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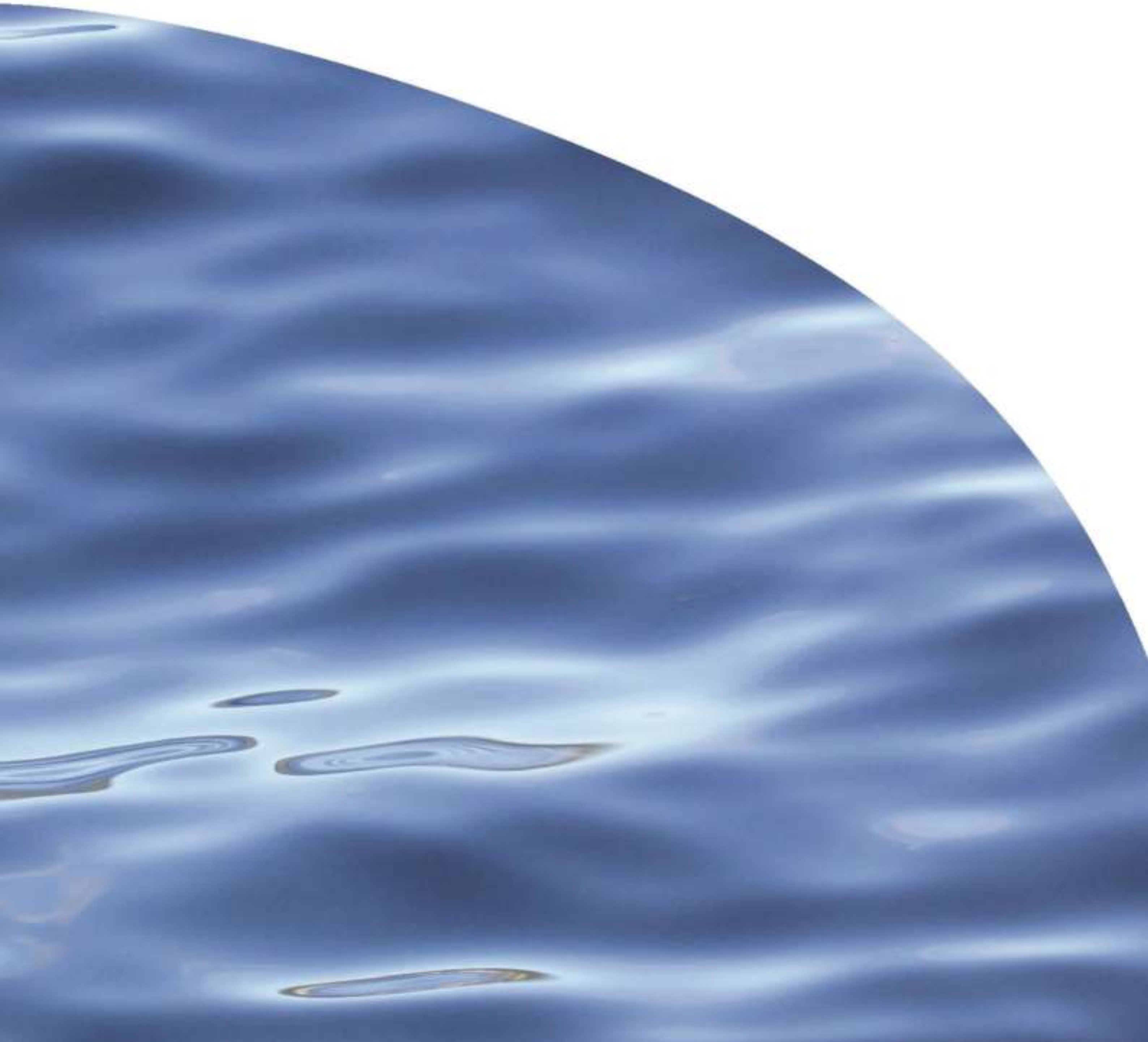
A REVIEW OF THE EFFECT OF WATER ABSTRACTIONS ON WELLINGTON RIVERS



A REVIEW OF THE EFFECT OF WATER ABSTRACTIONS ON WELLINGTON RIVERS

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Prepared for Greater Wellington Regional Council

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EXECUTIVE SUMMARY

This report provides a review and synthesis of relevant existing monitoring information in relation to the effect of water abstractions on the Hutt, Wainuiomata and Orongorongo rivers. These three gravel-bed rivers are in the Whaitua te Whanganui-a-Tara and provide most of the public water supply for Upper Hutt, Lower Hutt and Wellington cities, as well as Porirua City in the neighbouring whaitua. The flow in the Wainuiomata and Orongorongo rivers is hill-fed, and extraction from the forested headwaters combined provides almost 10% of the public water supply. The flow in the Hutt River and its tributaries is also predominantly hill-fed but there is a significant degree of interaction with underlying groundwater resources along the length of the river. Surface water extraction at the Kaitoke weir in the headwaters of the Hutt River provides 40% of public water supply and extraction from the Waiwhetu Aquifer in the lower reaches provides an additional 50%.

Current surface water allocation limits (in the proposed Natural Resources Plan) in the three rivers allow a volume equivalent to between 44% and 103% of current mean annual seven-day low flow (MALF-7d) to be extracted; for the Hutt River, minimum flows at gauging sites allow extraction equivalent to 40–57% of current MALF-7d. Actual water use is usually less than allocated water use in the Hutt River, but is likely to often exceed the combined allocation limit for the Wainuiomata and Orongorongo rivers. Standards for the protection of ecological values suggest that flow modification of greater than 20% leads to a high risk of moderate to major changes in ecosystem structure and function.

River Water Quality and Ecology monitoring and Recreational Water Quality monitoring in the three rivers shows that ecosystem health is generally excellent in the upper reaches and declines downstream to a fair to poor state due to elevated nutrients and faecal contamination, associated with increasing urban, peri-urban, and agricultural land use (and in places, forestry). It is likely that the cumulative effects of pastoral and urban land use, river engineering for flood protection and water abstraction are contributing to the state of water quality and ecology in the Hutt River, but it is difficult to partition effects based on existing monitoring data which is not specifically designed to assess the effects of flow modification.

Additional monitoring of a suite of water quality and ecological variables in the Hutt River was conducted for seven years (in the summer-autumns of 2011/12 to 2017/18) to assess the potential effects of a reduced minimum flow at the Kaitoke weir. Minimum flow fell from 0.6 m^3/s to 0.4 m^3/s for approximately 21 days between March and May 2013. For context, this increased the percentage of MALF-7d allocated from 57% to 72% at the Kaitoke weir, also, the 1:100-year naturalised low flow for this site is 0.7 m^3/s. In 2013, low flows did not limit fish passage as measured by hydraulic surveys. There was, however, evidence of changes in specific macroinvertebrate taxa below the weir; for example, decreases in %EPT taxa were associated with successively dryer conditions, lower river flows and longer accrual periods supporting increased periphyton biomass.

