river in the upper catchment (Kaitoke) or groundwater from the Waiwhetu Aquifer. Figure 3.5 compares three of the sub-scenarios that characterise the envelope of hydrological change for roughly the same volume of water abstracted; these are:

- **Scenario 2a** – Hutt River at Kaitoke minimum flow reduced to 0.4 m^3/s, year-round;
- **Scenario 2c** – increased groundwater abstraction (seasonally variable, peaking at 143 ML/d in January and February)
- **Scenario 2d** – increased groundwater abstraction (maximum rate achievable while keeping water level at foreshore above 2 m)

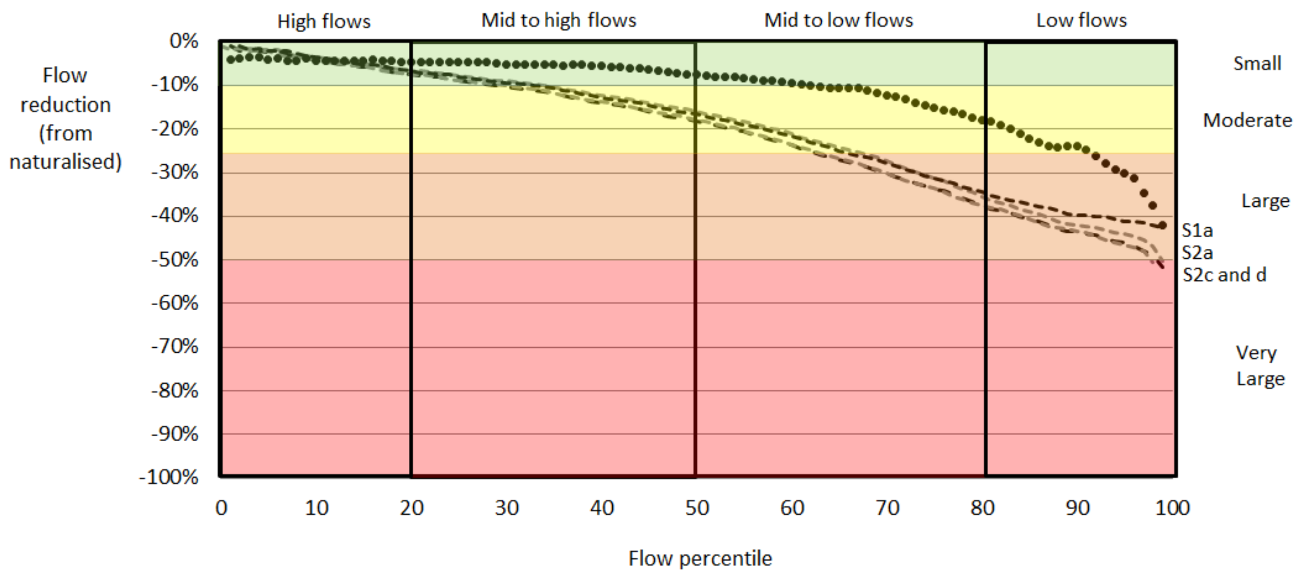


Figure 3.5. Comparison of the reduction from naturalised flow regime for different sub- scenarios relating to <u>increased abstraction</u> for Avalon (Lower River). Current regime (black dots) is shown for comparison.

Differences between these sub-scenarios depicted in Figure 3.5 (and in the more comprehensive statistics of Keenan (2020) and Holmes (2020)) are subtle and minor. All sub-scenarios can be considered to occupy the same range of change and effect as illustrated by the flow reduction curves. The greatest further proportional reduction from the maximum use, current use and naturalised regimes would occur in the low flow band. Sub-scenario 2d (abstracting from the Waiwhetu Aquifer) results in the least additional change of the three sub-scenarios, but also delivers a lower overall volume of water due to the constraint of the saltwater intrusion trigger.

Should further abstraction from the river or aquifer be contemplated, it seems the question is not so much about how effects in the Lower River will differ depending on choice of source, but rather how the effects are distributed along the river. Achieving additional supply volumes in sub-scenario 2a by increasing take at Kaitoke (i.e. with a lower minimum flow) leads to quite significant further hydrological change in the Upper River, as shown in Figure 3.3(a), as well as the change in the Lower River, as depicted in Figure 3.5. In contrast, achieving a greater supply volume by increasing the groundwater take has approximately the same additional impact on the Lower River (as increased surface take at Kaitoke), but no further effect in the Middle and Upper rivers.

4. Wainuiomata River Assessment Unit

4.1 Current Use

4.1.1 Attribute change from naturalised state

The current allocation of water from the Wainuiomata River does not remove any of the fundamental components of the natural flow regime. Floods and fresh flows (including algae flushing flows) retain a natural frequency, timing, and size. Natural seasonal changes from high winter to low summer base flows still occur and there are no large-scale manipulations of mid-high range flows, as might occur on rivers subject to either very large diversions or damming.

However, as with Te Awa Kairangi, parts of the natural low-flow regime for the Wainuiomata River are substantially altered. These changes, along with accompanying changes in other attributes, are discussed in the following section for the Upper, Middle, and Lower rivers.

Upper River

Flow alteration is highest in the Upper River that stretches for about 4 km between the intakes (on the main stem and George Creek) and the Wainuiomata Stream. However, the full extent of this alteration cannot be reliably quantified compared to other parts of the catchment due to a lack of relevant flow data. Best estimates, obtained by comparing abstraction volumes with flow at the upstream GWRC Manuka Track flow site, are that low flows in the Upper River can be reduced by 60-80%. Consequent changes in habitat availability for food productivity, algae, benthic macroinvertebrates and fish cannot be reliably quantified either due to a lack of monitoring data. In the absence of such data, it must be assumed that habitat change is still broadly commensurate with flow alteration and, therefore, is evaluated as large.

Immediately above the intakes, the Wainuiomata River is known to have excellent water quality and ecological health (based on a standard suite of indicators routinely measured by GWRC at Manuka Track state-of-the-environment monitoring site). Whether any significant ecological effects occur (or have occurred) downstream because of the current abstraction is largely unknown due to an absence of relevant routinely collected data (Clapcott 2020). Marked changes in the dissolved oxygen or water temperature profiles are not likely to result from abstraction in this type of river, although subtle alterations could be combining with other stressors to exacerbate undesirable conditions at times. Unlike for Te Awa Kairangi, there is insufficient state-of-the-environment or consent monitoring data to explore the effects of flow reduction on nutrient dilution capacity. Conceptually, it seems likely that the size of the abstraction at low flows in relation to the available natural dilution potential (from tributary streams) could be having a significant effect on river nutrient concentrations.

Middle River

The Middle River makes up a large majority (~70%) of the Wainuiomata River length below the abstraction. While some minor flow loss to groundwater occurs in the upper reaches of this sub-unit, tributary gains from the Wainuiomata Stream and Black Creek more than compensate; naturalised low summer flows at Leonard Wood Park are approximately twice those of Manuka Track in the headwaters of the Upper River. This natural flow accumulation buffers the abstractive losses from the upper reaches, but hydrological alteration under the current abstraction regime is still moderate relative to the naturalised flow regime (Figure 4.1). The biggest proportional flow reductions occur during times of low base flows (typically summer and autumn) as shown in Figure 4.1. Of most relevance to instream ecology are the changes to the magnitude and duration of extreme low flows that are below or equivalent to MALF (which occurs naturally at about the 90th percentile on this river; meaning flows are, on average, at or below MALF for about 10 percent of the year). Also of potential ecological significance, the alteration of mid-range flows is more substantial on this river compared with Te Awa Kairangi; for example, Figure 4.1 shows that the current abstraction regime starts to sharply reduce flow by more than 10 percent (relative to the naturalised flow) at about the 60th percentile whereas this does not occur until beyond the 70th percentile on Te Awa Kairangi (Figure 3.1)

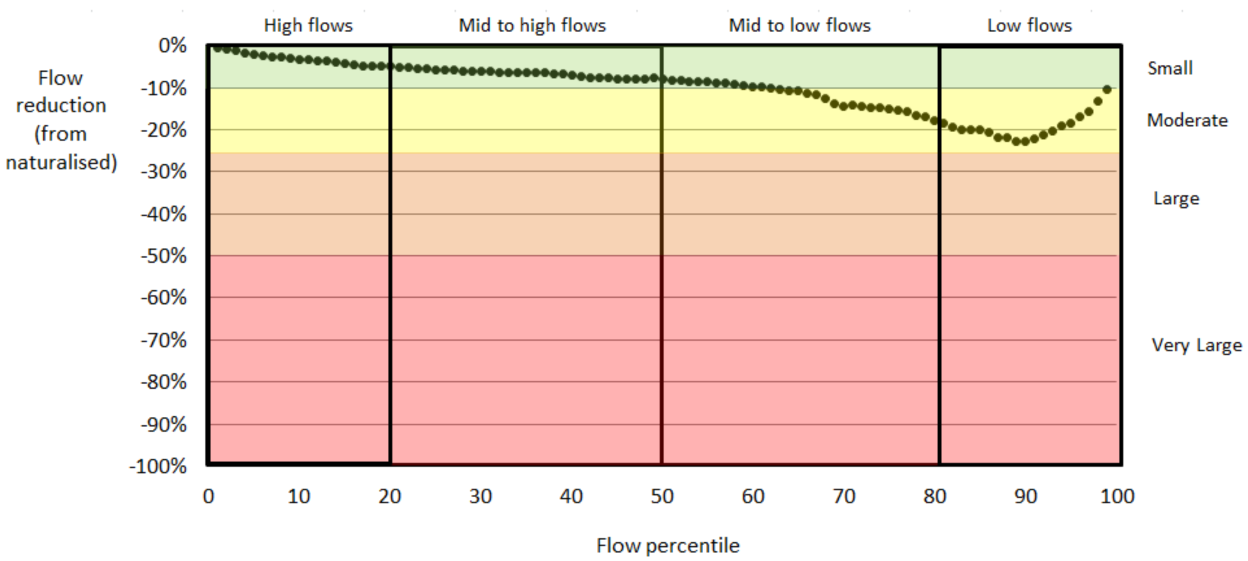


Figure 4.1. Reduction from naturalised flow regime at Leonard Wood Park caused by current abstraction (dotted line) for various flow percentiles and bands. Flow percentile bands (vertical black lines) show that greatest reductions occur at mid to low flows. Reductions categories are based on the hydrological alteration categories in Table 2.1 and progress from small (green shaded panel) to very large (red).

Loss of habitat, as defined by percent Area Weighted Suitability (AWS) analysis, ranges from small to large for food producing and benthic macroinvertebrates depending on which part of the flow regime or which species are being considered (Figures 4.2b); when focusing primarily on food producing habitat as a broader marker for ecosystem health, large losses occur at low flows (~25% of that available at MALF) and small to moderate losses occur at mid-range flows (~10% of that available at summer median). Habitat losses at low flows are small for native fish and moderate for trout (Figures 4.2c and 4.2d). Changes in algal physical habitat quality are also small, with minor declines predicted for three of the four algal species and a slight increase for the fourth. Shifts in water quality and other ecosystem health components resulting from current use regime cannot be quantified due to a lack of data. Marked changes in dissolved oxygen because of the abstraction remains unlikely through the Middle River, but more significant changes (increases) in water temperature are conceivable. The Middle River is characterised by more shallow runs than elsewhere in the catchment and is potentially more sensitive to temperature spiking during hot summer days.

Lower River

The Lower River is about 5 km long and discharges via a mobile gravel bar to the Cook Strait. This lowest stretch of the Wainuiomata River benefits from inflow from a few small gully streams and the Catchpool Creek such that summer base flows are about 50% higher than in the Middle River and three times those in the headwaters. Insufficient flow data means this sub-unit could not be included in the modelling of Keenan (2020) and a comprehensive list of flow alteration statistics is not available. However, correlation between spot gauging at White Bridge and the continuous record at Leonard Wood Park has allowed some analysis of both flow and habitat alteration.

Flow alteration from a naturalised regime is assessed as small to moderate (and incrementally less than for the Middle River). Reductions in habitat availability for all organisms are also predicted to be small, although it is noted that confidence is relatively low for this assessment. This is because the habitat suitability curves upon which the habitat modelling relies have been developed for wider, shallow channels with riffle-run-pool sequences (more akin to the Middle River) rather than the deeper U-shaped channel of the Lower River. While physical habitat space in the Lower River will be less sensitive to flow change than higher in the catchment (because good depth is retained even at very low flow), velocity and substrate changes are likely to be poorly modelled in this environment.

Mouth closure occurs where the Wainuiomata River enters the sea. This can restrict opportunities for fish to migrate into the catchment. It is not known what magnitude of flow event is typically required to open the river mouth to the sea nor how much flow is required to maintain the river mouth opening and, hence, access to the catchment. However, the current use regime has minimal impact on higher magnitude flow events and so it was the view of the Panel that current water use is not likely to significantly alter the frequency or duration of river mouth openings.

4.1.2 Effects realised under current use

The risk of ecosystem health effects from the current abstraction are highest in the Upper and Middle rivers and progressively diminish downstream from the point of take. Flow gradually accumulates downstream and, unlike Te Awa Kairangi, there is no further substantial abstraction in the lower catchment.

Whether the potential ecological effects of abstraction are realised cannot be determined with high confidence due to a lack of suitable monitoring data. The following points are made based on general ecological principals (note: some discussion about effects from Te Awa Kairangi section is equally relevant here and is repeated for clarity):

- Flows in the Wainuiomata River are not modified enough to cause localised extirpation of fish. Sporadic sampling in the catchment over time indicates that species diversity and distributions are generally consistent with expectations for this type of catchment (Cameron 2019). As with Te Awa Kairangi, the concerns regarding the effects of abstraction relate to abundance and not diversity of species. Whether fish abundance has been materially affected by the current abstractions depends to a large extent on the fish population carrying capacity of the river and whether flow and habitat are strongly limiting factors at low flows.

- Trout are not as well surveyed in the Wainuiomata River as Te Awa Kairangi but angling resources (e.g. NZ Fishing) describe the river as a “productive fishery holding a good population” though its middle and lower reaches. This implies that habitat or feeding opportunities under current abstraction regime (combined with other stressors) are sufficient to support a productive fishery.

- The relationship between change in habitat and effect on benthic macroinvertebrates is more linear and certain than for fish. As habitat diminishes so too will numbers of macroinvertebrates, and in a roughly proportionate manner. The moderate to large negative changes in low flows and accompanying habitat in the Upper and Middle rivers can be expected to have moderate to large negative impacts on macroinvertebrate communities in terms of abundance. However, the knock-on effect of this for higher trophic levels (i.e. fish) is less clear. Since fish are mobile the effect of diminishing benthic macroinvertebrate food supply in some reaches could be offset by refuge and feeding opportunities elsewhere (e.g. deeper pools lower in the catchment). It is also thought that, when considering macroinvertebrates as a food source to sustain higher trophic levels (especially drift feeding fish such as trout and river birds), changes in mid-range flows may be more consequential than changes at low flows (Hayes et al 2019). However, this may not apply to benthic native fish species that are less likely to drift feed and will be more dependent on benthic foraging for food supply. Under the current use regime, reductions of flows in mid-range are less significant (as a proportion of natural flow) than at low flows, but they are not minor (Figure 4.1) and negative effects could be expected to tend towards moderate.

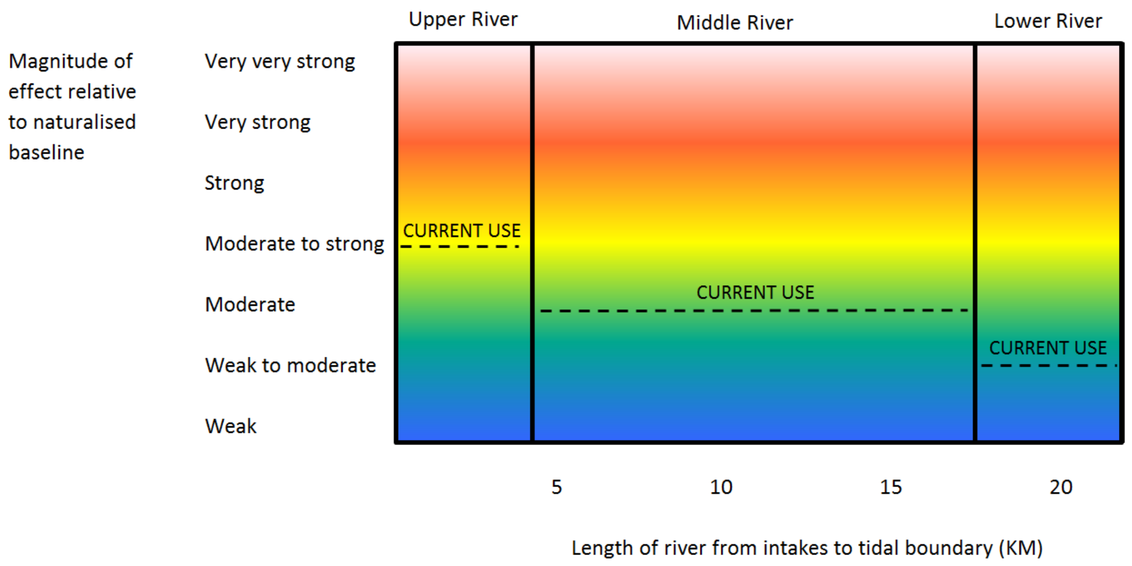
- While the small changes in physical habitat are not expected to have a material effect on algal river-bed cover, changes in frequency and duration of low flow and extreme low-flow (Keenan 2020) events are considered to be significant by the Panel. Accrual period length is a well understood positive driver of algal cover and biomass. In the Lower River, where the channel becomes more ‘U’ shaped and lower gradient, algal physical habitat is believed to experience moderate to large change as the system shifts from algal dominance in the Middle and Upper rivers to macrophyte dominance. There are insufficient data to determine how much of this shift is due to allocation vs natural channel features.