Across the seven years, monitoring showed that temperature diurnal variability and maximums increased downstream and over time probably related to solar radiation, air temperature and water depth. Nutrient concentrations and diurnal variability in dissolved oxygen increased downstream, neither of which were directly linked to low flows but may be influenced by low flows decreasing dilution capacity and supporting periphyton proliferation. Seasonal flow conditions had an overall effect on benthic macroinvertebrate community composition, but there were no upstream-downstream patterns in community metrics associated with abstraction at the Kaitoke weir. Periphyton biomass marginally increased immediately below the weir and blooms regularly occurred along the length of the Hutt River associated with prolonged low flows and nutrient enrichment. Cyanobacteria blooms also regularly occurred along the length of the Hutt, but not in all years and not in 2013 during reduced minimum flow conditions. Trout abundance was not linked to low flows and instead annual variability was more likely driven by the occurrence of floods. No native fish monitoring was undertaken. There has been no analysis of the combined dataset from all seven years to look at patterns among response variables in relation to flows.

A better understanding of patterns in water quality and ecology have been gained as a result of consent monitoring in the Hutt River. There is also some discharge consent monitoring data available for the Wainuiomata River, but very limited information on the Orongorongo. Comparisons above and directly below the Kaitoke weir show the likely effects of reduced low flows throughout the river (e.g. changes in benthic communities). However, the data are not enough to characterise the effects of flow allocation throughout the Hutt River. At least 10 years of data (and probably more) is likely to be needed to detect the effects of flow modification in the setting of natural stochastic variation in river flows. Even then, it will be difficult to partition the direct and indirect effects of flow reduction based on current metrics.

I accept based on a conceptual understanding of flow effects, that the Hutt and eastern rivers are already experiencing moderate to major changes in ecology as a result of the confounding effects of water extraction and other land use stressors. The hydraulic habitat is altered as a result of abstraction, but we are unsure how this interacts with other stressors (such as habitat modification and nutrient enrichment) to affect biota and ecological processes. This can most likely be 'quantified' using models that predict benthic invertebrate productivity across the hydrograph (which can be run using existing data) and by refining a groundwater-surface water model to take into account nutrients and temperature (probably requiring a targeted investigation across the flow regime). An updated groundwater-surface water model is likely to help understand patterns in primary productivity (e.g. periphyton) which in turns effects higher order components of the food web (ecosystem health), but also directly impacts on the recreational value of the rivers.

I recommend further investment is directed towards quantifying the potential risk of future flow allocation in the context of climate change predictions. If more water is needed for public water supply in the future, then a scenario model needs to be developed to understand what the best water take scenario is (i.e. the combined extraction from eastern and Hutt River surface and groundwaters) to minimise the environmental effects on these river systems.

In summary, priorities for characterising the effects of water abstraction on rivers in the Whaitua te Whanganui-a-Tara include:

Targeted studies:

- Improved estimation of natural flows to provide a benchmark to determine the magnitude of flow change due to water abstraction (I understand GWRC are currently undertaking this modelling).
- Development of a benthic process model (e.g. Ian Jowett's SEFA) using the naturalised hydrograph and an abstraction hydrograph; the difference between the two provides an estimate of the effect of abstraction on benthic invertebrate productivity in addition to invertebrate habitat. This modelling would provide greater understanding of the effects of flow alteration on the life supporting capacity of the river.
- Refining a groundwater-surface water model to take into account nutrients and temperature to provide greater understanding of the effect of surface or groundwater abstraction on primary drivers of benthic communities [I understand that GWRC and WWL are currently revising the Hutt Aquifer Model (HAM3), which incorporates flux between the lower Hutt River and Waiwhetu aquifer system, to incorporate improvements in the 3D conceptual geological model and allow for water quality modelling and uncertainty analysis (HAM5)] . Ideally the model will be useful for both water quality and quantity modelling, including climate change predictions.
- Undertake hydraulic habitat characterisation to validate and refine hydraulic habitat models. In the absence of long-term datasets characterising the distribution and abundance of biota throughout the rivers (e.g. native fish), habitat suitability models are the best tool available to estimate the effects of water abstraction on habitat.

Ongoing monitoring:

- Continue the monitoring of primary drivers with a focus on continuous data where possible (e.g. hydrology, temperature, dissolved oxygen, nutrients). This will support water quality and water quantity model development and provide a greater characterisation of the flow and habitat template. Consideration should be given to sites in the eastern rivers.
- Continue benthic community monitoring, where feasible, to maintain/provide a long-term dataset that could then be explored in relation to drivers. A minimum of 10 years of data (and more likely 20 years) is recommended to begin to detect the influence of flow modification compared to broad climatic influences. Monitoring could be in a reduced capacity, for example a targeted site(s) once a year for macroinvertebrates and restricted to periods of low flow for periphyton.
- Consider introducing weighted habitat sampling of macroinvertebrates in addition to riffle sampling. This will allow detection of overall change in abundance/diversity rather than focussing on flow-insensitive habitats. Likewise, explore flow-sensitive metrics as well as pollution-sensitive community metrics to help elucidate the relative influence of stressors on benthic communities.

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1. INTRODUCTION

1.1. Context

The Whaitua te Whanganui-a-Tara encompasses the area between the Remutaka ranges and the west coast and extends from the Akatarawa Saddle in the north to Cook Strait in the south (Figure 1). The whaitua can be divided into four sub-zones[1] that encompass the major river catchments present, including: a) Hutt River, b) Eastern zone including Orongorongo and the Wainuiomata rivers, c) Southern Coast and Western Coast stream catchments including Makara Stream, and d) Wellington Harbour stream catchments (Figure 1).

A Whaitua te Whanganui-a-Tara (WTWT) committee has been established to set freshwater objectives for the Te Whanganui-a-Tara catchments as part of Greater Wellington Regional Council's (GWRC) response to implementing the National Policy Statement for Freshwater Management (NPSFM 2014). To do so, the WTWT committee requires advice on the current state of the catchments' water quality and ecology and water quantity. Recent summary documents have been produced to address these information needs including:

- Greer M, Ausseil O 2018. Whaitua Te Whanganui-a-Tara River and stream water quality and ecology. Prepared for Greater Wellington Regional Council. Aquanet Consulting Limited, Palmerston North. 124 p plus appendices.
- Keenan L, Thompson M, Harkness M, Mzila D 2019. Whaitua Te Whanganui-a-Tara water quantity and allocation: state and trends. Greater Wellington Regional Council, Publication No. GW/ESCI-T-DRAFT, Wellington.