- The Upper River undergoes the greatest degree of flow alteration. In addition, there are other factors contributing to overall ecological health. The Upper River is affected by Water Treatment Plant discharges (including out of catchment overflow returns) and transition through the reservoir creating further departure from a natural flow regime (although not necessarily further flow loss). On the other, the channel and riparian margins in the Upper River are largely unmodified by land use (other than the reservoir) or flood management works, and the bedrock containment of the relatively narrow channel sustains greater water depths in places than the Middle River. Steeper terrain and shading vegetation reduce solar radiation exposure and water temperatures remain lower through summer. To an extent, some of these catchment factors may combine to help offset the worst of the effects of the abstraction. In the Middle and Lower rivers, effects relating to the abstractive losses are attenuated significantly by natural flow gains, although other catchment factors, such as a lack of stream shading, become less favourable for sustaining good ecosystem health.

In summary, it is not possible to be confident or unequivocal about the magnitude of ecological effects realised under the current use regime in the Wainuiomata River. Some attribute changes are suggestive of minor effects (e.g. small changes in available native fish habitat space) and some observations also support a theory of minor effects (e.g., the apparently healthy brown trout population). However, such individual attribute examples are not conclusive evidence for minor ecosystem health impacts in the more holistic sense. There is some evidence of moderate to large habitat loss for food producing macroinvertebrates meaning that, put simply, space is not likely be a problem for fish, but food availability may be. Clapcott (2020) notes that the data needed to be more conclusive about overall ecosystem health impacts simply are not available for this catchment and there are obviously no pre-abstraction conditions to refer to.

In the absence of sufficient evidence it is necessary to take a precautionary view of likely ecological effects. This means applying a minimum operator principle (i.e. defining overall effect by the attribute or river sub-unit/reach that is most limited by abstraction) and relying on available modelled flow alteration and habitat change statistics with relatively conservative interpretations. Under this approach, the most reasonable assessment for the majority of the Wainuiomata River under the current use regime is of moderate negative ecosystem health effects. Ecological impacts may be moderate to strong in the Upper River where flow alteration is greatest and likely diminish to relatively weak effects in further down the catchment, where natural flow gain and greater water depths reduce sensitivity of the river ecosystem to flow loss. It must be noted, however, that conclusions regarding effects in the lower part of the catchment are subject to relatively low confidence due to habitat model limitations. Much of the macroinvertebrate life in the run-dominated lowest reaches will not conform to the riffle-limiting assumptions of the habitat modelling. Likewise, as mentioned previously the fish habitat suitability curves were developed in shallow run-riffle-pool gravel bed rivers rather than the macrophyte dominated U-shaped channels that are prevalent in the lower Wainuiomata River.

(a) Attribute: Flow



NOTE: flow assessments for the Upper and Lower river are interpretations based on general hydrological understanding. These sub-units were not subject to the hydrological modelling by Keenan (2020)

(b) Attribute: Macroinvertebrate habitat

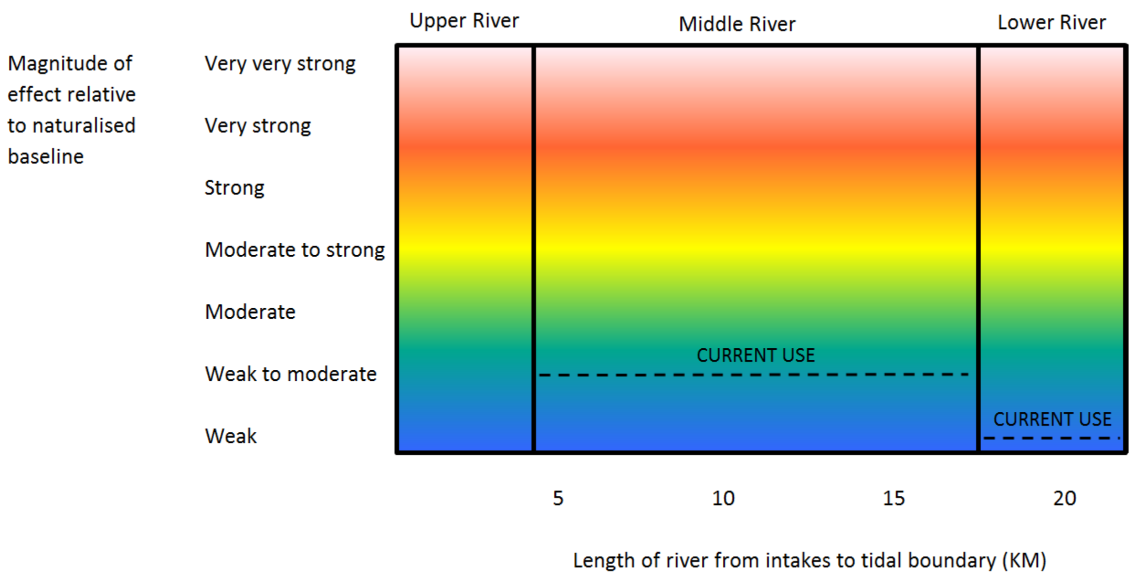
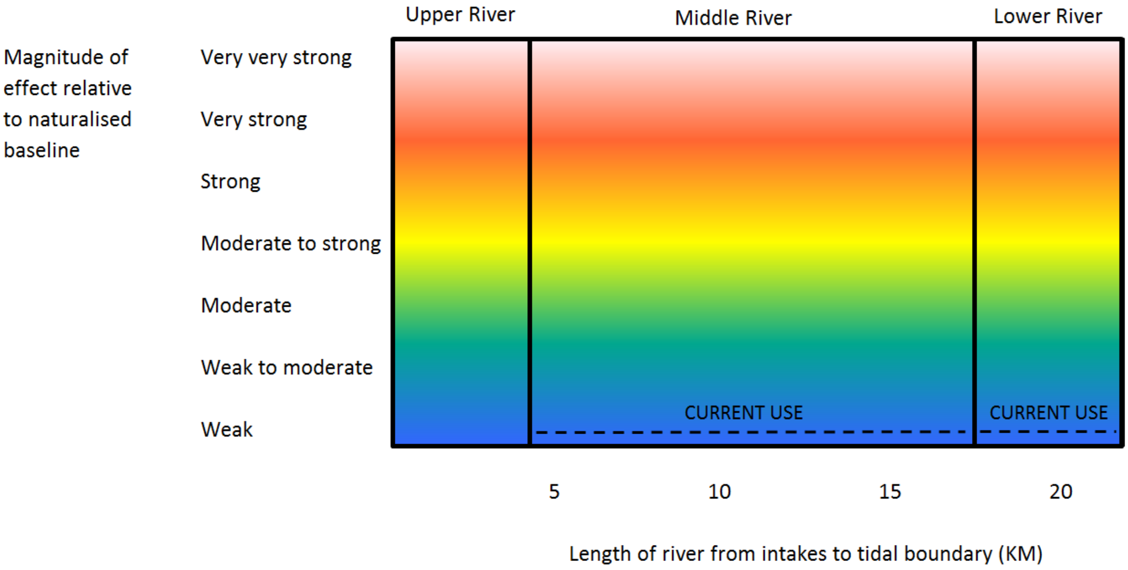


Figure 4.2. Assessment of predicted effects under <u>current use</u> (Scenario 0) for the primary attributes in Appendix 3. On the horizontal axis, the three sub-catchment segments (Upper, Middle, Lower) are sized according to the approximate length of river in each. This allows a sense of the physical 'extent' of river to which the change and effect predictions apply.

(c) Attribute: Native fish habitat



(d) Attribute: Trout habitat

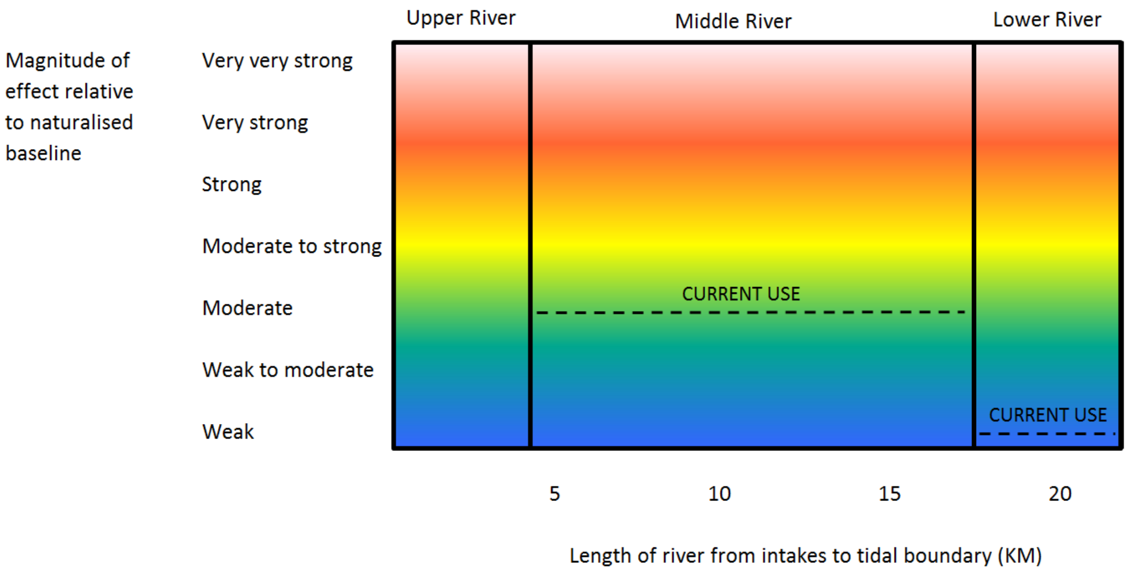


Figure 4.2 cont. Assessment of predicted effects under current use (Scenario 0) for the primary attributes in Appendix 3. On the horizontal axis, the three sub-catchment segments (Upper, Middle, Lower) are sized according to the approximate length of river in each. This allows a sense of the physical 'extent' of river to which the change and effect predictions apply.

4.2 Scenarios of higher and lower abstraction

4.2.1 Attribute change from current use and naturalised state

Only two of the scenarios listed in Section 2.4 were tested for the Wainuiomata River; Scenario 1 in which maximum use occurs under the existing consents, and Scenario 3 in which maximum use occurs but with a higher minimum flow at Manuka Track (130 L/sec) to afford greater instream protection. Scenario 2, in which greater volumes than currently consented can be abstracted, was not considered for this catchment as Wellington Water Ltd does not consider it a technically or environmentally viable option. Furthermore, the sub-scenarios tested for Te Awa Kairangi are not relevant here as there is only a single surface water intake location (and no additional groundwater taken in the lower catchment).

In addition to the shift that has already taken place from naturalised to current use in the Wainuiomata River, there is potential for some further relatively large changes in state if water use is maximised within existing consent limits. This contrasts somewhat with the situation in Te Awa Kairangi where, compared with the shift that has already taken place, further flow alterations relating to the various abstraction scenarios are more modest.

Some key points of note relating to hydrological alteration are:

- The largest changes in the Middle River occur under Scenario 1 in which all available water that can be taken (under current consent and regional plan rules) is taken[6]. The key change under this maximum use scenario is that greater volumes of water are abstracted through the mid to low-flow range where, currently, demand does not require it. This is shown in Figure 4.3 where the maximum use (Scenario 1) plot departs from the current use (Scenario 0) plot by a significant margin in the mid to low-flow range, reducing naturalised flows in this part of the hydrograph by up to 30% as opposed to 10-15% under current use. This mid-range flow alteration was not especially apparent in Keenan's (2020) modelling results as they were deliberately focused on the lower flow regime. However, the Panel considers it important to recognise because of the potential for ecological impact, a point that is picked up again in the habitat assessment later in this section.

- Extreme low flows (those below MALF) under Scenario 1 change only slightly in terms of magnitude and duration compared with current use suggesting that consents are normally fully exercised when demands are highest, usually through the driest parts of summer. This is illustrated in Figure 4.3 by the converging plots for maximum use and current use for low flows above about the 90th flow percentile. Nevertheless, maximum use does result in more low flow events as the greater abstraction of mid-range flows brings the river into a lower flow state more often than current use.

- Overall, the potential for mid-range flows to be abstracted under fully exercised consents shifts the interpretation of hydrological alteration from 'moderate' under the current regime to 'moderate to strong' under Scenario 1. While flow data are unavailable to assess the

---

6 The likely practical and/or operational constraints to this actually occuring are acknowledged and discussed further in the 'Assumtions and limitations' section.

Upper and Lower rivers in the same way as above, it is expected that the scale of change will be a band higher and lower, respectively, compared with the Middle River. Figure 4.4a summarises these assessments and compares them with the current use regime.

- Under Scenario 3, the benefit of the higher minimum flow for the Middle River can be seen in Figure 4.3. Extreme low flows are slightly less modified from naturalised state than under the current or maximum use regimes. However, these benefits are modest and not sufficient in themselves to shift alteration bands. The potential minor benefits are offset by the mid-range flow reductions that could still occur under existing consents (even with the higher minimum flow). Consequently, the assessment for Scenario 3 for the Middle River is for a shift from 'moderate' to 'moderate to strong' change. Again, this assessment can be extrapolated to the Upper and Lower rivers as shown in Figure 4.4a.

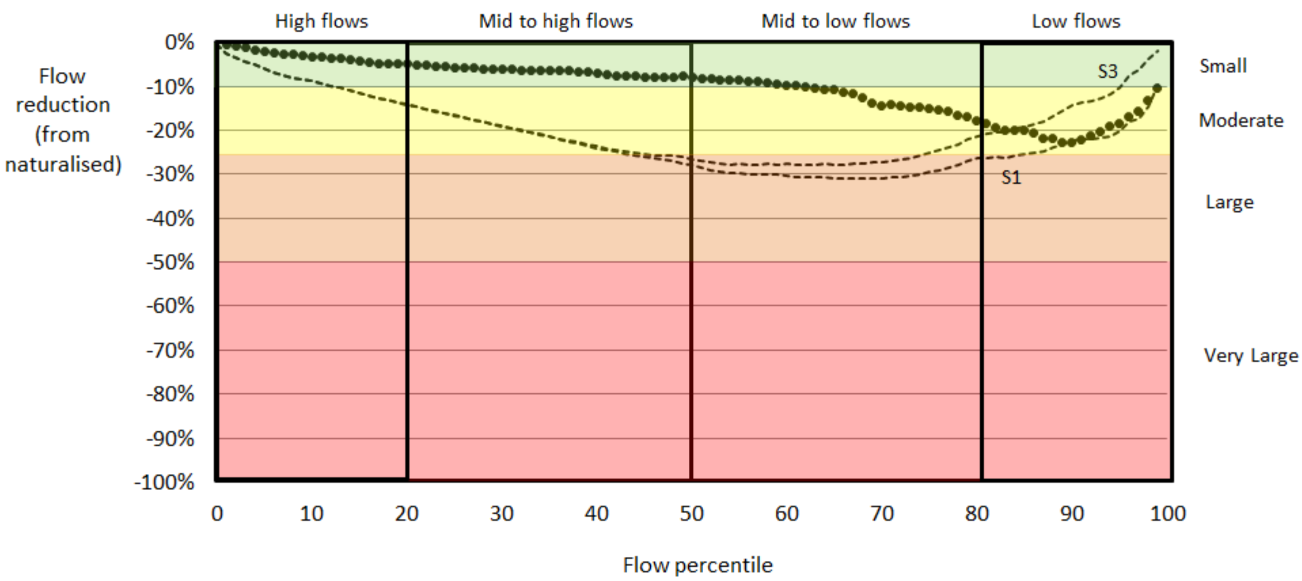


Figure 4.3. Reduction from naturalised flow regime at Leonard Wood Park for various flow bands caused by Scenario 1 Maximum Use and Scenario 3 Reduced Use/Higher Minimum Flow. Scenario 0 Current Abstraction (dotted line) from Figure 4.1 is included for comparison. Flow reductions categories are based on the hydrological alteration categories in Table 2.1 and progress from small (green) to very large (red).

Tables A4.2 to A4.4 in Appendix 3 summarise the assessments of change in habitat availability under Scenarios 1 and 3. Some key points are:

- The most significant change is a relatively large loss of macroinvertebrate habitat in the Middle River under the maximum use scenario. The predicted loss is sufficient to move from an assessment of small to moderate change under current use to very large under maximum use. Habitat availability for native fish and trout in the Middle River does not seem nearly as sensitive to increased abstraction under maximum use, with incremental declines in habitat availability from current use resulting in small to moderate (native fish) and moderate to large (trout) changes overall relative to the naturalised state.

- Loss of macroinvertebrate habitat in the Lower River under maximum use is also predicted to be the largest of the attributes modelled. Loss from naturalised state is regarded as small under current use and would shift to large under maximum use. No band shift is expected for either native fish or trout in this segment and their habitat losses would remain small under maximum use.

- Habitat losses for the Middle and Lower rivers under Scenario 3 (maximum use but a higher minimum flow) are essentially the same as those under the maximum use Scenario 1 for macroinvertebrates. For native fish and trout, losses return to the same as under current use and represent small and moderate negative changes, respectively, from naturalised state.

- In the absence of quantitative data on habitat in the Upper River, predictions about how sensitive this part of the river is to further changes in abstraction regime cannot be made with confidence. A precautionary view is that changes would be greater than those predicted to occur in the Middle River.

4.2.2 Effects on attributes

Figure 4.4 provides a visual summary of the effects assessments and compares scenarios with naturalised and current use regimes.

Overall, the maximum use Scenario 1 indicates that increased abstraction from the Wainuiomata River could cause significant negative ecosystem health effects. Of concern is the apparent sensitivity of macroinvertebrate habitat to further flow loss in the mid to low-flow range. The modelling results suggest that good quality riffle habitat (ideal habitat for macroinvertebrates) is in short supply in this segment and disappears quickly with reducing flows. The consequence of this for the wider ecosystem is somewhat unpredictable. Limited good quality habitat might mean that higher trophic level species are not overly dependent on it. The counterview is that short supply makes such habitat important for supporting macroinvertebrate productivity which in turn supports higher trophic level animals such as fish. Additional effects of increased abstraction are unclear but could range from a slowing of flow to elevated water temperatures and reduced dissolved oxygen

Increased abstraction scenarios which result in the loss of riffle habitat in the lower reach of the Wainuiomata River may result in a shift from algal dominated system to a macrophyte one. The ecosystem.

While habitat availability for fish (native and trout) appears much less sensitive to increases in abstraction, the indirect impacts on fish from loss of macroinvertebrate food productivity are of more concern. The severity of such impacts will depend on many other factors including river carrying capacity and background stress conditions and availability of alternative food sources, such as macroinvertebrates produced in macrophyte beds which are not able to be modelled effectively.

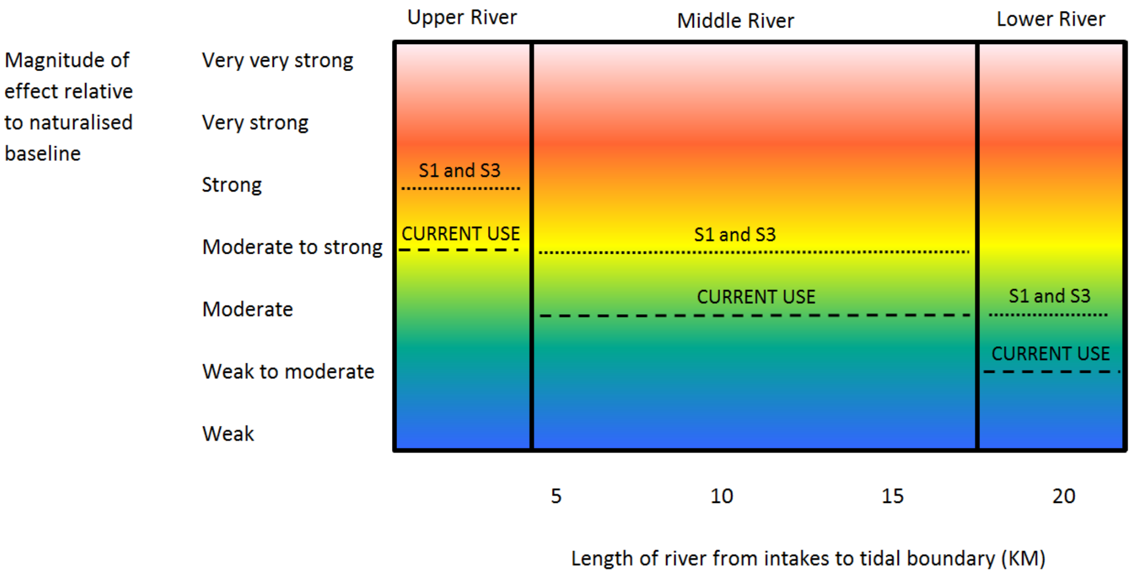
The magnitude of extreme low flows (less than MALF) are not expected to further reduce under fully exercised consents as there is no more water availability at these times. However, any significant further abstraction from low to mid-flow range will bring the river into extreme low flow conditions more quickly and for a longer duration. This is expected to incrementally increase the potential for negative ecosystem health effects. In particular, the increased frequency and magnitude of low flows is likely to promote algal growth in the Upper and Middle rivers, and algal and macrophyte growth in the Lower River.

The greater alteration of mid-range (and even higher range) flows under the other scenarios means that the risk of impacting river mouth opening timing, frequency and duration is increased. However, due to the absence of any data on this potentially significant control on native fish recruitment for the catchment means that uncertainty regarding any possible effect remains very high.

Compared with Te Awa Kairangi, there is a paucity of good quality data for the Wainuiomata River that means even more reliance must be placed on conceptual understandings of bio-physical responses to flow change. While the Flow Panel have high to moderate confidence in the hydrological and habitat modelling for Leonard Wood Park (and that results for this reach are reasonably representative of the Middle River), the same cannot be said for the Lower or Upper rivers. Confidence in assessments for the Lower River is low due to modelling constraints mentioned in Section 4.1.2. The impacts in the Upper River also remain somewhat unquantified due to a lack of suitable data. Nevertheless, the Middle River comprises a large majority of the impacted river length and is likely to be a useful proxy for considering effects for the river unit as a whole; in addition to being the most extensive reach it is more sensitive to flow change than the Lower River and, arguably, more vulnerable to further modification than the Upper Reach because of multiple land use stressors.

With respect to increasing the minimum flow at Manuka Track (and thereby reducing abstraction at the lowest flows), beneficial effects are likely to be modest in both magnitude and extent. The largest assumed benefit would occur for the Upper River (based on proportional flow retention) but without habitat or other ecosystem response data this cannot be quantified. Any significant benefit that might occur in the Upper River will quickly diminish downstream. Modelling for Leonard Wood Park shows slight decreases in the magnitude of extreme low flows, but ecosystem improvements would probably be undetectable (measurable) and not enough to change the band of alteration. Furthermore, when combined with the potential for increased abstraction at mid-range flows any habitat benefits would be offset and ecological effects would, overall, be worse than under the current use regime.

(a) Attribute: Flow



NOTE: Flow assessments for the Upper and Lower river are interpretations based on general hydrological understanding. These sub-units were not subject to the hydrological modelling by Keenan (2020)

(b) Attribute: Macroinvertebrate habitat

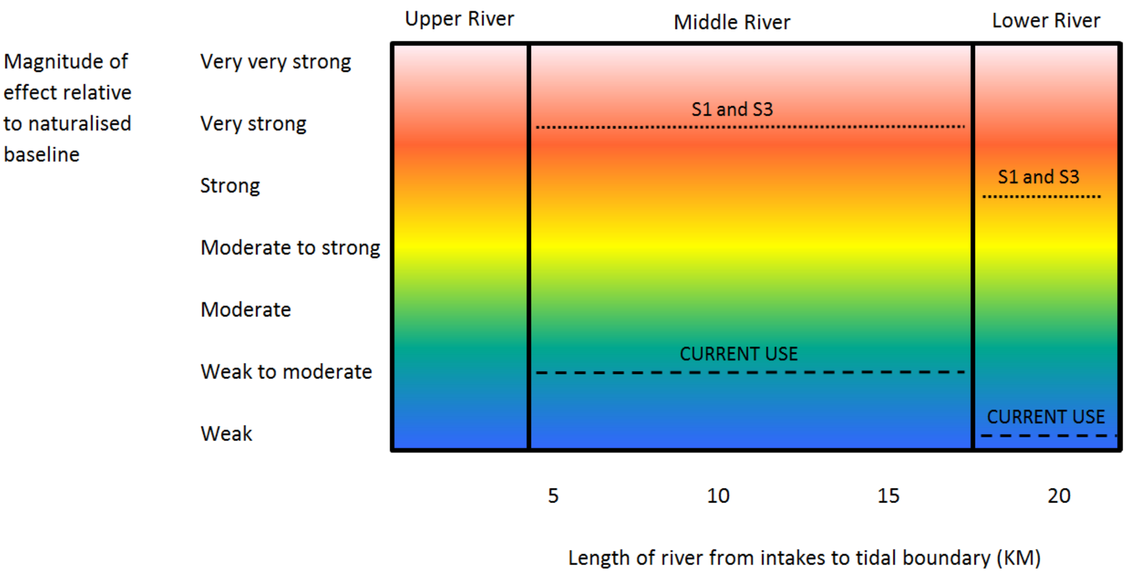
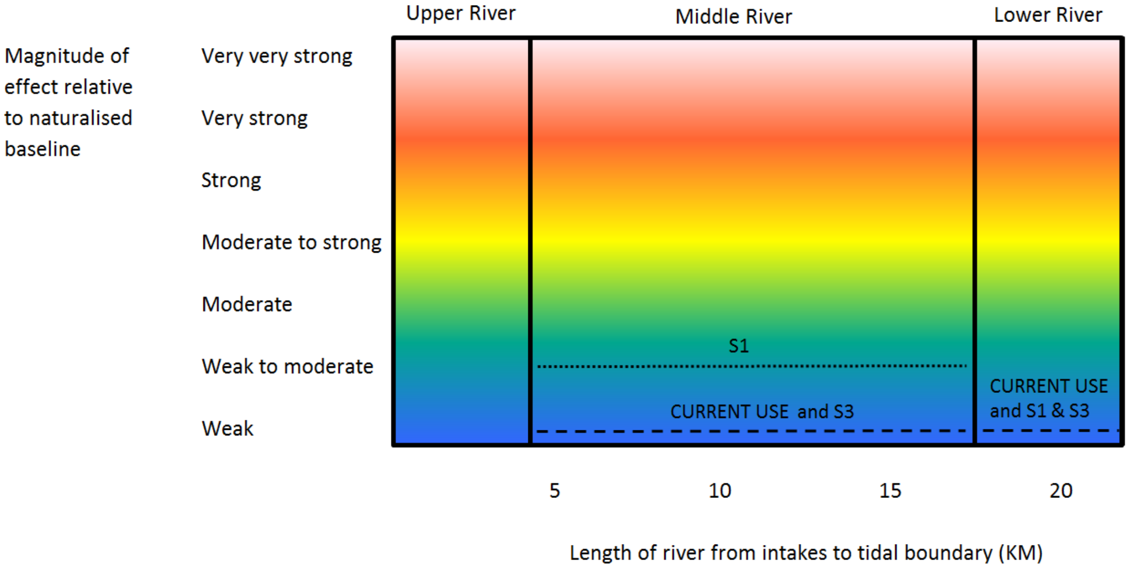


Figure 4.4. Assessment of predicted effects under <u>higher abstraction</u> (Scenarios 1) and <u>lower abstraction</u> (Scenario 3) regimes for the primary attributes in Appendix 2. Current use regime (Scenario 0) from Figure 4.2 is included again for comparative purposes.

(c) Attribute: Native fish habitat



(d) Attribute: Trout habitat

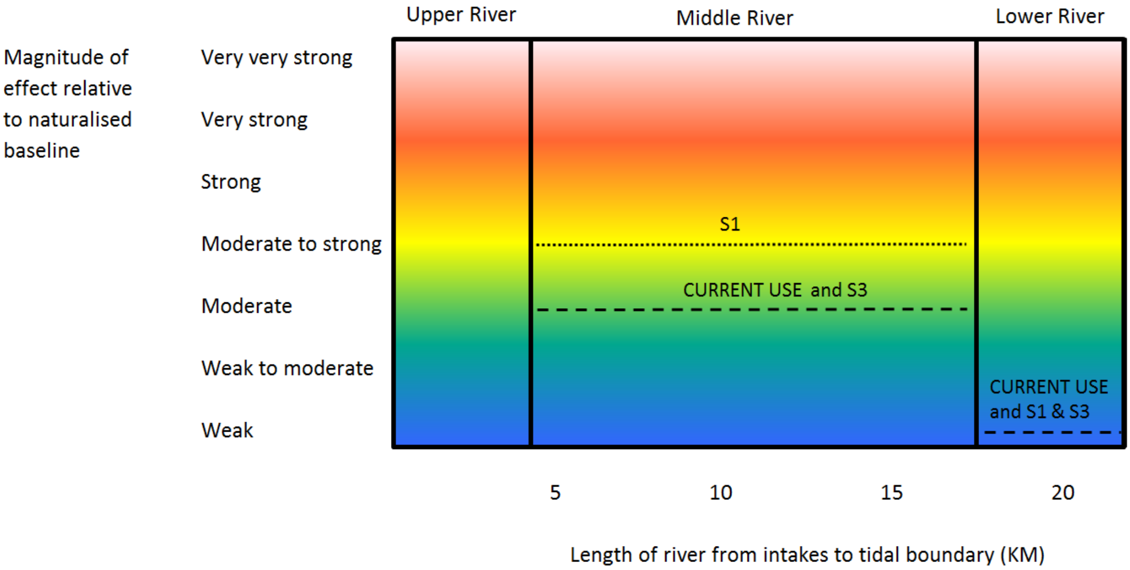


Figure 4.4 cont. Assessment of predicted effects under higher abstraction (Scenarios 1) and lower abstraction (Scenario 3) regimes for the primary attributes in Appendix 2. Current use regime (Scenario 0) from Figure 4.2 is included again for comparative purposes.

5. Orongorongo River Assessment Unit

This section presents an assessment of attribute change and effect under different abstraction scenarios in the Orongorongo River.

Data availability for the Orongorongo River is very limited compared with Te Awa Kairangi and Wainuiomata. Flow could only be naturalised for one location, 'Truss Bridge' directly downstream of the abstraction locations, and the subsequent record was not considered robust enough by Keenan (2020) for further hydrological scenario modelling. No hydraulic-habitat surveys have been carried out in this river so inclusion in the flow-habitat analysis by Holmes (2020) was not possible. Other water quality/ecological data are also very sparse.

The assessment in this section is, therefore, high level and based primarily on the Panel's conceptual view of abstractive effects in this type of river environment. Accordingly, it is accompanied by a relatively low level of confidence.

5.1 Current use

The only consented water abstraction from the Orongorongo River is for public water supply, from the main river and a small tributary, Big Huia Creek. The abstracted water is fed to the Wainuiomata water treatment plant through a tunnel. The consent specifies a maximum instantaneous abstraction rate of 0.8 m^3/s from the river (with lower limits from the tributaries) and a combined maximum take of 40 ML/day. The minimum flow specified for the Orongorongo River is 0.1 m^3/s (100 L/s) at the Truss Bridge recorder site and water abstraction must cease when river flow is less than this.

Keenan (2020) approximates a natural 7-day MALF at Truss Bridge of around 0.26 m^3/s and that annual low flows in the upper catchment are generally reduced by around 40–60% due to the water supply abstraction. Such reductions are of the same general order of magnitude as those in the upper segment of Te Awa Kairangi due to the Kaitoke take and can reasonably be interpreted to occupy a similar band of hydrological change and ecological effect (i.e. 'large to very large'). Without downstream monitoring it is not possible to be certain how far the effects of the heavy flow alteration propagate. A 'drought' flow survey was conducted in 1999 (Opus 2000 – and see Figure 5.1) which, together with a handful of spot flow gauging over time at the catchment mouth, suggest fairly modest natural flow gains occur during summer dry spells. Assuming MALF approximately trebles between the main area of abstraction and the river mouth, as indicated by Figure 5.1, the proportional flow alteration from the abstraction could be expected to reduce by roughly the same proportion. That is, natural annual low flows could still be expected to be reduced by 15–20% in the lower river (suggesting the 'large/very large' alteration in the upper catchment becomes more 'moderate' further down).

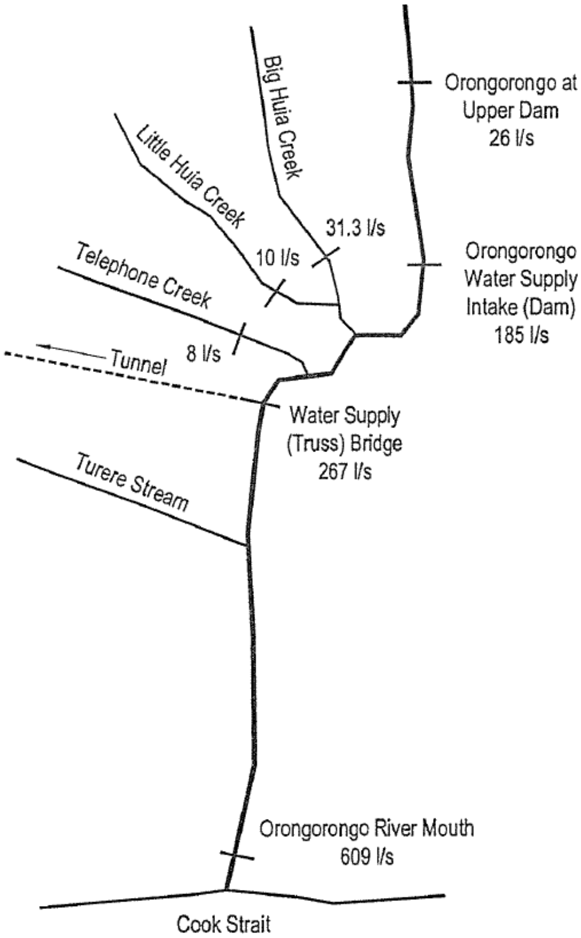


Figure 5.1. Orongorongo River catchment low flow survey, 16 February 1999. Survey conducted when flows were approximately at natural 7-day MALF with no public supply abstraction occurring. Reproduced from Opus (2000).