The WTWT committee also require guidance on the likelihood of effects of future resource management scenarios on the ecological, social, cultural and economic values in the Te Whanganui-a-Tara whaitua. To do this, panels of experts will be established to review the current state documents as well as new scenario information currently being developed.

A primary resource use in the Te Whanganui-a-Tara whaitua is the allocation of surface and groundwater for municipal water supply to the Wellington metropolitan area. Surface water is drawn from the Hutt River at the Kaitoke weir, just north of Upper Hutt, as well as from multiple weirs along the Wainuiomata and Orongorongo rivers. The Macaskill Lakes are used to supplement water takes in the Hutt River during periods of low river flow or high, sediment-laden, flow. Groundwater is drawn primarily from the Waiwhetu artesian aquifer at eight bore locations in the lower Hutt valley known as the Waterloo wellfield. An additional three bores at Gear Island provide supplemental supply.

[1] These sub-zones are potential, but not confirmed, freshwater management units.

Water allocation is subject to resource consents which ensure compliance with minimum flows and extraction volumes. A variation to the relevant Hutt River surface water allocation permit was granted in 2011 to allow maintenance of the Macaskill storage lakes. The variation allowed minimum flows below the Kaitoke weir to be reduced for a period of 3 years and included the implementation of a monitoring regime and a Hutt River Low Flow Management Plan. The subsequent monitoring has provided some information on the effects of water allocation on the ecology of the Hutt River. There were no monitoring conditions prior to the variation.

1.2. Purpose of this report

This report provides a review and synthesis of relevant monitoring information in relation to the cumulative effect of water abstractions on the Hutt, Wainuiomata and Orongorongo rivers. The review will be used primarily for the Whaitua te Whanganui-a-Tara but also for the ongoing operational management of the abstractions including informing consent conditions.

Specific questions addressed in this review include:

1. Considering the intensive Hutt River Ecological Monitoring Programme through seven consecutive summers to 2017/18, is the effect of the Kaitoke water abstraction on benthic communities of the Hutt River well characterised and is there any evidence to suggest that the adverse effects are any more than minor?
2. Considering the broader set of monitoring and investigation information available for the Hutt, Wainuiomata and Orongorongo rivers and the nature of the abstraction activity (in the context of other catchment pressures):
    a. Have sufficient data been collected and analysed to reasonably characterise the ecological effects of the abstraction activities on these rivers?
    b. Is there any evidence of sensitivity (to abstraction) in ecological metrics in any parts of the catchments that might be considered significant?
    c. Are there any gaps in the type of information available (including spatial/temporal resolution) that you consider important/fundamental to drawing conclusions about the effect of the abstractions?
3. Based on conclusions relating to the questions above, what monitoring and/or targeted investigations should either continue or be introduced in the future to confidently characterise the effects of the activity?

An economic analysis, of costs to the community or expected value derived from recommendations, is outside the scope of this report.

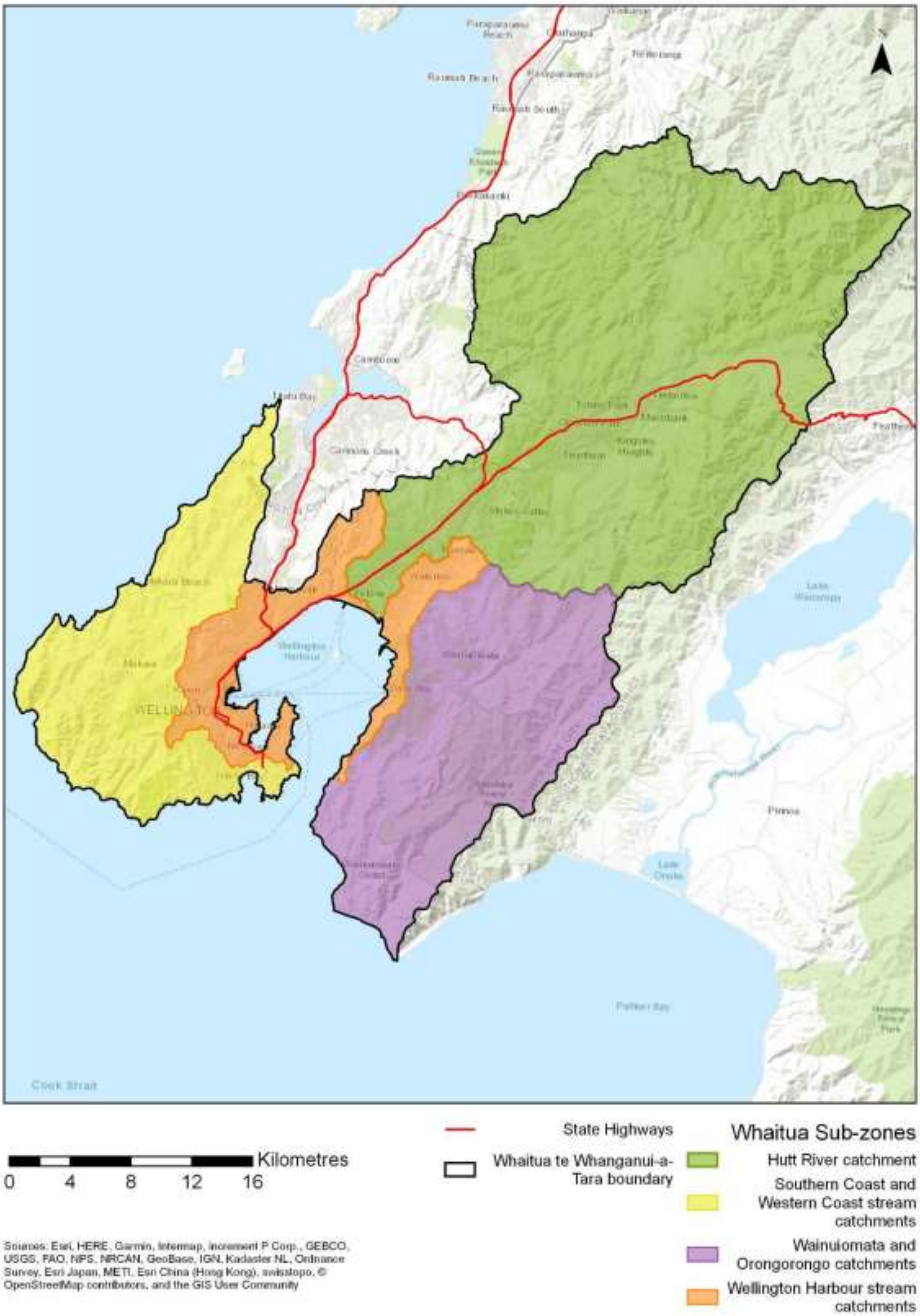


Figure 1. Map of Whaitua Te Whanganui-a-Tara with individual sub-zones identified. Reproduced from Greer & Ausseil (2018).