Note diagram is not to scale.

A few kilometres downstream of the water supply protection area and the location of the abstractions, the river emerges into the wide Orongorongo valley. Within this reach the active channel frequently migrates within the alluvial valley floor, and in places some braiding may occur. While there are no records of channel drying in the lower reaches, periodic cessation of flow in some places seems likely. The frequency, extent and duration of any such dry riverbed areas could be increased in by the abstraction upstream. Stagnant ponding can occur in the very lowest reach when the gravel bar on the south coast closes the river mouth (Opus 2000).

Habitat loss at low flows must be considered commensurate with the 'large to very large' low flow reductions until demonstrated otherwise. The wide and shallow channel in the alluvial valley will make this river particularly susceptible to the effects of abstraction with relatively steep reductions in physical space and hydraulic parameters likely to occur with declining flows and increased vulnerability to water temperature increases. On the other hand, the consequence of reduced and prolonged low flows may be offset to a degree by the relatively high run-off potential in the Orongorongo catchment compared with other catchments in the Wellington region; to illustrate, the annual average and maximum 'days of accrual' (consecutive low flow days between algae flushing events) for the Orongorongo River are 16 and 100, respectively, compared with 28 and 200 for the Wainuiomata River[7]. However, this greater specific catchment discharge also means that the Orongorongo River is often favoured over the Wainuiomata River as a more reliable supply at lower flows.

Water quality and ecology is excellent upstream, and in the vicinity, of the abstractions, with minor degradation of nutrient concentrations and macroinvertebrate health in the lowest reaches – thought to be a consequence primarily of agricultural runoff (Opus 2000 and Greer and Ausseil 2019). However, as Clapcott (2020) points out in her recent review of available information, there is a fundamental lack of data with which to draw conclusions about the overall ecological impacts of abstraction in this catchment. This includes the lack of habitat survey data already mentioned as well as insufficient spatial and temporal resolution for variables that are measured.

Overall, there is uncertainty about the extent to which current allocation of water from the Orongorongo River fundamentally alters some primary components of the natural flow regime. Floods and fresh flows (including algae flushing flows) retain a largely natural frequency, timing, and size. Natural seasonal changes from high winter to low summer base flows still occur and there are no large-scale flow manipulations (as might occur on rivers subject to either very large diversions or damming). However, as for Te Awa Kairangi and Wainuiomata rivers, mid to low flows in the Orongorongo River undergo large reductions. Also, the possibility of flow cessation in some lower river reaches has not been ruled out, nor the extent to which abstraction causes or aggravates such events. Based on the broad principles relating to the susceptibility of the Orongorongo River ecosystem to abstraction described above, the overall assessment is that ecosystem health that is likely to be more negatively impacted than the Wainuiomata River under the current use regime.

5.2 Consequences of higher or lower abstraction

Scenarios of higher and lower abstraction could not be modelled for the Orongorongo River. Some conclusions about likely river responses and ecological outcomes can be extrapolated from the neighbouring Wainuiomata River. However, there are also some distinct catchment differences that suggest extrapolating some aspects of the predicted change and effect could be misleading. Key points are:

- In addition to the likely shift that has already taken place from naturalised to current state, there is potential for some further relatively large changes if water use is maximised within existing consent limits. The magnitude of extreme low flows (less than MALF) are not expected to further reduce under more fully exercised consents as there is no more water availability at these times. However, any significant further abstraction from low to mid-flow range will bring the river into extreme low flow conditions more quickly and for longer durations. This can reasonably be expected to increase aquatic stress and negative ecosystem

[7] Based on periphyton accrual period analysis by GWRC in 2011. Refer to Thompson and Gordon (2011) for further detail.

health effects. Given the shallow channel morphology one would expect a greater risk of elevated water temperatures arising from further reducing flow compared to some of the other reaches considered in the Te Awa Kairangi and Wainuiomata rivers.

- Some reduction in the river's flushing flow potential may be expected with greater abstraction at mid-range flows. However, without knowing what magnitude and timing of flushing flows is ecologically meaningful in this catchment (e.g. for mobilising bed material and/or displacing algae), conclusions beyond pointing out a likely catchment vulnerability cannot be drawn.

- Due to the semi-braided nature of the channel there is a greater risk of side channels getting cut off and fish and invertebrate becoming isolated or stranded. In addition, an issue for the Orongorongo River which is not shared with Te Awa Kairangi and Wainuiomata is the potential for the abstraction to increase the occurrence of riverbed drying. At this stage, the degree to which this occurs (if at all) is unknown under the naturalised or abstractive scenarios (including the current level of abstraction). The cessation of flow within reaches of the mid-river has the potential to affect the ecology in a more profound manner than simply reducing the amount of habitat that is available. Riverbed drying will reduce connectivity and stop fish from migrating through the catchment as part of their life cycle or to avoid stressful conditions. It is also noted that there is a poor understanding of what magnitude of flows are required to open and maintain an opening at the river mouth. It could be that significant reductions in the mid-range flows could lead to earlier closing of the river mouth and disrupted movement of migratory species.

- With respect to increasing the minimum flow at Truss Bridge (and thereby reducing abstraction at the lowest flows), beneficial effects are likely to be modest in both magnitude and extent[8]. The largest assumed benefit would occur for the upper segment of the river (based on proportional flow retention), but without habitat or other ecosystem response data this cannot be quantified, nor can the extent to which benefits would diminish downstream. When combined with the potential for increased abstraction at mid-range flows any habitat benefits would likely be offset and ecological effects would, overall, be incrementally more negative than under current use regime.

To conclude, the lack of data to examine abstractive effect on the Orongorongo River combined with high natural catchment value warrants, in the Panel's view, an additional layer of caution in the interpretation of effect and change. It is recommended that the potential abstractive effects are more thoroughly examined before any changes to the abstraction regime are considered, including more fully exercising the existing consent. Clapcott's (2020) review provides some relevant advice in this respect and the potential vulnerability of the river to bed drying is considered especially important.

This assessment has not considered abstractive impacts on the tributary Big Huia Creek from which some of the total water allocation is sourced. The intake on this stream is approximately 100 m

[8] Comments here are based on the premise of increasing the minimum flow by a similar proportion as was tested in Scenario 3 for the Te Awa Kairangi and Wainuiomata rivers (i.e. increasing by about one third). Increasing the minimum flow by greater amounts could potentially produce more than modest ecological health benefits.

upstream from the Orongorongo River confluence and relies on a weir control structure (4 m in height). Flow has not been monitored since the 1980s and there are no minimum or residual flow consent conditions, so the level of hydrological alteration and effect is unknown. Seven-day MALF at the weir was estimated to be about 40 L/sec by Opus (2000) and the consent authorises up to 225 L/sec to be abstracted. This indicates the potential for extremely large alteration of the hydrological regime in this reach. Part of the reach downstream of the weir receives year-round flow from Little Huia Creek (Opus 2000) but whether the section between this and the weir dries under certain abstraction conditions (i.e. all low flow being removed) is unknown. It is reasonable to think that a large flow reduction and possible hydraulic disconnection occurs on occasion, although the impact of this is unknown.

6. Consequences of climate change

The best available modelling information (Pearce et al 2017, Singh et al 2016) suggests a complex picture for the effects of climate change on flows in Te Whanganui-a-Tara. There is spatial variability in predictions (mainly from west to east) and seasonally specific and quite different directional change from baseline in some climate and hydrological parameters. Nevertheless, there are some broad expectations of change that can be interpreted in an ecosystem health context. The future is likely to bring progressively warmer baseline temperatures, more 'hot' days, and longer durations of dry spells in summer and autumn (i.e. increased drought frequency and intensity)[9].

A summary of downscaled NIWA modelling (from Pearce et al 2017) in Thompson (2019) shows that reductions in mean annual low flow (MALF) of up to 20% in some parts of Te Awa Kairangi catchment by mid-century (and to a lesser extent in the Wainuiomata) with such reductions being more widespread through the Te Whanganui-a-Tara by the end of the century under a high emissions pathway (see Figure 6.1). One or two sub-catchments (e.g. the Mangaroa River in Te Awa Kairangi catchment) may realise slightly higher MALF reductions than 20%. Mean catchment flows are unlikely to be significantly affected, although more subtle changes in hydrograph dynamics may well be masked by such averages.

Exacerbating the stress brought on by lower flows will be the higher air temperatures (and therefore water temperatures); mean maximum daily temperatures increasing by around 3 $^{\circ}$C by the end of the century with hot days (i.e. those with maximum temperature >25°C) increasing from 10 to 30 per year on average.

Shifting to this new climate regime will be a gradual process and, to an extent, natural ecosystem adaptation and functional change over time to a 'shifting baseline' would be expected. Such gradual change will both disguise some of the real impacts but also mitigate some of the peak ecosystem stresses that might be more apparent with a quick shift. Even so, the most reasonable conclusion at this stage is that, if realised, the effect of climate change would be to generally shift assessments of the current regime and scenarios further towards more negative ecosystem health outcomes.

It is not possible to draw detailed distinctions between the three water supply catchments in terms of ecosystem vulnerability to changing climate. At a conceptual level, although predicted climate-related reductions in low flows are more pronounced in Te Awa Kairangi, it is also likely to be a little more resilient than the Wainuiomata or Orongorongo as a function of its size and nature of groundwater exchanges (that can dampen temperature responses).

[9] https://www.gw.govt.nz/assets/Climate-change-2/WhaituaClimateChangeprojections.pdf

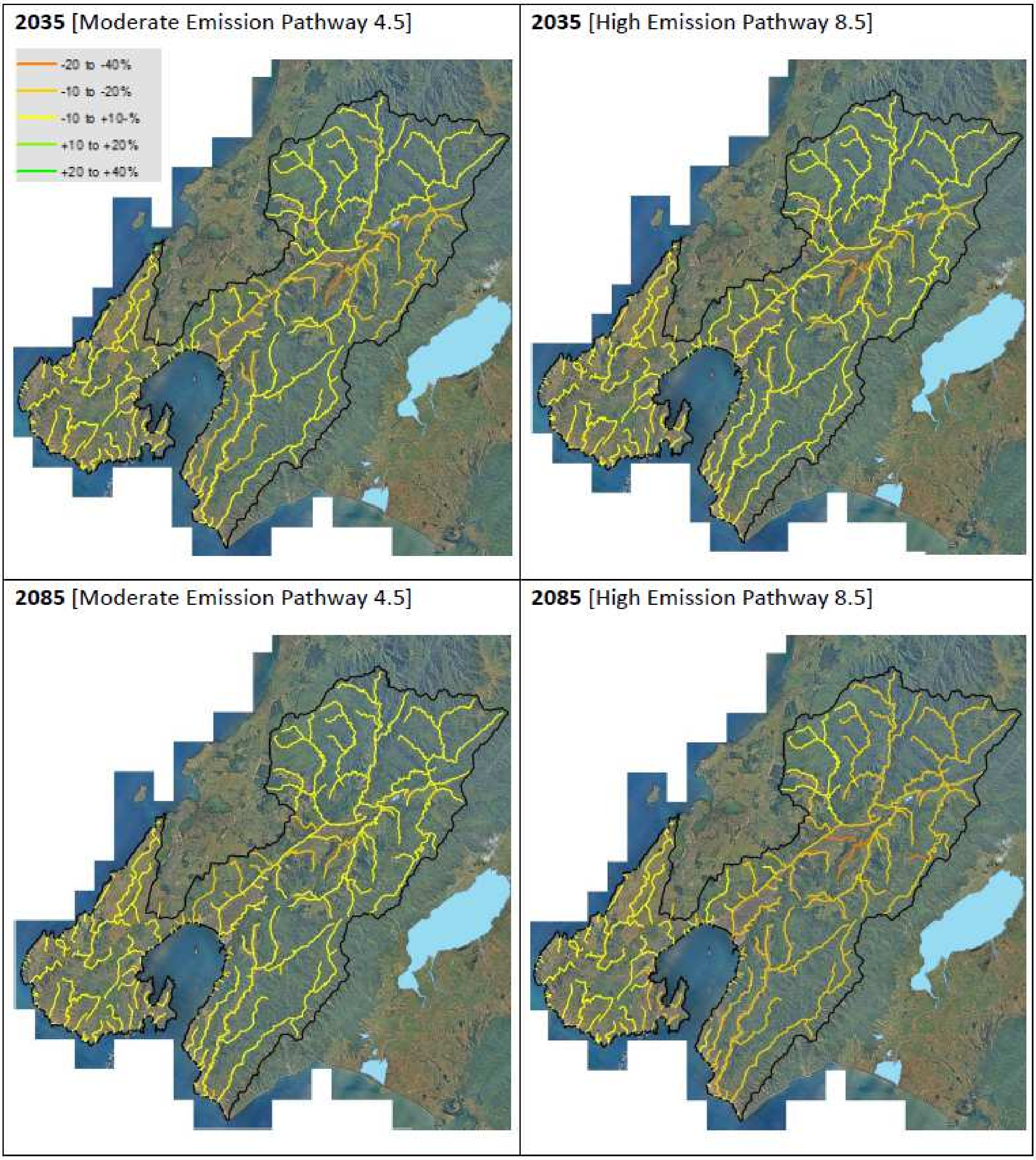


Figure 6.1. Predicted change in MALF under moderate and high emission scenarios for two future time slices (multi-model median percentage change from present day). Reproduced from Thompson (2019). Source data (percentage change for REC segment) from NIWA.

7. Concluding remarks

This section provides a collection of thoughts emerging from the Panel discussions that may be of additional interest to the Whaitua Committee.

7.1 Confidence in assessments – spatial variability

The difficulty in assigning confidence to interpretations of ecosystem impact, and some of the reasons why, have already been noted in several places in this report. Here, a final comment on relative confidence is made based on the Panel's overall sense of the type and quality of information available for the assessments.

Broadly, confidence is highest for the middle segment of Hutt River. This part of the river has been subject to three hydraulic-habitat surveys, is rich in hydrological data and has been a focus for toxic algae and other water quality/ecology surveys. The Middle River stretch of the Wainuiomata River also has more data available than other parts of this river and has a channel morphology that is better suited to the habitat modelling methods. Confidence in the assessments for the Upper and Lower stretches of both Te Awa Kairangi and Wainuiomata rivers is incrementally lower, and lowest for the Orongorongo River where very little information beyond the abstraction point is available; the assessment for the Orongorongo has relied almost exclusively on a conceptual view of likely flow and ecosystem responses for this type of river.

7.2 Secondary minimum flows

The scenarios assessed in this report focused only on the minimum flows in the upper catchments of the three rivers used to control the public supply takes. This was deliberate as these minimum flows control 95-98% of the total catchments' water abstraction. However, in Te Awa Kairangi and Wainuiomata rivers there are also secondary minimum flows (at Birchville and Leonard Wood Park, respectively) in the regional plan that are used to control some minor abstractions in the lower catchments.

While the merits of these secondary minimum flows have not been specifically assessed, they should not be overlooked in the overall approach to reviewing limits. The following information and comments may be relevant for consideration:

- The minimum flow on Te Awa Kairangi at Birchville (Middle River) is currently 1,200 L/sec and was set based on interpretations from hydraulic-habitat analysis in the mid-1990s (Jowett 1993). There are currently only two consents with cease-take conditions related to the Birchville site and together they account for about 25 L/sec (or slightly less than 1% of the naturalised MALF). The minimum flow equates to only about 35% of naturalised MALF, which affords a very low level of instream protection compared with other rivers in the Wellington region and nationally, although is proportionally equivalent to the primary minimum flow upstream at Kaitoke. The Birchville habitat modelling results suggests some quite serious losses occur well above the existing Birchville minimum flow, i.e. >50% relative to MALF for some food producing and macroinvertebrate species and 30-50% for some fish (Holmes 2020).

- Flow in Te Awa Kairangi at Birchville has not dropped below 1,200 L/sec since the 1970s (well before minimum flows were applied in this catchment in the late 1990s). Since minimum flows were introduced to the regional plan and consents, the Birchville minimum flow has not been observed. In a sense then, the Birchville minimum flow is so low as to have been effectively redundant over the past 20 years. On the other hand, so little abstraction is tied to this management site that the risk and consequence to date has probably been negligible, and it at least exists as a safety net should more extreme low flows occurs in the future (likely with climate change). Nevertheless, it may be prudent to more fully assess the risks posed by the current minimum flow setting (including whether it remains appropriate for managing non-public supply takes) and to consider whether the protection level afforded is consistent with the requirements of the NPS-FM.

- Related to the above point, the Committee may wish to consider the merits of a minimum flow control site being established in the Lower River (Avalon). With this reach being the most sensitive to cumulative abstraction, and therefore potentially a bottleneck for allocation upstream, a control site would give additional surety that flow objectives are being met and abstractions managed appropriately through the Lower River. Notwithstanding any practical and engineering challenges, there may also be benefits in co-locating new flow measurements with any new monitoring site established for more comprehensive lower catchment water quality measurements.

- The situation is a bit different for the Wainuiomata River. The secondary minimum flow at Leonard Wood Park is 300 L/sec, equating to about 75% of naturalised MALF (which is proportionally significantly higher than the Birchville minimum flow). Further IFIM work by Harkness (2002) and subsequently review by Hay (2011) has been hampered by data suitability issues, but broadly suggests the minimum flow of 300 L/sec is in step with current thinking about habitat protection. The more recent re-analysis by Holmes (2020) also suggests that habitat losses at around 300 L/sec in the middle river segment are quite modest (10-30% relative to MALF for most macroinvertebrates and 0-20% for adult native fish and trout).

- There is currently only one consent (for 33 L/sec) tied to the Leonard Wood Park minimum flow and it is subject to relatively frequent cease take requirements in summer. Potential for substantially larger volumes of abstraction to be attached to this minimum flow in the future is low (given catchment allocation status). Overall, the Leonard Wood Park minimum flow is probably set at a level that is consistent with avoiding large negative ecosystem changes and effects.

7.3 Change from existing abstraction regimes

Modelling for this report shows that, in theory, quite significant increases in abstraction in the low to mid-range flows could occur under existing public supply consents (in all rivers). It is acknowledged though that the likelihood of anything close to ‘maximum use’ occurring is very low for a range of reasons (the necessary additional demand is unlikely, additional storage is unavailable and WWL always need to operate with a margin). However, what is less clear to the Flow Panel is how much more could plausibly be taken under the existing consents. It would be useful for Wellington Water Ltd to provide some reassurance to the Whaitua Committee on this issue. If there remains any doubt about whether the current regime is, in practical terms, actually one of maximum use, it may be that further modelling/analysis by WWL and/or GWRC could be useful. With refined assumptions this could help more accurately determine risks associated with fully exercised consents.

In more general terms, the modelling and assessment undertaken for this Whaitua process does not equate to the level of assessment required should a significant change from the existing regime be seriously contemplated. Rather it is sufficiently indicative of risk to suggest that any marked and systematic increase in abstraction, whether by way of more fully exercising existing consents, reducing the minimum flow or increasing paper allocation should be subject to a more rigorous effects assessment. Clapcott (2020) summarises some elements of investigation that might be appropriate. Likewise, benefits associated with increasing minimum flows would need to be more fully assessed.

7.4 Climate change

Climate change is likely to aggravate ecosystem stress conditions in the water supply catchments at dry times of the year in the future. However, the gradual shift allows for an adaptive approach to abstraction management to counter climate effects (should this be necessary). In practice this could be achieved through a range of short- and long-term measures, many of which are described in various Wellington Water Ltd reports (most recently in Blyth and Williams 2020). Here, it is just noted that there may be opportunities for the Committee to consider how the allocation framework in the regional plan could best enable/require such adaptation. The Committee may also wish to direct further investment towards quantifying the potential ecosystem risks of flow allocation in the context of climate change predictions. It is likely that more sophisticated bio-physical models will be required (as recommended by Clapcott 2020) to do this.

7.5 Non-ecological values

The scope of this report has been firmly constrained to consideration of ecosystem health effects. Nevertheless, some of the assessments can be interpreted in the context of other values. The premise is that an allocation regime set based on sustaining ecosystems will likely sustain other community values, since they are often heavily reliant on a healthy biological system. This premise does not of course apply as a rule and the Panel cautions against stretching assessments too far when trying to interpret for other values.

Some general comments can be made:

- With respect to recreational opportunities, it is thought unlikely that the current abstraction regime significantly diminishes the quality of swimming holes. These tend to be located either in protected scour zones (e.g. where rock provides a stable incised bed and gravel does not accumulate) or in pools within riffle-run-pool sequences where depth becomes adequate in the faster flowing water (usually towards a bank). Protected scour zones are generally stable over time and the location of pools will move around depending on gravel movement. In either case swimming holes tend to hold their depth even at quite low flows. Of perhaps more concern for swimming (or contact recreation) at low flows is nuisance algae, and especially algae blooms in Te Awa Kairangi catchment. Recreational boating (kayaking, rafting) tends to be less appealing in the middle and lower segments of Te Awa Kairangi at low summer flows where downstream current is weaker and riffles and shallow bed features are naturally more exposed. However, tubing is popular through the upper river. While it is assumed unlikely that any of these activities are curtailed by loss of flow/depth relating to abstraction (river connectivity remains throughout), specific objectives and criteria informed by discussions with recreational users would be needed to fully test this assumption.

- With respect to Mana Whenua values, the Flow Panel understands Te Kahui Taiao will be advising the Committee. Here it is noted that the overall approach in this report to viewing scenarios and effects against a naturalised baseline could readily feed into the work of other such panels; fundamentally, change from naturalised state can be interpreted very widely across values and world views as a broad indicator of system health. That said, it is also noted that the assessments in this report relating to the river main stems may be less pertinent to consideration of the NPS-FM compulsory mahinga kai value than some of the smaller tributary streams, except that the main stems are a critical migratory corridor for species that inhabit tributary streams.

References

Beca 2008. Draft guidelines for the selection of methods to determine ecological flows and water levels. Prepared by Beca Infrastructure Ltd for the Ministry for the Environment.

Blyth J and Williams G. 2020. Whaitua Te Whanganui-a-Tara: Overview of the Wellington metropolitan water supply network and consideration of future pressures on infrastructure.

Clapcott J 2020. A review of the effect of water abstraction on Wellington rivers. Prepared for Greater Wellington Regional Council. Cawthron Client Report 3448

Clausen, B.; Jowett, I.G.; Biggs, B.J.F.; Moeslund, B. (2004). Stream ecology and flow management. In: Tallaksen, L.M.; Van Lanen, H.A.J. (eds). Developments in water science 48, pp. 411-453. Elsevier, Amsterdam

Dunbar, M.J.; Acreman, M.C. (2001). Applied hydro-ecological science for the twenty-first century. In: Acreman, M.C. (ed.). Hydro-ecology: Linking hydrology and aquatic ecology - Proceedings of Birmingham workshop, July 1999, pp. IAHS, Birmingham

Greer 2020. Whaitua Te Whanganui-a-Tara Expert Panel Process – Background and methodology. Memo prepared by Aquanet Ltd for Greater Wellington Regional Council.

Greer M 2020. Whaitua Te Whanganui-a-Tara – Water quality and ecology scenario assessment: Expert Panel outputs and interpretation. Report prepared for Greater Wellington Regional Council by Aquanet Consulting Ltd.

Harkness M 2003. Instream habitat survey of the Wainuiomata River. Wellington Regional Council Resource Investigations Department Technical Report. 34 p

Hay J 2010. Instream flow assessment options for Greater Wellington Regional Council. Cawthron Client Report 1770.

Hay J 2011. Review of instream habitat modelling for the Wainuiomata River. Cawthron Institute advice letter to Greater Wellington Regional Council. 5 p

Hay J. 2017. Re-calculating habitat retention for rivers in the Ruamāhanga catchment. Letter of advice (Cawthron ID 1728) prepared for Greater Wellington Regional Council

Hayes J, Hay J, Gabrielsson R, Goodwin E, Jellyman P, Booker D, Wilding T, Thompson M 2018a. Review of the rationale for assessing fish flow requirements and setting ecological flow and allocation limits for them in New Zealand—with particular reference to trout. Prepared for NIWA, Envirolink, Greater Wellington Regional Council and Hawke's Bay Regional Council. Cawthron Report No. 3040. 149 p.

Hayes JW, Goodwin EO, Shearer KA, Hicks DM 2019 Relationship between background invertebrate drift concentration and flow over natural flow recession and prediction with a drift transport model. Canadian Journal of Fisheries and Aquatic Sciences 76(6): 871-885.

Heath MW, Greenfield S 2016. Benthic cyanobacteria blooms in rivers in the Wellington Region. Findings from a decade of monitoring and research. Greater Wellington Regional Council Report GW/ESCI-T-16/32. 97p plus appendices

Holmes R 2020. Flow-habitat modelling outputs for the Hutt and Wainuiomata Rivers. Prepared for Greater Wellington Regional Council by Cawthron. Client report no. 3480.

Hudson, H.R.; Byrom, A.E.; Chadderton, W.L. (2003). A critique of IFIM - instream habitat simulation in the New Zealand context. Science for Conservation 231.

Hudson HR 2010. Assessment of potential effects on instream habitat with reduced flows in the Hutt River at Kaitoke. Environmental Management Associates, Christchurch. Report 2010-06. 103 p.

Jowett I 1993. Minimum flow assessment for instream habitat in Wellington rivers. Prepared for wellington Regional Council. NZ Freshwater Miscellaneous Report No. 63. NIWA, Christchurch. 33 p.

Jowett, I.G. (1997). Instream flow methods: a comparison of approaches. Regulated Rivers: Research & Management 13(2): 115-127.

Jowett IG, Hayes JW, Duncan MJ 2008. A guide to instream habitat survey methods and analysis. NIWA Science and Technology Series 54, NIWA Wellington. 121 p.

Keenan L 2020. Hydrological impacts of water allocation in major rivers of Whaitua Te Whanganui-a-Tara. Prepared for Greater Wellington Regional Council by Awanui Science.

Keery J, Binley A, Crook N, Smith JWN 2007. Temporal and spatial variability of groundwater–surface water fluxes: Development and application of an analytical method using temperature time series. Journal of Hydrology 336 (1 2): 1-16.

Lamouroux, N.; Jowett, I.G. (2005). Generalized instream habitat models. Canadian Journal of Fisheries and Aquatic Sciences 62(1): 7-14

Mathur, D.; Bason, W.; Purdy, E.; Silver, C. (1985). A critique of the instream flow incremental methodology. Canadian Journal of Fisheries and Aquatic Science 42: 825-831

Ministry for the Environment 2017. National policy statement for freshwater management 2014 (Updated August 2017 to incorporate amendments from the National Policy Statement for Freshwater Amendment Order 2017) Ministry for the Environment Wellington. 47 p.

Opus 2000. The abstraction of water from the Orongrongo catchment for public water supply: Volume 2 – assessment of environmental effects.

Orth, D.J. (1987). Ecological considerations in the development and application of instream flow-habitat models. Regulated Rivers: Research and Management 1: 171-181

Pilkington S 2016. Hutt, Waikanae and Otaki Rivers Sportfish Monitoring Results 1999-2016. Prepared on behalf of the Flood Protection Group, Wellington Regional Council Fish and Game NZ, Wellington.

Pearce P, Fedaeff N, Mullan B, Sood A, Bell R, Tait A, Collins D and Zammit C 2017. Climate change and variability – Wellington region. Prepared for Greater Wellington Regional Council by NIWA. Client report 2017066AK.

Richter BD, Davis MM, Apse C, Konrad C 2012. A presumptive standard for environmental flow protection. River Research and Applications 28: 1312-1321.

Rolls RJ, Leigh C, Sheldon F 2012. Mechanistic effects of low-flow hydrology on riverine ecosystems: ecological principles and consequences of alteration. Freshwater Science 31(4): 1163-1186

Ruamāhanga Whaitua Committee 2018. Ruamāhanga Whaitua Implementation Programme.

Singh S, Ibbitt R and Mullan B 2016. Sustainable Yield Model Upgrade 2016. Prepared for Wellington Water Ltd by NIWA. Client report 2016057CH.

Stalnaker CB, Lamb L, Henriksen J, Bovee KD, Bartholow J 1995. The instream flow incremental methodology: a primer for IFIM. Biological Report 29, National Biological Service, Fort Collins, CO.

Tharme RE 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications 19: 397-441.

Thompson 2019. Predicted impacts of climate change on key hydrological statistics. Memo prepared for the Te Whanganui-a-Tara Whaitua Committee and Expert Panels. Greater Wellington Regional Council.

Thompson M 2017. Minimum flow and allocation options for the Ruamāhanga River and major tributaries; a technical assessment to support decision making by the Ruamāhanga Whaitua Committee. Greater Wellington Regional Council GW/ESCI-T-18/64.

Wellington Water 2018. Hutt River Ecological Monitoring Plan – Summer 2017/18. Prepared for Greater Wellington Regional Council. Wellington. 27p plus appendices.

Yarnell S, Stein E, Webb J, Grantham T, Lusardi R, Zimmerman J, Peek R, Lane B, Howard J and Sandoval-Solis S. 2019. A functional flows approach to selecting ecologically relevant flow metrics for environmental flow applications. River Res Applic. 2020;36:318–324.

Appendix 1. Expert Panel Terms of Reference

Panel purpose and objectives

Whaitua Te Whanganui-a-Tara (WTWT) has been established to set freshwater objectives and limits for the Te Whanganui-a-Tara catchment, as part of GWRC's response to implementing the National Policy Statement for Freshwater Management (NPSFM 2014).

The purpose of the Flow Panel (the Panel) is to provide expert advice and judgement on the likely significance of bio-physical responses in three water supply rivers to different scenarios of water abstraction. The panel's outputs are intended to be high-level assessments that will feed into a broader Freshwater Quality and Ecology Expert Panel and also be considered alongside other scientific, social, cultural and economic information to help the Whaitua Committee set freshwater objectives.

The objectives of the Flow Panel are:

- Develop a shared understanding of the bio-physical state and characteristics of the Hutt, Wainuiomata and Orongorongo rivers, based on information in the technical library and a field visit.
- Drawing on the technical library and expertise/experience, evaluate several different scenarios (four main scenarios with some sub-scenarios) that may induce bio-physical responses in the main stem rivers (primarily related to fish and macroinvertebrate health, but not limited to these).
- Produce a panel summary for each assessment unit for each of the various indicators which will include the predicted significance of effect and level of confidence in the assessment, as well as some high-level explanatory comments.

Process

There will be at least one workshop (refer section 4) plus the associated preparation including reading and a fieldtrip.

The general methodology in regards to assessing the scenarios is expected to be as follows:

1. As part of the preparation, each panel member is to individually begin forming a view on the likely scale of effects under various scenarios;
2. In the workshop, there will be chaired, structured discussion to initially draw out individual views, identify common ground and points of disagreement;
3. The panel will then discuss and decide **by consensus** the final "panel summary" for assessment units and indicator (with any major disagreements being noted)
4. Steps 2-3 are to be repeated until all assessment units and indicators have been evaluated.

Further details of the scope of information to be made available to Panel members and matters that are anticipated to require their attention is provided at the end of this document. Details are being refined as technical work is completed so final scope/approach is subject to change.

Responsibilities and Expectations

GWRC will provide a Chair (Penny Fairbrother) for the workshops. One of the panel members will act as the lead panelist and facilitate the workshops and write up the final panel summaries.

There will be a total of four panel members and the intent is for each panel member to apply their expert knowledge and:

- Work in a timely manner to review appropriate information within the technical library and produce individual pre-assessments prior to the planned workshops.
- Operate without bias, prejudice or organisational agendas.
- Undertake the pre-assessments independently, using best judgement.
- Make a decision on all assessments, regardless of their level of confidence (which can be documented).
- Act professionally and respectfully towards other panel members during the workshops.
- Work together to come to a consensus decision on each of the final "panel summaries".
- If a panel member does not agree with a final panel summary and no resolution can be made, a note will be made expressing why there was disagreement and the workshop will progress. It is expected that disagreements will be noted with sufficient detail that each panel member can be confident in their assessments use in any consequential RMA processes.
- Stand by the process, their individual assessments and the final decisions made (except where disagreement has been expressed and noted as per the above and/or where further information becomes available that significantly impacts a panel member's understanding of an issue).
- Act ethically and professionally, and conduct their practice in accordance with:
- The New Zealand Code of Professional Standards and Ethics in Science, Technology, and the Humanities.
- The Environment Courts Code of Conduct for Expert Witnesses.

Conflicts of Interest

Panel members are expected to identify and manage any conflicts by:

- Declaring them to the GWRC Project Manager
- Genuinely considering all options without bias, prejudice or organisational agendas
- Genuinely contributing to consensus decision-making.

Scope of information available to Flow Expert Panel members

Three key pieces of information will be available to the Panel and considered 'essential reading':

1. **Report** that provides a review of 'the effect of water abstraction on the water supply rivers'. This reports provides a synthesis of the abstraction activities, data that have been collected to date to monitor effects and some conclusions about the likely ecological consequences of the existing takes. Author Joanne Clapcott.

2. **Report** that provides the results of flow modelling for various scenarios of abstraction/minimum flow. The key outputs in this report are statistics relating to hydrological alteration generated using the IHA (Indicators of Hydrological Alteration) and RVA (River Variability Analysis) methods. Predicted changes from natural and existing state are compared. Author Laura Keenan.

3. **Report/memo** that provides a re-analysis of IFIM survey data from the water supply rivers to assess likely physical habitat changes (trout and selected native fish) and some commentary on how flow alteration may effect river productivity. Author Robin Holmes.

The broader science library will be available to all members and they are also encouraged to circulate between themselves any other existing (published) reference material they consider pertinent or helpful to the Panel workshop.