2. ECOLOGY AND FLOWS

2.1. Introduction

2.1.1. Background

The biota that lives in rivers and streams and associated biological processes are determined primarily by the flow regime (Palmer & Ruhi 2019). Understanding flow-ecology relationships is therefore necessary for determining the potential effects of flow allocation. Flow-ecology relationships are shaped by flows across the hydrograph (Biggs et al. 2008). 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 across the hyporheic boundary. 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.

The primary result of reduced low flows is the reduction in the area of wetted habitat available to in-stream biota. Further, as flow declines a greater proportion of the river becomes slower, which favours biota more suited to slow-water environments. For example, associated with relatively more slow-water habitat is a greater proportion of depositional areas, which favours biota suited to fine sediment environments (Dewson et al. 2007).

Low flows also affect the sources and exchange of material and energy in riverine ecosystems (Rolls et al. 2012). Reducing the transport capacity of the river has consequences for filter-feeding invertebrates, invertebrate drift and subsequently drift-feeding fish (Hayes et al. 2019). Water quality can be affected by very low flows which are less able to dilute suspended sediments, nutrients and/or contaminants. 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 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 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).

Wetted area and hydraulic-habitat heterogeneity can be determined by hydraulic-habitat characterisation and subsequent modelling (i.e. from width, depth and velocity measurements). Changes in benthic community composition and abundance as a result of flow alteration can be detected by measuring across the range of hydraulic habitats present and especially in slow-flow habitats, rather than just in riffles where macroinvertebrate and periphyton monitoring are designed to detect water quality effects. Diversity assessments also need to take account of multi-scale patterns (e.g. fish migration, off-channel refugia). In the absence of enough information to quantify flow-ecology relationships, modelling of habitat suitability and benthic processes can be used to predict changes in benthic community composition and abundance as a result of flow alteration.

2.1.2. Te Whanganui-a-Tara

Surface and groundwater flows in the Whaitua Te Whanganui-a-Tara are subject to water abstraction primarily in Hutt Valley and the Wainuiomata and Orongorongo catchments. The headwaters of these rivers (upstream of water abstraction) are designated as water collection areas and are actively managed by GWRC and Wellington Water Limited (WWL) via a water collection areas management plan (GWRC 2016). Active management aims to ensure that enough clean water is delivered to meet the Wellington region's needs with a minimal amount of intervention at the water treatment plants.

2.2. Hutt River

The Hutt River flows south from the Tararua Range via two branches which join at Kaitoke and then flows along the Hutt Valley to discharge into Wellington Harbour at Petone. The river has four major tributaries (the Pakuratahi, Mangaroa, Akaratawa and Whakatikei rivers) and several smaller tributaries with catchments along the Hutt Valley. The land cover in the Hutt catchment (650 km^2) includes native vegetation (66%), exotic forestry (13%), farmland (11%) and the urban areas (8%) of Upper Hutt and Lower Hutt cities. The 54-km long Hutt River is a predominantly cobble-bed river with a long history of flood protection and river control works. Cross-section surveys show channel widths are far less than their natural state, constrained by extensive bank protection with rock and willow, as well as local bedrock confinement (Hudson 2010). Floods no longer shape the physical habitat like they once did, and lateral channel and off-channel connectivity is spatially limited.

2.2.1. Hydrology

Keenan et al. (2019) describe the hydrological system of the Hutt River as well as long-term state and trends in water quantity. The Hutt River and its tributaries have a significant degree of interaction with underlying groundwater resources which influences surface flow along the length of the river (Figure 2). River flow and rainfall infiltration from surrounding hills charges the shallow unconfined Upper Hutt aquifer system to a depth of 50 m. River flow is also the most significant contributor to the Lower Hutt groundwater system which comprises three main aquifers including the high yielding Waiwhetu Aquifer, which sits at 20 m to 30 m deep. This aquifer is recharged by the river just downstream from Taita Gorge but is then largely confined from the ground surface across much of the Lower Hutt valley floor.

River works for flood protection have altered the habitat template of the Hutt River, constraining the river to a more 'benign' channel form and hydraulic character. Significant groundwater interaction also shapes the hydrology of the river providing a more stable flow environment than might otherwise be observed in a hill-fed river system.

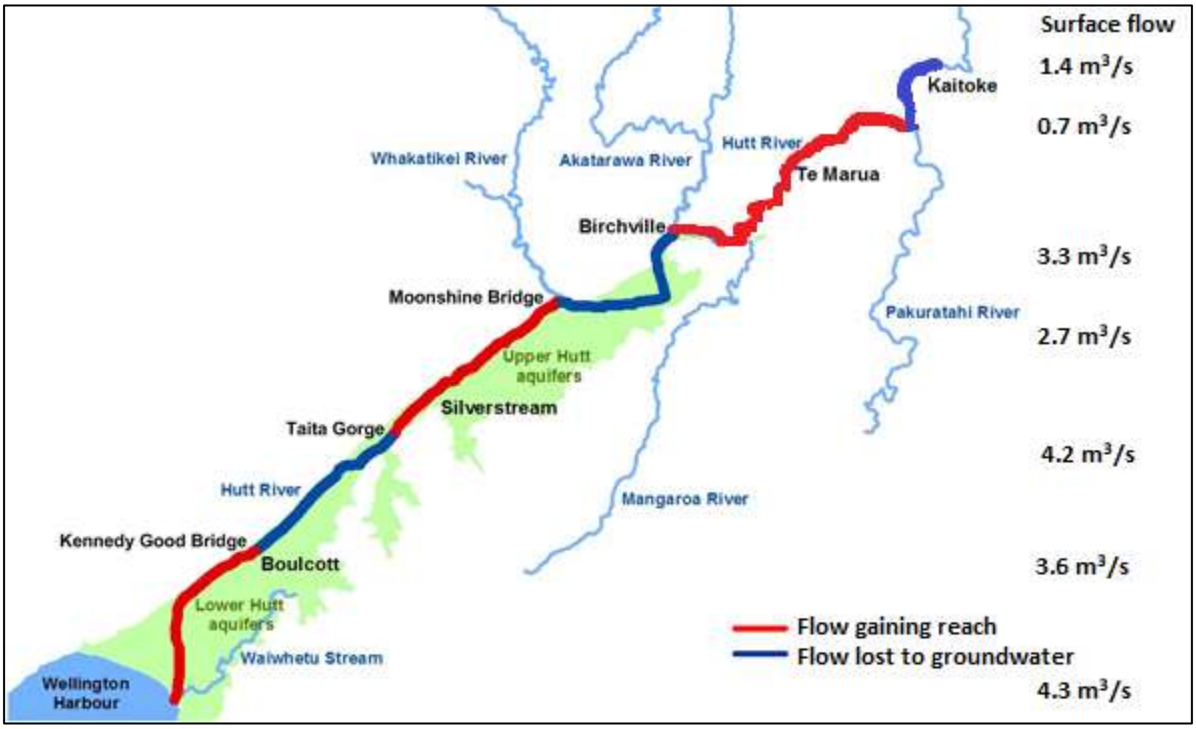


Figure 2. Schematic diagram of the Hutt River catchment and aquifers illustrating groundwater gaining and losing reaches and approximate surface flow from concurrent gauging during low flow conditions (adapted from Heath & Greenfield 2016 after Keenan et al. 2019).