Appendix 2. Attribute table

Attribute		Narrative & scope	Parameters to consider	Assessment informed by…	Effects to consider	Values to consider [primary in bold]
Tier 1	Flow	Master variable, directly affected by allocation regime The entire hydrological regime but focused on the magnitude, duration and variability of low flows (being the most highly impacted by abstraction in the water supply catchments). Changes to the size and frequency of mid-range and flushing flows will also be considered. Flood flows are out of scope.	• MALF (various durations) • Date, count and duration of low flows • Q5-Q95, median and FRE3 flows, including accrual periods between flush flows	• Flow statistics will be provided to the panel by Greater Wellington Regional Council • Stats will largely be the outputs of mean daily flow modelling showing hydrograph alteration between scenarios as well as Indicators of Hydrological Alteration (IHA)/River Variability Analysis (RVA) results	• All flow dependent aspects of habitat, water quality, plant growth, fish and macroinvertebrates	• **Life supporting capacity** • Natural character • Mahinga Kai
	Physical habitat	Physical habitat becoming a limiting factor for aquatic life is generally regarded as a key risk associated with river abstraction. Physical habitat is defined here primarily by a range of hydraulic and morphological features (including substrate types).	• Water depth • Point velocity • Wetted width • Habitat types (pools, runs, riffles, glides, back eddies etc.)	• Modelled and observed relationships between flow and hydraulic variables for point locations and IFIM survey reaches. • Habitat suitability curves • The panel, based on their understanding of the general relationships between flow change and hydraulic/ morphological/ substrate change for the types of river environment being assessed.	• Effects of habitat change on plant growth, fish and macroinvertebrates	• **Life supporting capacity** • Natural character • Mahinga Kai
Tier 2	Water quality	Some water quality changes can occur with change in flow. Of primary importance when considering life supporting capacity and run of river abstraction regimes are water temperature and dissolved oxygen.	• Water temperature • Dissolved oxygen	• Consideration of results for higher attributes • Monitoring data and past studies in these catchments • The panel, based on their understanding of the general relationships between flow change and DO/Temp change for the types of river environment being assessed.	• Effects of water quality change on plant growth, fish and macroinvertebrates	• **Life supporting capacity** • Natural character • Mahinga Kai
	Plant growth (algae)	Changes in algae growth rates/coverage can become apparent with change in flow regime. This attribute includes cyanobacteria and, to a much lesser extent, macrophytes (lower Wainuiomata River only)	• Periphyton cover and biomass • Cyanobacteria cover • Macrophyte cover (Wainuiomata R.)	• Consideration of results for higher attributes • Periphyton (including diatoms, green algae and cyanobacteria) habitat suitability curves. • The panel, based on their understanding of the general relationships between flow change and plant growth for the types of river environment being assessed.	• Effects of change in plant growth on fish and macroinvertebrates • Effects of change in plant growth on natural character and human health	• **Life supporting capacity** • Human health • Natural character • Mahinga Kai
Tier 3	Macroinvertebrates	Changes in invertebrate community composition in response to higher tier attribute changes	• MCI • Macroinvertebrates in flow sensitive communities	• Consideration of results for higher attributes • Habitat suitability curves • The panel, based on their understanding of the general relationships between flow change and macroinvertebrate communities for the types of river environment being assessed.	• Composition change • Effects on higher and lower trophic levels	• **Life supporting capacity** • Natural character • Mahinga Kai
	Fish	Native and sport fish community health can change in response to flow regime and its consequent effects on habitat, water quality, feeding opportunities (algae, macroinvertebrates)	• Fish abundance and diversity	• Consideration of results for higher attributes • Available fish monitoring data • The panel, based on their understanding of how the changes Tier 1 and 2 attributes will impact fish communities, the threat classification of different species, and the distribution of threatened species in water take catchments.	• Effect on fish community abundance and diversity • Effects of change on lower trophic levels	• **Life supporting capacity** • Recreational (angling) • Mahinga Kai
	Overall suitability for recreation	Recreational opportunities and experiences can be impacted by abstraction regimes. Here suitability is constrained to human health risks and aesthetic/amenity values	• Parameters above under the flow, habitat, and plant growth attributes	• Consideration of results for flow, habitat, and plant growth attributes • The panel, based on their understanding of how the changes in attributes will impact recreation in the types of river environment being assessed.	• Human health (cyanobacteria) • Amenity/aesthetics (nuisance algae/macrophytes, hydraulic/morphological change)	• **Human health** • **Natural character** • **Amenity/aesthetics**

Appendix 3. Hydraulic-habitat modelling

What is it?

Since its development in the 1970s hydraulic-habitat modelling, within the framework of the Instream Flow Incremental Methodology (IFIM), has become the most widely used and accepted method of assessing environmental flow requirements, especially for maintaining fish populations (e.g. Stalnaker et al. 1995; Tharme 2003).

Hydraulic-habitat models quantify the response of physical habitat to changes in the flow regime, which can help evaluate potential consequences for instream physical habitat availability under different proposed flow scenarios (Jowett et al. 2008). They require detailed hydraulic data, as well as knowledge of the ecosystem and the physical requirements of stream biota. The basic premise of habitat-based methods is that if there is no suitable physical habitat for the given species / life stage, then it cannot exist. However, if there is physical habitat available, then a species / life stage may or may not be present in a survey reach, depending on other factors not directly related to flow, or to flow-related factors that have operated in the past (e.g. floods). In other words, habitat methods can be used to set the 'outer envelope' of suitable living conditions for the target biota.

Biological information is supplied to the model in the form of habitat suitability criteria (curves) (HSC) for different species and life stages (e.g. juvenile and adult). HSCs are a quantitative representation of how well-suited different water depths, velocities or substrate composition are for a particular species and/or life stage. These factors are collectively termed 'physical habitat'. Other relevant factors, such as cover, aquatic vegetation and presence of other species, can be incorporated into the evaluation of habitat suitability, although this is not common in New Zealand. The predictions of hydraulic-habitat models are highly sensitive to the HSC used in them and this can lead to biased instream flow assessments (Hayes et al. 2018). If these criteria specify deep water and high velocity requirements, maximum habitat availability will generally be provided by a relatively high flow. Conversely, if the habitat requirements specify shallow water and low velocities, maximum habitat availability will generally be provided by a relatively low flow and habitat will decrease as the flow increases. The habitat-based method does not automatically assume that the natural flow regime is optimal for all aquatic species in a river. Depending on the species / life stage, reducing or decreasing flow relative to the natural flow regime may improve habitat conditions. However, altering the relative availability of suitable habitat for different species compared to under natural flow conditions has the potential to change the composition and relative abundance of different species within an aquatic community, which could lead to shifts in ecosystem structure and function.

The concept of how flow reduction can alter the distribution and availability of suitable physical habitat for fish with slow-moderate water velocity preference (e.g. eels) is illustrated in Figure A3.1. At high flow (but much less than flood flow) the fish will find suitable habitat a little way out from the margins where it is deep enough for them and where water velocities are slow to moderate. Closer to the middle of the channel the water may be too fast to provide suitable habitat even though depth is suitable. As the flow reduces the water velocity in mid-channel reduces and may become suitable. Some of the habitat closer to the stream margins may become too shallow and slow to be suitable—but overall, across the entire channel there is more habitat than at the high flow. Then as the flow is reduced further toward low flow, the wetted channel narrows substantially (drying from the margins) and much of the remaining wetted channel becomes too shallow to be suitable. The fish are confined to the deeper water in mid-channel. Overall, there is a reduction in habitat from the optimum level provided by the moderate flow. Hydraulic-habitat modelling is based on this concept: quantifying the relationship between available suitable habitat and flow over a simulated (modelled), incremental flow range.

Hydraulic-habitat modelling informs negotiations on parts of the environmental flow setting process. Environmental flows describe the different parts of the flow regime necessary to sustain different environmental values (e.g. ecological, cultural, recreational values). In New Zealand they typically constitute a minimum flow (i.e. the flow below which no further abstraction is allowed) and an abstraction limit (i.e. the maximum amount of water that can be removed from the river). However, theoretically a range of different aspects of the flow regime can be incorporated in the definition of an environmental flow. For example, minimum flows may be defined to protect habitat availability, or higher flows may be required to provide for flushing of periphyton (algae / slime) and fine sediment, channel forming flows, fish migration cues or connectivity to river floodplain habitats. Other parts of the flow regime may also support recreational (e.g. fishing, boating) and other values (e.g. cultural values).

Ecological flow regime assessment is concerned with the ecological components of an environmental flow regime. Hydraulic-habitat modelling helps to inform the identification of ecological flow requirements by characterising changes in physical habitat availability as flow changes, helping to define minimum flows and to identify lower mid-range flows that temporarily wet benthic invertebrate habitat important for supporting stream ecosystem productivity. The hydraulic modelling component can also provide information for understanding flow requirements for flushing the bed (i.e. of slime and silt) and maintaining the channel form.

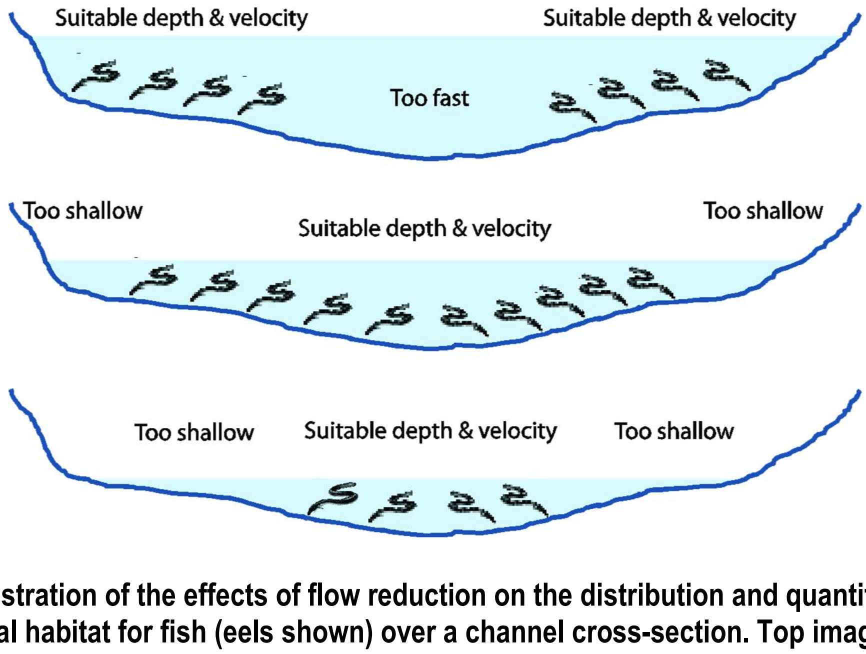


Figure A3.1. Illustration of the effects of flow reduction on the distribution and quantity of suitable physical habitat for fish (eels shown) over a channel cross-section. Top image: high flow; middle image: moderate flow; bottom image: low flow. In this example habitat is maximised at moderate flow.

It is important to note that there are a range of issues with placing an over reliance on the habitat modelling approach when setting flows. The habitat predictions of hydraulic-habitat models are highly sensitive to the habitat suitability criteria (HSC) used in them (Jowett et al. 2008). Habitat suitability criteria have been developed with different methodologies and within different rivers. In some cases, HSC have been developed in rivers that do not have the full spectrum of potentially available habitat and so can be inaccurate when applied to rivers that have a wider range of depths and velocities. This can be mitigated to some extent by using generalised habitat suitability criteria that are developed from data sets gathered from multiple rivers, or by modelling a range of different HSC for the same species and considering the aggregate of the predictions (as was done in Holmes et al. 2020 when modelling brown trout responses to the scenarios presented in this report). In addition, for many native fish only one or two HSC may be available, and these are often based on sparse data. The habitat modelling approach also neglects to consider many indirect ecosystem processes that can be affected by flow. For example, invertebrate drift concentrations can reduce with flow which compounds any effect of a reduction in area or quality of fish habitat. Further criticisms of this approach include a lack of biological realism (Hudson et al. 2003, Orth 1987) and mechanism (Mathur et al. 1985). These issues notwithstanding, the process is still a reasonably robust method for determining the relative severity of effects on habitat quality or availability when comparing different flow modification scenarios and has been applied widely throughout New Zealand and the world to assess the impacts of abstraction or river impoundment (Lamouroux & Jowett 2005, Dunbar & Acreman 2001).

How is hydraulic-habitat modelling done?

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

The calibration data are collected to simulate hydraulic conditions (i.e. water depth and velocities) in the river for a range of flows using a hydraulic model. These modelled hydraulic characteristics are then compared with habitat suitability criteria for the target species to assess how the combined quality and quantity of physical habitat varies as flow changes. This allows prediction of usable physical habitat for the species and/or life stages of interest at a range of flows. Usable physical habitat is commonly expressed as Weighted Usable Area (WUA) in m^2 per m of river channel. WUA is an aggregate measure of physical habitat quality and quantity and will be specific to a given discharge and species. A more recent alternative term for WUA is AWS (area-weighted suitability), which hereafter is used in preference to WUA throughout this report. The relationship between simulated AWS and flow can then be used to characterise the consequences for physical habitat of different water management scenarios (Figure A3.2). Flow limits can then be set so that they achieve specific management goals, such as meeting freshwater objectives defined in a regional plan.

Various approaches can be taken to assess appropriate flow limits for protecting instream values based on the results of instream habitat modelling. It is important to realise that AWS provides only a relative estimate of suitable habitat. When interpreting the AWS–flow curves, it is the shape of the curve (e.g. the flows at which the optimum AWS and major changes in slope occur) that are of interest, rather than the magnitude (or height) of the curves. In New

Zealand, the determination of flow limits has typically focussed on defining minimum flow requirements. One approach to defining this limit involves identifying a breakpoint (or 'inflection point') on the habitat/flow relationship (Jowett 1997). This has possibly been the most used procedure in New Zealand for defining minimum flow limits based on habitat methods. While there is no percentage or absolute value associated with a breakpoint, it is a point of diminishing return, where proportionally more habitat is lost with decreasing the flow than is gained by increasing the flow. Another approach now more commonly adopted involves maintaining a percentage of the maximum habitat area or a proportion of the habitat available at mean annual low flow. Differing protection levels can then be prescribed for species/communities based on their value (e.g. rare species may have 100% protection level; less significant communities may have an 85% habitat protection level). This approach is probably better aligned with the principles of the NPS-FM.

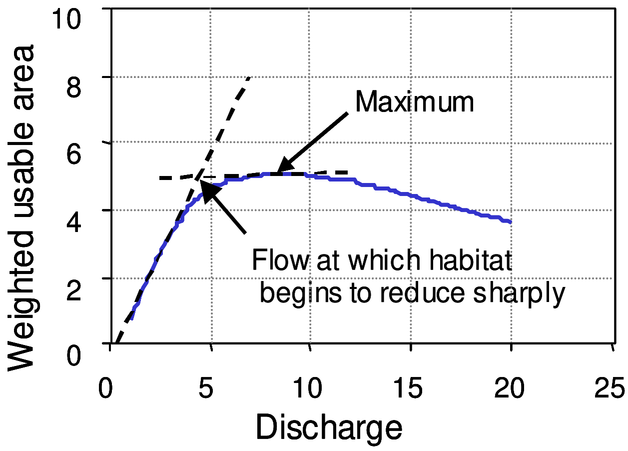


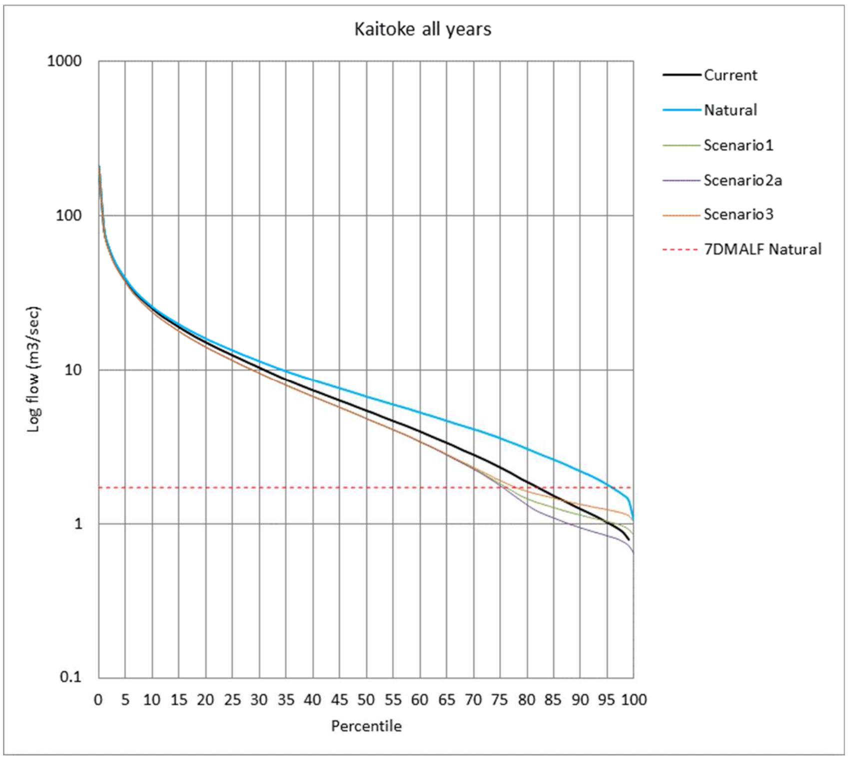
Figure A3.2. Illustration of a typical weighted usable area (habitat–flow (discharge)) relationship for a fish species in a river with a confined channel. AWS rises to a maximum and then declines at higher flows owing to water velocities becoming too high. Also shown is the point where habitat begins to decline sharply with further flow reduction. Sometimes minimum flows are set at or close to this 'break point' because flow higher than it offers decreasing proportional benefit. Units for discharge are m^3/s and for AWS are m^2/m.