Monthly mean flows in the Hutt River and its tributaries are, on average, lowest during summer and highest during winter, with the seasonal pattern strongest in flow gaining reaches (e.g. Hutt River at Birchville and Taita Gorge). The river is relatively flashy—Hutt River at Birchville has 28.9 FRE3 events per year on average, the third highest return rate of 66 other rivers compared nationally (Duncan & Woods 2013); and predicted to be among the flashiest of all rivers nationally, excluding the west coast rivers of the South Island (Booker 2015).

Based on a 50-yr record (1968–2018), mean flow in the mainstem of the Hutt River ranges from 7.9 m^3/s at Kaitoke to 22.18 m^3/s at Birchville and 25.05 m^3/s at Taita Gorge. Mean annual 7-day low flow (7-d MALF) is 1.41 m^3/s at Kaitoke, 2.76 m^3/s at Birchville and 4.15 m^3/s at Taita Gorge (Table 1). Monitoring of flows began after the establishment of water takes for municipal supply; abstraction typically reduces flow by > 50% below the Kaitoke weir, which has a marked effect on flows at Birchville (25% estimated reduction in MALF-1d) and Taita Gorge (20% reduction in MALF-1d), and a diminishing effect further downstream as major tributaries contribute flow to the Hutt River (Hudson 2007).

Table 1. Flows and allocation in the Hutt River as in the proposed Natural Resource Plan.

	Mean flow (m^3/s)	**Mean annual 7-day low flow (m^3/s)**	**Default Allocation Amount (m^3/s)**	**Minimum flows (m^3/s)**
Hutt River			2.14	
Hutt River at Kaitoke	7.90	1.41		0.6
Hutt River at Birchville	22.18*	2.76*		1.2
Hutt River at Taita Gorge	25.05*	4.15*		

*Flow affected by upstream abstraction, primarily for public water supply.

While no long-term (50 y) trends in annual rainfall or flow have been observed, periods of higher rainfall and flow correlate to positive Interdecadal Pacific Oscillation (IPO) such as in the 1970/80s and the opposite in late 90s/2000s. Similarly, there is a tendency for more severe and frequent/longer low flow periods in the Hutt during negative phases of the IPO.

Climate change projections for Whaitua te Whanganui-a-Tara have a high range of uncertainty, but the anticipated effects on the hydrology of the Hutt River include a) an increased average air temperature of 1 °C by 2040 and 1–2.5 °C by 2090, which will probably lead to increased rainfall intensity (up by 5–15% by 2040 and 5–30% by 2090) affecting flood magnitude and frequency, and b) a decrease in summer and autumn rainfall, with increased drought intensity likely and decreased mean annual low flows by up to 40% by 2090 (Pearce et al 2017), and an average decrease in mean annual low flows of 10–20% (Mike Thompson, pers. comm).

2.2.2. Allocation and minimum flows

Minimum flow and water allocation limits for the Hutt River are outlined in the proposed Natural Resources Plan (pNRP) for the Wellington region. The minimum flow (Policy WH.P1) is 0.6 m^3/s at Kaitoke water supply intake and 1.2 m^3/s at Birchville. The total allocation amount for the Hutt River catchment management unit is specified in the pNRP as 2.14 m^3/s, but the current actual allocation (below median flow for river allocation) is 2.53 m^3/s (which equates to 59% of current estimated MALF-7d at Melling Bridge, the most downstream management point in the catchment). The pNRP allows for whichever is the greatest of the existing consented amount or the default allocation amount. The default core allocation limit (Policy P13) for rivers with mean flows of greater than or equal to 5 m^3/s (unless otherwise stipulated) is 50% of MALF, and the supplementary allocation is up to 50% of the portion of flow in the river above the median flow at the point of abstraction (as long as flushing flows are preserved). The pNRP (Policy P121) also specifies trigger groundwater levels in the Waiwhetu Aquifer for managing abstraction to avoid the risk of saline intrusion. Water levels should be maintained above 2.0 m above sea level at the foreshore, and abstraction should cease if water level in the aquifer falls below 1.7 m.

Minimum flows were predominantly based on an Instream Flow Incremental Methodology (IFIM) study carried out in the Wellington Region by Jowett (1993). The methods ensure an amount of instream habitat thought appropriate to sustain aquatic life (particularly fish) is retained. Jowett (1993) concluded that to retain two-thirds of instream (brown trout and general benthic invertebrate) habitat required 41% of observed MALF at the Birchville site (i.e. 1.13 m^3/s in 1993).

In a later IFIM study at three Hutt River sites, Harkness (2002) recommended a minimum flow of 1.55 m^3/s at the Taita Gorge site to retain two-thirds habitat suitable for trout. Harkness (2002) noted that given the groundwater interaction along the length of the Hutt River, a 1.2 m^3/s minimum flow level set at Birchville may not be equivalent to 1.55 m^3/s at Taita Gorge. Indeed, concurrent flow gauging showed that 1.2 m^3/s at Birchville corresponded to about 1.0 m^3/s at Taita Gorge. Further study to define the gains and losses to/from groundwater was recommended to help inform appropriate minimum flows.

Allocation limits specified in the pNRP are based on interim limits in the proposed National Environmental Standard on ecological flows and water levels (MFE 2008). They were introduced to the pNRP to address an absence of any pre-existing limits or catchment specific assessment to derive such limits. Ninety-nine percent of surface water allocations in the Hutt are for public water supply, providing 40% of total supply to Upper Hutt, Lower Hutt, Porirua and Wellington cities. Wellington Water Limited (WWL; a company owned by six councils representing Wellington, Porirua, Hutt, Upper Hutt and South Wairarapa) is responsible for public water supply. Most of the surface water for public supply is taken from the river at the Kaitoke weir, which was constructed in the 1950s along with the Te Marua Water Treatment Plant. The associated Macaskill storage lakes were built in the mid-1980s.