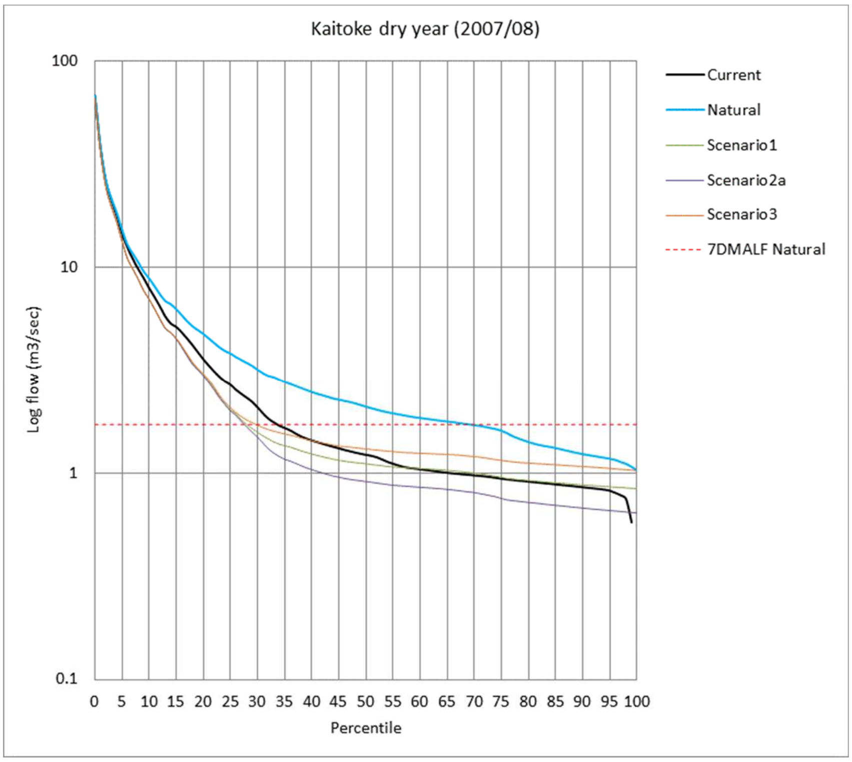
Appendix 4. Flow duration curves

Te Awa Kairangi River

Upper River

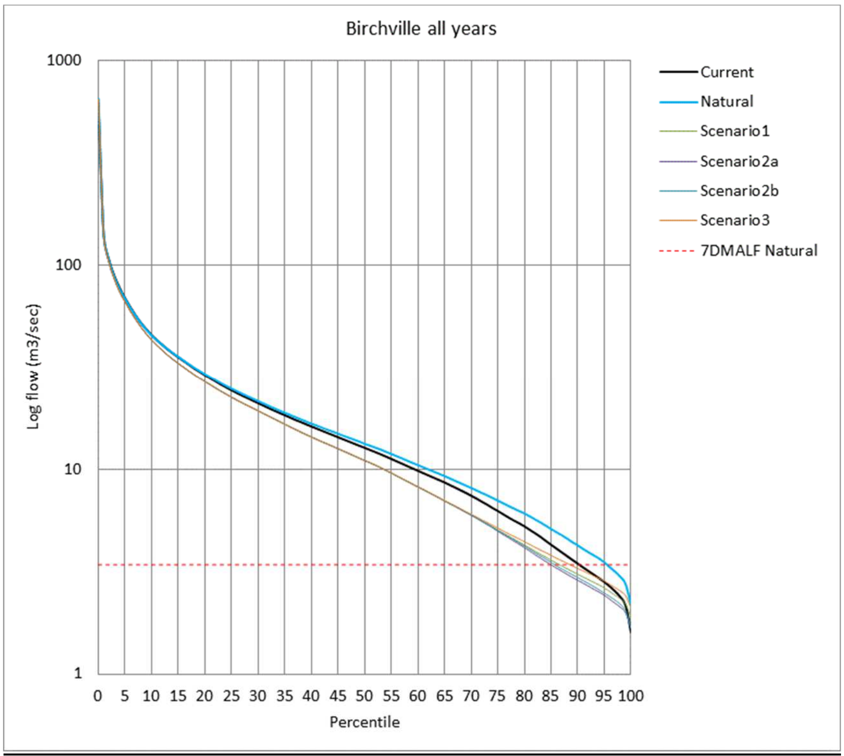
<u>Kaitoke</u>

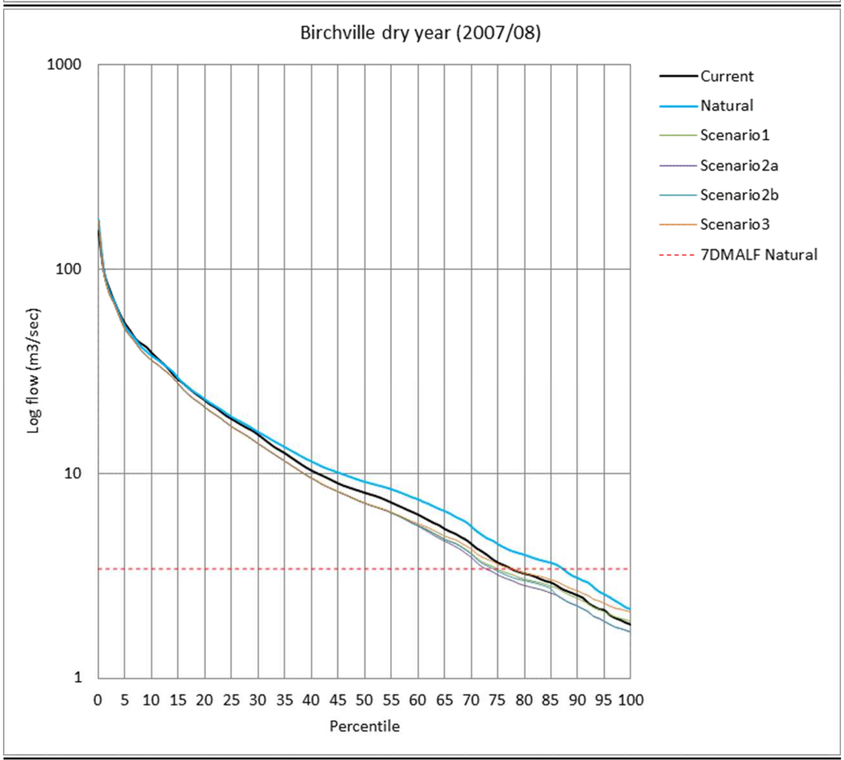




Middle River

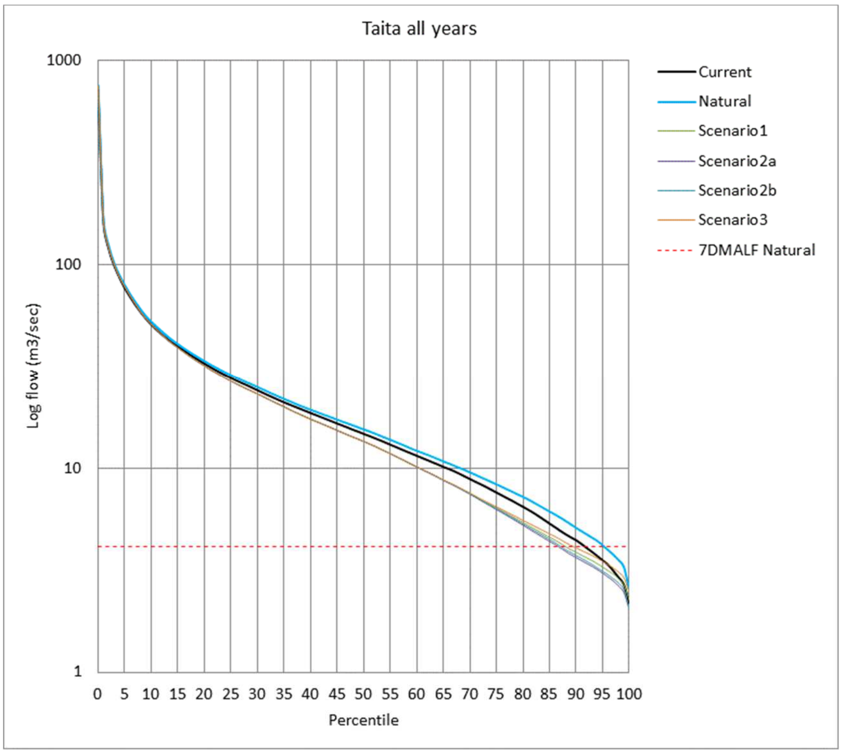
Birchville

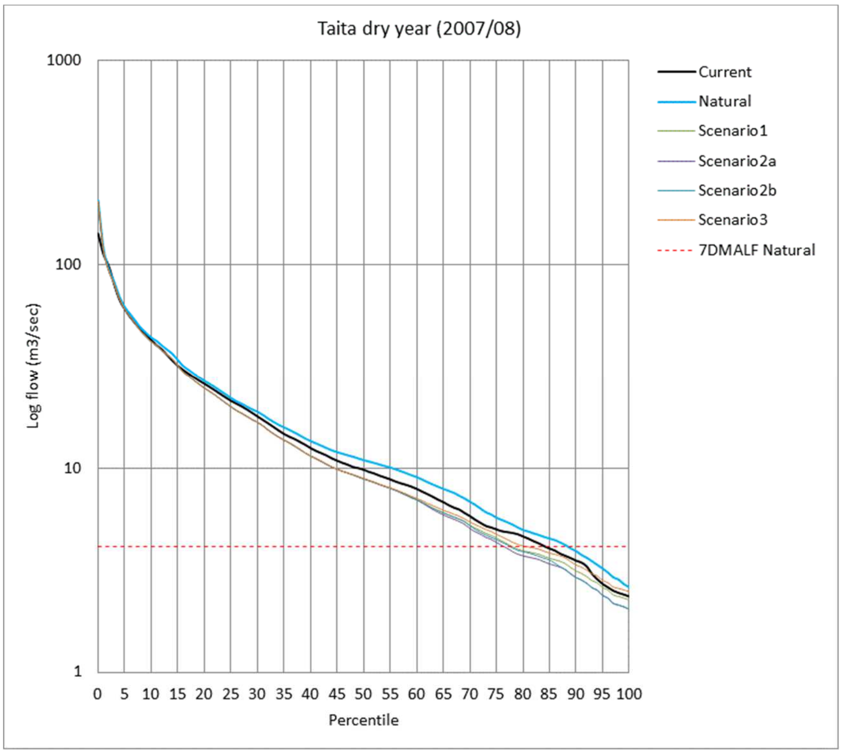




Middle River

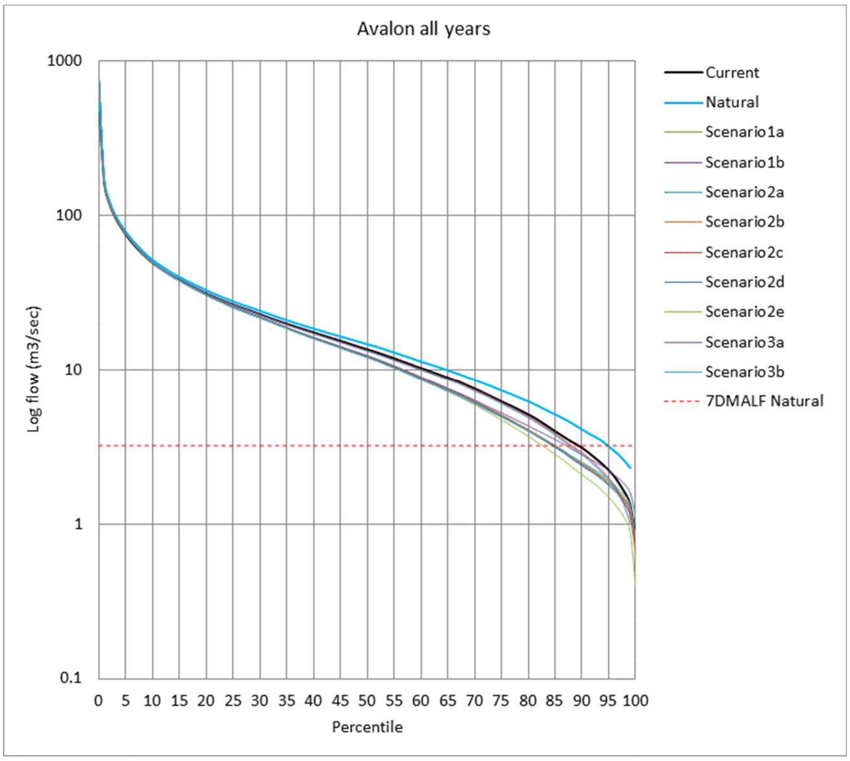
<u>Taita Gorge</u>

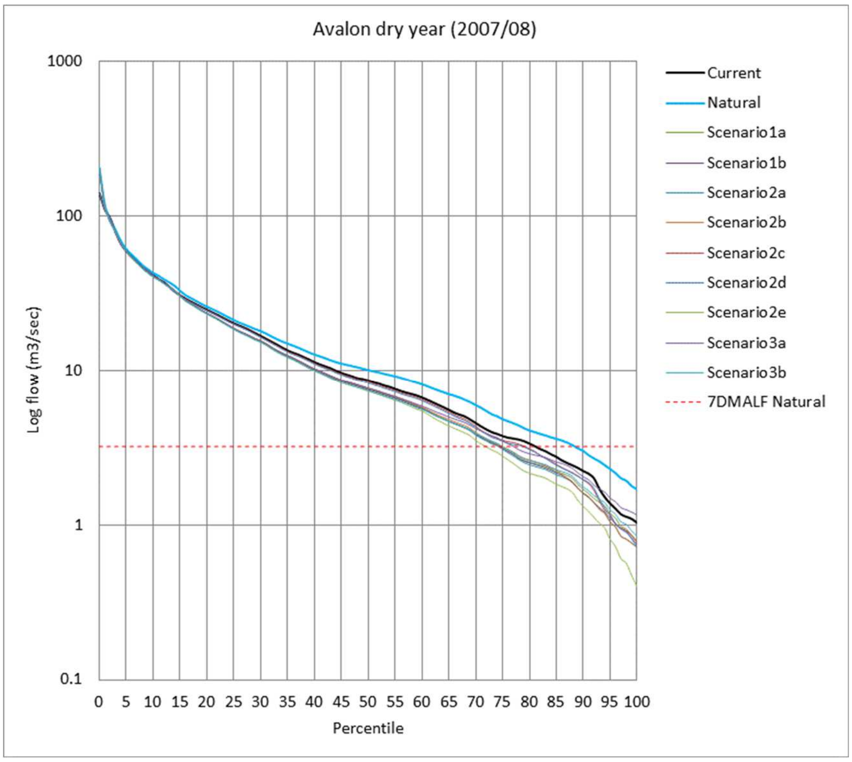




Lower River

Avalon

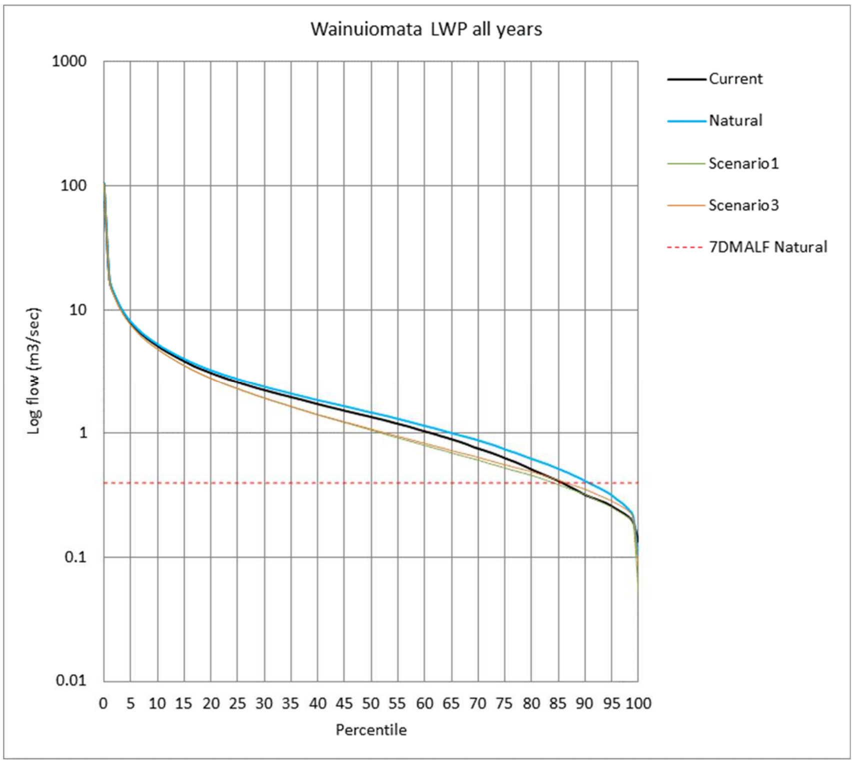


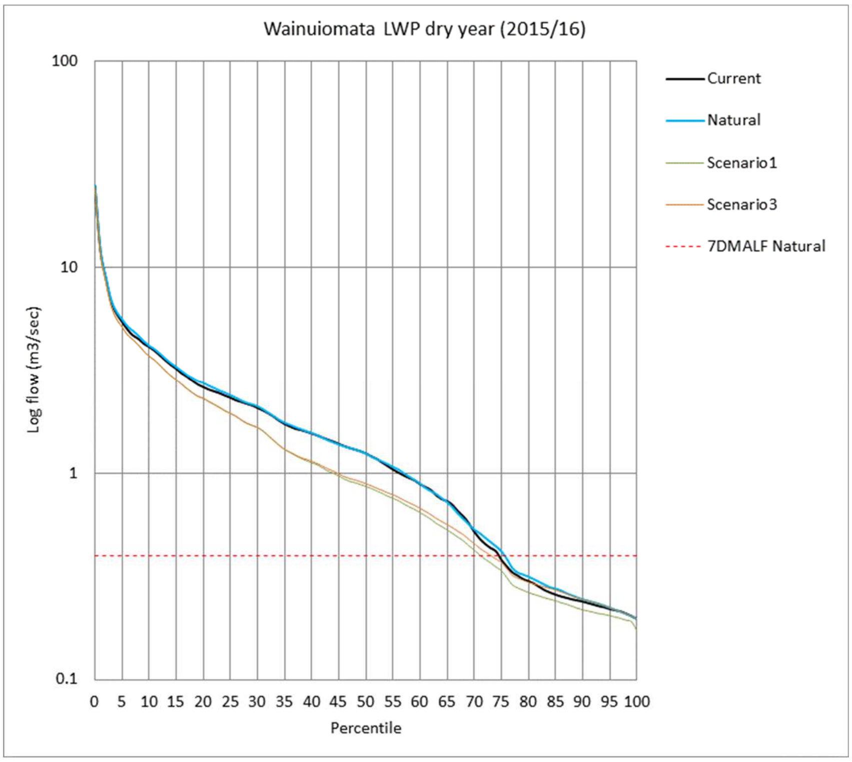


Wainuiomata River

Middle River

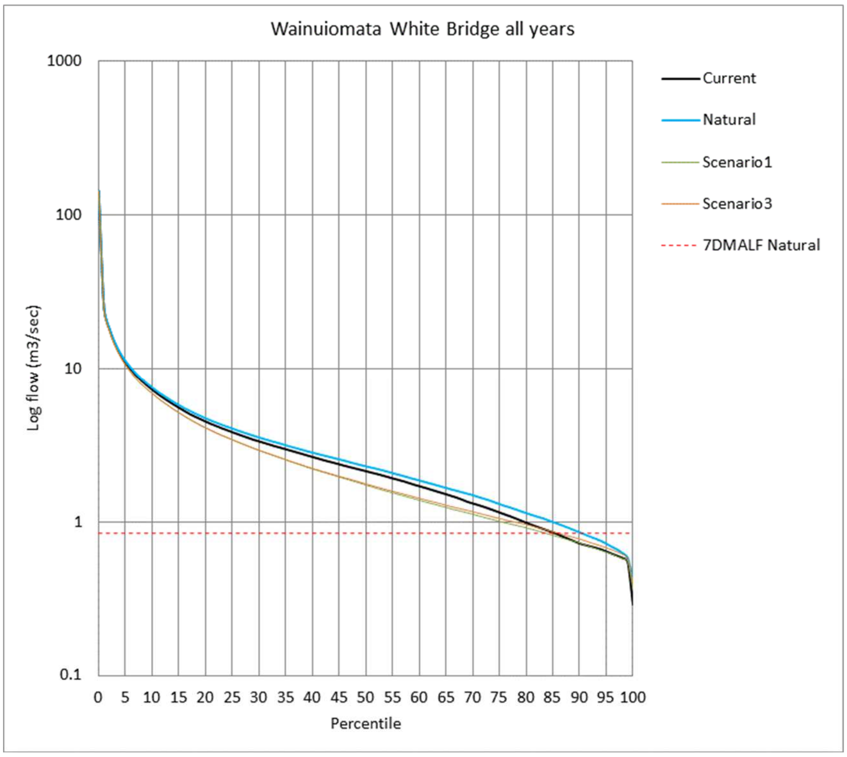
<u>Leonard Wood Park</u>

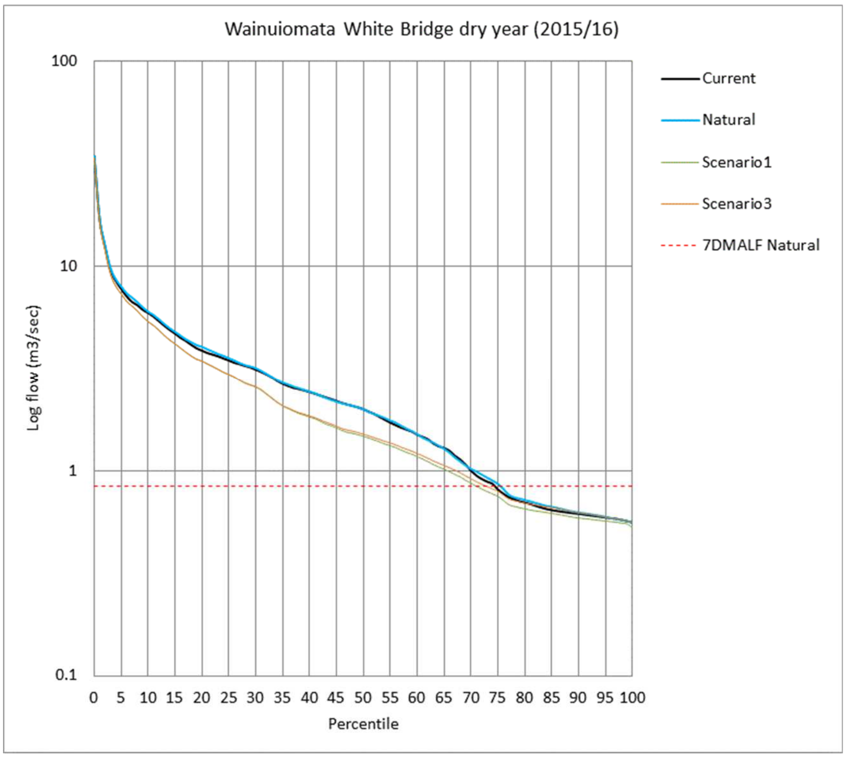




Lower River

<u>White Bridge</u>





Appendix 5. Expert panel assessments for Te Awa Kairangi

Table A5.1. Panel assessment of Tier 1 flow changes and effects

Scenario			Te Awa Kairangi sub-units and reporting reaches			
			Upper River	Middle River		Lower River
Number	Description		Kaitoke	Birchville	Taita Gorge	Avalon
			v Natural	v Natural	v Natural	v Natural
0	Current Use	Change	Very Large (-)	Moderate (-)	Small to Moderate (-)	Moderate to Large (-)
		Effect	Very Strong (-)	Moderate (-)	Moderate (-)	Strong (-)
		Confidence	Moderate to high	High	High	Moderate
1	Maximum Use	Change	Very large (-)	Moderate to Large (-)	Moderate to Large (-)	Very large (-)
		Effect	Very Strong (-)	Moderate to Strong (-)	Moderate to Strong (-)	Very Strong (-)
		Confidence	Low	Moderate	Moderate	Moderate
2	Increased abstraction (a and b)	Change	Very large (-)	Large (-)	Moderate to Large (-)	Very large (-)
		Effect	Very Strong (-)	Strong (-)	Moderate to Strong (-)	Very Strong (-)
		Confidence	Low	Moderate	Moderate	Moderate
	Increased abstraction (d)	Change				Very large (-)
		Effect				Very Strong (-)
		Confidence				Moderate
	Increased abstraction (e)	Change				Very very large (-)
		Effect				Very very strong (-)
		Confidence				Moderate to High
3	Decreased abstraction (higher minimum flow)	Change	Moderate (-)	Moderate (-)	Moderate (-)	Very large (-)
		Effect	Large (-)	Moderate (-)	Moderate (-)	Very Strong (-)
		Confidence	Low	Moderate	Moderate	Moderate

Table A5.2. Panel assessment of Tier 2 habitat for macroinvertebrates (incl. food producing)

Scenario			Te Awa Kairangi sub-units and reporting reaches				
			Upper River	Middle River			Lower River
Number	Description		Kaitoke	Birchville	Silverstream	Taita Gorge	Avalon
			v Naturalised	v Naturalised	v Naturalised	v Naturalised	v Naturalised
0	Current Use	Change	Large (-)	Small (-)	Small (-)	Small (-)	Moderate to Large (-)
		Effect	Strong (-)	Weak to Moderate (-)	Weak to Moderate (-)	Weak to Moderate (-)	Moderate to Strong (-)
		Confidence	Low	Moderate	Moderate	Moderate	High
1	Maximum Use	Change	Very large (-)	Small to moderate (-)	Small to moderate (-)	Small to moderate (-)	Large (-)
		Effect	Very Strong (-)	Weak to Moderate (-)	Weak to Moderate (-)	Weak to Moderate (-)	Strong (-)
		Confidence	Low	Moderate	Moderate	Moderate	High
2	Increased abstraction (a and b)	Change	Very large (-)	Small (-)	Small (-)	Small (-)	Very large (-)
		Effect	Very Strong (-)	Weak to Moderate (-)	Weak to Moderate (-)	Weak to Moderate (-)	Very Strong (-)
		Confidence	Moderate	Moderate	Moderate	Moderate	High
	Increased abstraction (d)	Change					Very large (-)
		Effect					Very Strong (-)
		Confidence					High
	Increased abstraction (e)	Change					Very very large (-)
		Effect					Very very strong (-)
		Confidence					Moderate to High
3	Decreased abstraction (higher minimum flow)	Change	Large (-)	Small (-)	Small (-)	Small (-)	Large (-)
		Effect	Strong (-)	Weak to Moderate (-)	Weak to Moderate (-)	Weak to Moderate (-)	Strong (-)
		Confidence	Low	Moderate	Moderate	Moderate	High

Table A5.3. Panel assessment of Tier 2 habitat for native fish

Scenario			Te Awa Kairangi sub-units and reporting reaches				
			Upper River	Middle River			Lower River
Number	Description		Kaitoke	Birchville	Silverstream	Taita Gorge	Avalon
			v Naturalised	v Naturalised	v Naturalised	v Naturalised	v Naturalised
0	Current Use	Change	Large (-)	Small to Moderate (-)	Small (-)	Small to Moderate (-)	Small to Moderate (-)
		Effect	Strong (-)	Weak (-)	Weak (-)	Weak (-)	Small to Moderate (-)
		Confidence	Low	Moderate	Low	Moderate	Moderate
1	Maximum Use	Change	Large (-)	Small to Moderate (-)	Small (-)	Small to Moderate (-)	Moderate to Large (-)
		Effect	Strong (-)	Weak (-)	Weak (-)	Weak (-)	Moderate to Strong (-)
		Confidence	Low	Moderate	Low	Moderate	Moderate
2	Increased abstraction (a and b)	Change	Large (-)	Moderate (-)	Small (-)	Small to Moderate (-)	Moderate to Large (-)