From 1968 to 2001, WWL was permitted to take all the water at the weir to a maximum of 100 megalitres per day (i.e. 1.16 m^3/s). Since 2001, WWL have been consented to abstract up to 150 megalitres per day (i.e. 1.74 m^3/s), with an instantaneous rate of no more than 1.85 m^3/s (i.e. 131% of current MALF-7d at Kaitoke), as long as a minimum residual flow of 0.6 m^3/s is maintained downstream of the Kaitoke weir. The 1:100-year naturalised low flow for this site was 0.7 m^3/s (Lew et al. 2000a).

For a period of three years (2011–2014), the permitted minimum residual flow was reduced from 0.6 m^3/s to 0.4 m^3/s to allow for upgrades to the storage lakes. As part of the consent conditions to reduce the minimum residual flow, WWL were required to prepare and implement a Hutt River Low Flow Management Plan and a Hutt River Ecological Monitoring Plan (see Section 2.2.3). There was no ecological monitoring requirement in place prior to this time.

The groundwater trigger levels for the Waiwhetu Aquifer were informed by a three-dimensional numerical groundwater flow model developed by Gyopari (2014). The model predicts that the natural aquifer throughflow at the coast has been reduced by between 80 and 90% by surface and groundwater abstraction. Further, current abstraction results in significant drawdown (2 m+) of the Waiwhetu Aquifer increasing drawdown from the Hutt River by around 45%, leading to a total river loss of 60–100 ML/day (i.e. 1.16 m^3/s). Submarine discharge from the aquifer is also estimated to be reduced by 50–70% during water abstraction.

The model was further used to show that the sustainable water yield from the Aquifer is predicted to drop by 15% if a 0.75 m sea level rise occurs, and then by 31% for a 1.5 m rise. Sea level rise is predicted to increase by 0.12–0.24 m by 2040 and 0.36–0.98 m by 2090 (Pearce et al. 2017). Gyopari (2014) recommended further model uncertainty analysis and detailed exploration of the offshore submarine spring discharges to improve the predictability of groundwater resources[2]. Currently, 93% of groundwater allocations in the Hutt are for public water supply, providing 50% of the total supply to local cities on average but during dry periods this increases significantly to nearly 70%.

[2] It is my understanding that GWRC is currently updating the Hutt Aquifer Model in response to this recommendation and to improve water quantity and quality flux in the Lower Hutt River and Waiwhetu Aquifer.

Keenan et al. (2019) state that Hutt River surface water and connected groundwater allocation currently exceeds the allocation amounts specified in the pNRP (i.e. it is fully allocated). However, actual water use is usually below the allocation amount. For example, during periods when river flow was less than median flow from 2000 to 2018, the average abstraction rate was 1.16 m^3/s, which was 67% of the consented rate of 1.74 m^3/s at the Kaitoke weir. Similarly, the average groundwater abstraction rate from the Waiwhetu Aquifer during 2000 to 2019 was 76% of the consented groundwater allocation (which may have been in part due to the need to meet seawater intrusion of groundwater restrictions). Long-term average water take for public supply is likely to remain significantly below 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.

Finally, permitted (non-consented) takes are estimated to be less than 1% of MALF on average, but there may be hot spots of demand in developing farmland areas where reticulated supply is absent, such as in the Mangaroa River catchment. A recent desktop model estimated that the theoretical maximum permitted takes (under the proposed GWRC Natural Resources Plan) for the Hutt River including all tributary catchments equated to an average rate of 0.23 m^3/s (Nation 2019). However, these estimates would only be realised if all parcels of land fully used all stock, domestic and other permitted water allowances at all times; therefore, they should be considered to substantially overstate actual permitted use. Actual permitted water use cannot be reliably quantified as they are neither registered with GWRC nor metered. In general, the demand for water is likely to increase significantly as a result of climate change.

2.2.3. Stream water quality and ecology

Regular regional council monitoring

Greer and Ausseil (2018) provide an overview of the stream water quality and ecology of the Hutt River by comparing available water quality and ecology data to i) proposed Natural Resources Plan outcomes, ii) established guideline values from the literature and iii) the National Policy Statement for Freshwater Management 2014 attribute states.

Stream water quality and ecology data had been collected by GWRC as part of the River Water Quality and Ecology (RWQE) monitoring programme (7 sites), the GWRC Recreational Water Quality monitoring programme (6 sites), and Hutt City Council’s *E.coli* monitoring programmes (6 sites). Variables included water quality data (i.e. temperature, dissolved oxygen concentrations, nutrient concentrations, faecal containment levels and total suspended solid concentrations), periphyton, cyanobacteria, macrophyte and fine sediment cover data, and macroinvertebrates. Data from 2012 to 2016 were analysed to assess current state.

Greer and Ausseil (2018) concluded that ecosystem health in the upper reaches of the Hutt River and in the tributaries of Pakuratahi, Akatarawa and Whakatikei rivers, is currently excellent or near excellent. However, the lower reaches of the Mangaroa and Hutt rivers are moderately degraded, as indicated by macroinvertebrate community health and *E.coli* levels. The degradation of the Mangaroa River is primarily due to faecal contamination from livestock and eutrophication-driven periphyton growth, probably caused by agricultural land use, although elevated nutrients may be coming from peri-urban areas, groundwater and/or the Waipango Swamp/Peatland. The drivers of ecological degradation in the lower reaches of the Hutt River are not as clear. Apart from cyanobacteria blooms in the middle (and lower) reaches of the river where DIN concentrations are highest, the river is not overly impacted by nuisance periphyton blooms, fine sediment cover is generally low, and there is no evidence of nutrient or metal toxicity. There is evidence of faecal contamination from wastewater, making the lower river unsuitable for contact recreation at times.

The effects of flow modification due to abstraction and land use (e.g. reduced base-flows, increased flood frequency) as well as other unmeasured factors, including instream and riparian habitat degradation, stock access and river engineering activities, were not assessed by Greer and Ausseil (2018). It is likely that the cumulative effects of pastoral and urban land use, water abstraction and river engineering for flood protection are contributing to the state of water quality and ecology in the Hutt River.

No native fish monitoring has been routinely undertaken in the Hutt River. A summary of data from the New Zealand Freshwater Fish Database notes that 13 species of native fish have been found in the Hutt River and tributaries (between 2000 and 2017), eight of which are classified as at risk or threatened (Greer & Ausseil 2018). Suitable inanga spawning habitat has also been found in the lower reaches of the Hutt River. The Hutt and tributary rivers (Akatarawa, Mangaroa, Pakuratahi and Whakatikei) are all identified as important trout fishery rivers and spawning waters in Schedule I of the pNRP (Greer & Ausseil 2018). On average, 9172 angler days per annum are spent on the Hutt River, based on four national angler surveys conducted between 1994 and 2015 (Unwin 2016).