		Effect	Strong (-)	Moderate (-)	Weak (-)	Weak (-)	Moderate to Strong (-)
		Confidence	Low	Moderate	Low	Moderate	Moderate
	Increased abstraction (d)	Change					Moderate to Large (-)
		Effect					Moderate to Strong (-)
		Confidence					Moderate
	Increased abstraction (e)	Change					Large (-)
		Effect					Strong (-)
		Confidence					Moderate
3	Decreased abstraction (higher minimum flow)	Change	Large (-)	Small to Moderate (-)	Small (-)	Small to Moderate (-)	Moderate to Large (-)
		Effect	Strong (-)	Weak (-)	Weak (-)	Weak (-)	Moderate to Strong (-)
		Confidence	Low	Moderate	Low	Moderate	Moderate

Table A5.4. Panel assessment of Tier 2 habitat for trout

Scenario			Te Awa Kairangi sub-units and reporting reaches				
			Upper River	Middle River			Lower River
Number	Description		Kaitoke	Birchville	Silverstream	Taita Gorge	Avalon
			v Naturalised	v Naturalised	v Naturalised	v Naturalised	v Naturalised
0	Current Use	Change	Large (-)	Small to Moderate (-)	Small (-)	Small to Moderate (-)	Moderate to Large (-)
		Effect	Strong (-)	Weak (-)	Weak (-)	Weak (-)	Moderate to Strong (-)
		Confidence	Low	Moderate	Moderate	Moderate	Moderate
1	Maximum Use	Change	Large (-)	Small to Moderate (-)	Small (-)	Moderate to Large (-)	Very Large (-)
		Effect	Strong (-)	Weak (-)	Weak (-)	Moderate to Strong (-)	Very Strong (-)
		Confidence	Low	Moderate	Moderate	Moderate	Moderate
2	Increased abstraction (a and b)	Change	Large (-)	Moderate (-)	Moderate (-)	Moderate to Large (-)	Very Large (-)
		Effect	Strong (-)	Moderate (-)	Moderate (-)	Moderate to Strong (-)	Very Strong (-)
		Confidence	Low	Moderate	Moderate	Moderate	Moderate
	Increased abstraction (d)	Change					Very Large (-)
		Effect					Very Strong (-)
		Confidence					Moderate
	Increased abstraction (e)	Change					Very Large (-)
		Effect					Very Strong (-)
		Confidence					Moderate
3	Decreased abstraction (higher minimum flow)	Change	Large (-)	Small to Moderate (-)	Small (-)	Moderate to Large (-)	Moderate to Large (-)
		Effect	Strong (-)	Weak (-)	Weak (-)	Moderate to Strong (-)	Moderate to Strong (-)
		Confidence	Low	Moderate	Low	Moderate	Moderate

Appendix 6. Expert panel assessments for Wainuiomata River

Table A6.1. Panel assessment of Tier 1 flow changes and effects

Scenario			Wainuiomata River sub-units and reporting reaches	
			Middle River	Lower River
Number	Description		Leonard Wood Park	White Bridge
			v Naturalised	v Naturalised
0	Current Use	Change	Moderate (-)	
		Effect	Moderate (-)	
		Confidence	Moderate	
1	Maximum Use	Change	Moderate to Large (-)	
		Effect	Moderate to Strong (-)	
		Confidence	Moderate	
3	Decreased abstraction (higher minimum flow)	Change	Moderate to Large (-)	
		Effect	Moderate to Strong (-)	
		Confidence	Moderate	

Table A6.2. Panel assessment of Tier 2 habitat for macroinvertebrates (incl. food producing)

Scenario			Wainuiomata River sub-units and reporting reaches	
			Middle River	Lower River
Number	Description		Leonard Wood Park	White Bridge
			v Natural	v Natural
0	Current Use	Change	Small to Moderate (-)	Small (-)
		Effect	Weak to Moderate (-)	Weak (-)
		Confidence	Moderate	Low
1	Maximum Use	Change	Large to Very Large (-)	Large (-)
		Effect	Strong to Very Strong(-)	Strong (-)
		Confidence	Moderate	Moderate
3	Decreased abstraction (higher minimum flow)	Change	Large to Very Large (-)	Large (-)
		Effect	Strong to Very Strong(-)	Strong (-)
		Confidence	Moderate	Moderate

Table A6.3. Panel assessment of Tier 2 habitat for native fish

Scenario			Wainuiomata River sub-units and reporting reaches	
			Middle River	Lower River
Number	Description		Leonard Wood Park	White Bridge
			v Natural	v Natural
0	Current Use	Change	Small (-)	Small (-)
		Effect	Weak (-)	Weak (-)
		Confidence	Moderate	Low
1	Maximum Use	Change	Small to Moderate (-)	Small (-)
		Effect	Weak to Moderate (-)	Weak (-)
		Confidence	Moderate	Low
3	Decreased abstraction (higher minimum flow)	Change	Small (-)	Small (-)
		Effect	Weak (-)	Weak (-)
		Confidence	Moderate	Low

Table A6.4. Panel assessment of Tier 2 habitat for trout

Scenario			Wainuiomata River sub-units and reporting reaches	
			Middle River	Lower River
Number	Description		Leonard Wood Park	White Bridge
			v Natural	v Natural
0	Current Use	Change	Moderate (-)	Small (-)
		Effect	Moderate (-)	Weak (-)
		Confidence	Moderate	Low
1	Maximum Use	Change	Moderate to Large (-)	Small (-)
		Effect	Moderate to Strong (-)	Weak (-)
		Confidence	Moderate	Low
3	Decreased abstraction (higher minimum flow)	Change	Moderate (-)	Small (-)
		Effect	Moderate (-)	Weak (-)
		Confidence	Moderate	Low