Targeted investigations

A focussed investigation of benthic cyanobacteria blooms (commonly referred to as ‘toxic algae’) by Heath and Greenfield (2016) provides further insights into the potential influence of flow modification on the ecological state of the Hutt River. *Microcoleus autumnalis* (previously known as *Phormidium autumnale*) was identified as the dominant cyanobacterium in the Hutt with expansive blooms frequently containing anatoxins. Flushing flows were identified as the key variable regulating *Microcoleus* abundance, with longer accrual (growth) periods between large flushes

(> 9x median flow events) associated with a greater magnitude of *Microcoleus* growth, but no relationship obvious for smaller flushes (> 3x median flow events).

Habitat suitability modelling showed that *Microcoleus* can grow in a wide range of flows and that water abstraction during summer low flows is unlikely to result in more suitable habitat for *Microcoleus* growth. However, a desktop analysis by Heath and Greenfield (2016) shows water abstraction during low flows may reduce the capacity of the river to dilute nutrient inputs, which are an important driver of *Microcoleus* bloom development.

The Pakuratahi and Mangaroa rivers as well as groundwater inputs upstream of Silverstream Bridge were identified as the largest sources of nitrogen to the Hutt River, with a 10-fold increase in dissolved inorganic nitrogen (DIN) levels between the Kaitoke weir (median 0.015 mg/L) and Silverstream Bridge (median 0.22 mg/L). During summer low-flows groundwater inputs were found to more than double the nitrogen loads in a 950-m reach above Taita Gorge. A preliminary desktop analysis suggested water abstraction at the Kaitoke weir may be contributing to a modest (1.4-fold) increase in Hutt River DIN concentrations downstream of both the Pakuratahi and Mangaroa rivers.

2.2.4. Wellington Water consent monitoring

Assessment of effects from reducing residual flow at Kaitoke

Data were collected in the Hutt River by WWL from 2010 to 2018 to assess the potential effects of reduced flows on stream water quality and ecology. Conditions of the variation to the resource consent granted to WWL in 2011 (for reducing the residual flow downstream of the Kaitoke weir from 0.6 to 0.4 m^3/s) included the submission and implementation of the Hutt River Ecological Monitoring Plan (HREMP), annual reporting of the annual monitoring, and immediate reporting of any unusual adverse monitoring results. Monitoring and management regimes were proposed to remain in place for the duration of the water permit (i.e. until the consent expiry date of 17 August 2036), but were suspended in March 2019 pending external review and are due for reinstatement in 2020.

Monitoring included a range of parameters at up to 7 sites (Figure 3), including:

a. water quality parameters (temperature, dissolved oxygen (DO)) at 5 sites measured at 2-weekly intervals from 1 November to 30 April
b. nutrients (dissolved reactive phosphorus (DRP), nitrate-nitrogen (NO_3-N) and ammoniacal nitrogen (NH_3-N)) at 6 sites measured at 2-weekly intervals from 1 November to 30 April
c. macroinvertebrates (and associated physical habitat assessment) in riffle habitat at 5 sites at least once per year between 1 November to 30 April during certain flow conditions

d. deposited sediment assessment in run habitat at 5 sites alongside macroinvertebrate sampling
e. periphyton assessment (including cyanobacteria and filamentous algae) at 7 sites between 1 November to 30 March during certain flow conditions.

Consent conditions also required a repeat of the fish passage survey outlined in Hudson (2010) and the collection of water depths, substrate size and cyanobacteria cover at 7 sites during certain flow conditions to develop cyanobacteria and filamentous algae habitat preference curves.

Figure 3. Hutt River Ecological Monitoring Plan monitoring locations (from Tonkin & Taylor 2012).

The lower residual flow limit of 0.4 m^3/s downstream of the Kaitoke weir was not required during the summer 2011/12 period due to average to above average minimum flows (Tonkin & Taylor 2012). However, the summer did experience a sustained low flow period from 7 to 23 February, which resulted in greater diurnal fluctuations in temperature and DO at downstream locations (e.g. Taita, Te Marua, Birchville) compared to upstream (e.g. Kaitoke), associated with increased benthic cyanobacteria photosynthesis.

Over the summer-autumn of 2012/13, the low flow limit of 0.4 m^3/s downstream of the Kaitoke weir was triggered from 11 March to 2 May 2013 (Tonkin & Taylor 2013).

Longitudinal patterns in DO and temperature were very similar to those observed in the previous summer. During the prolonged periods of low flow, periphyton biomass and cover (including cyanobacteria) did progressively increase at all sites; biomass remained below benthic biodiversity guideline value (50 mg chl-*a*/m^2) above the Pakuratahi River confluence and exceeded it a third of the time below, whereas cyanobacteria mat coverage did not exceed 20% in the upper river, but coverage increased in a downstream direction and frequently exceeded 20% at Silverstream Bridge. Nevertheless, cyanobacteria coverage did not exceed the 'action' level of > 50% at any site during the 2012/13 summer survey. Monitoring identified changes in macroinvertebrate community composition over time, but changes were relatively minor close to the weir and greater further downstream associated with urban and agricultural effects. There was a change in the macroinvertebrate community observed at median (0.818 m^3/s), low (0.62 m^3/s) and very low (0.42 m^3/s) flow throughout the summer, but there was less within-site variability than between-site variability regardless of flow conditions. Errors in flow estimates occurred so that flow may have been as low as 0.33 m^3/s downstream of the Kaitoke weir at times. A survey confirmed no low flow barriers for fish.

The third and last summer-autumn (2013/14) where the reduced low flow limit was in place, was an average flow year and flow did not fall below 0.6 m^3/s downstream of the Kaitoke weir (Tonkin & Taylor 2014). Patterns in DO and temperature were very similar to those observed in the previous years; with maximum water temperature of 25.3 °C and maximum DO of 123% observed in late February at the Taita Gorge site, but this did not coincide with low flow. Temperature, DO and nutrients were consistent with historical SOE monitoring results. There were no significant differences in the number and diversity of invertebrates immediately upstream and immediately downstream of the abstraction point, but macroinvertebrate metrics suggested a decline in stream health downstream of the Pakuratahi River confluence. There was relatively less periphyton or cyanobacteria observed in 2013/14 compared to previous years; cyanobacterial mat cover was below the MfE alert level 20% at sites H1 to H7 on all occasions and did not reach the > 50% coverage trigger specified for cyanobacteria toxicity testing at any site over the monitoring period (Tonkin & Taylor 2014).

Based on relatively consistent results from the first four years of monitoring, water nutrient sampling was reduced from biweekly to monthly and the number of sites reduced from 7 to 5 in the summer of 2015/16 (Tonkin & Taylor 2016). Issues with temperature and DO logger calibration became apparent in 2014 through to 2016, making it difficult to confirm that 2015/16 was warmer than previous years. Both 2014/15 and 2015/16 were relatively dry years, but the lower number of flushing flows in the lower river over the 2015/16 summer compared to 2013/14 and 2014/15 may explain the higher levels of periphyton and toxic cyanobacteria observed. Patterns in macroinvertebrates were consistent with previous years. Tonkin & Taylor (2016) concluded that "Monitoring over the past five summers has shown that the increased water take at the Kaitoke weir in the 2012/13 summer did not result in any significant deviation from the patterns observed in other years under normal low flow conditions."

By 2017/18 (the last of seven summer-autumns before consent monitoring was suspended), water quality measurements were undertaken at only 4 sites (Wellington Water 2018). A maximum water temperature of 31.3°C and maximum DO of 164% was observed in late January at the Taita Gorge site. Despite the high DO concentrations (associated with periphyton photosynthesis), minimum DO levels did not fall below critical levels (i.e. 7-day mean minimum of 5 mg/L). Nutrients continued to show patterns of increasing concentrations downstream. Whilst flow often receded close to 0.6 m^3/s downstream of the Kaitoke weir, there were 8 'flushing flows' (3x median flow events) during summer. Sediment and periphyton levels were generally lower than previously observed, probably due to flushing flows. Macroinvertebrate metrics suggested poor ecological status downstream of Mangaroa confluence.

From 1999 to 2018, annual drift dive surveys of large and medium size trout in Wellington rivers have been undertaken by Fish & Game to explore the relationship between trout abundance and the frequency and extent of river control works in the Hutt, Waikanae and Otaki rivers. The data have been analysed in two relevant reports. Pilkington (2016) illustrated a general positive trend in trout numbers in the Hutt River in the last 18 years with a lack of large floods in recent years supporting good recruitment and survival. Hudson (2018) illustrated longitudinal variability in medium and large trout abundance in the Hutt River, possibly due to differential migration, and a link between trout abundance and flow variability (i.e. floods) associated with broad-scale climatic patterns, which was evident across large gravel-bed rivers in the Wellington region.

Following seven years of consent monitoring sampling, Tonkin & Taylor (2018) concluded that the effect of water abstraction on the Hutt River ecology was well characterised and there was little additional benefit or justification for ongoing monitoring. Further, the similarity in trout abundance patterns over time in the Hutt, Waikanae and Otaki rivers showed that factors other than the Low Flow Management Plan were important in determining trout abundance.

Assessment of effects from supernatant discharge at Te Marua

Data were collected in the Hutt River by WWL from 1995 to 2018 to assess the potential effects of supernatant discharge on stream ecology. Supernatant is discharged into the river from the Te Marua Water Treatment Plant (WTP) only after it has been demonstrated that all discharge standards are achieved, including a requirement for 'no detectable residual chlorine' (Stantec 2018a). Substrate composition, periphyton and macroinvertebrate community composition were measured above and below (at a total of 3 sites) the WTP discharge. There were no significant differences in metrics observed above and below the discharge. Also, there are no apparent trends in metrics associated with river flow at time of sampling. Metric results show excellent ecosystem health at all sites.

2.3. Wainuiomata and Orongorongo rivers

The Wainuiomata catchment area is approximately 130 km^2 with some urban areas (4.5% catchment area) in the headwaters including the township of Wainuiomata, indigenous forest (65% catchment area) predominantly within the GWRC managed Wainuiomata-Orongorongo Water Collection Area, and pasture in the lower valley (9.5% catchment area). Other land cover includes gorse/broom (18.2%) and exotic forestry (3%).

The Orongorongo catchment is approximately 90 km^2 and is dominated by indigenous forest (95% of catchment area), predominantly within the Rimutaka Forest Park or the GWRC-managed Wainuiomata-Orongorongo Water Collection Area, with some gorse/broom (2.5%) and pasture (2%) in the very lower reaches of the valley.

2.3.1. Hydrology

River flow is driven by rainfall infiltration from surrounding hills as there are no known significant groundwater systems in the Wainuiomata and Orongorongo rivers. Monthly mean flows are, on average, highest during winter and lowest in summer and early autumn. Mean flow in the Wainuiomata River ranges from 0.9 m^3/s at Manuka Track to 2.33 m^3/s at Leonard Wood Park, and in the Orongorongo River at Truss Bridge it is 1.16 m^3/s (Figure 4; Table 2). Based on a 35-yr record, the mean annual 7-day low flow is 0.18 m^3/s at Wainuiomata at Manuka Track, 0.29 m^3/s at Leonard Wood Park and 0.32 m^3/s at Orongorongo River at Truss Bridge (Keenan et al. 2019).

Table 2. Flows and allocation the Wainuiomata and Orongorongo rivers as in the proposed Natural Resource Plan.

	Mean flow (m^3/s)	**Mean annual 7-day low flow (m^3/s)**	**Default Allocation Amount (m^3/s)**	**Minimum flows (m^3/s)**
Wainuiomata River			0.18	
Wainuiomata River at Manuka Track	0.9	0.18		0.1
Wainuiomata River at Leonard Park Wood	2.33	0.29		0.3
Orongorongo River			0.95	
Orongorongo River at Truss Bridge	1.16	0.32		0.1

No overall trends in low flow magnitude and frequency were detected for the Wainuiomata River using data records for the available period (late 1970s or early 1980s to 2018), but there was a strong connection between negative IPO phases and frequent and prolonged low flows (Harkness 1998; Keenan et al. 2019). Climate change projections for the eastern catchments are the same as for the Hutt River and include a) an increased average air temperature of 1 °C by 2040 and 1–2.5 °C by 2090, which will probably lead to increased rainfall intensity (up by 5–15% by 2040 and 5–30% by 2090) affecting flood magnitude and frequency, and b) a decrease in summer and autumn rainfall, with increased drought intensity likely and decreased mean annual low flows by an average 20% and up to 40% by 2090.

2.3.2. Allocation and minimum flows

Minimum flow and water allocation limits for the eastern rivers are outlined in the proposed Natural Resources Plan (pNRP) for the Wellington region (Table 2). The minimum flow (Policy WH.P1) for Wainuiomata River is 0.1 m^3/s at Manuka Track (i.e. 56% of MALF-7d) and 0.3 m^3/s at Leonard Wood Park (i.e. 103% of MALF-7d). For Orongorongo River at Truss Bridge the minimum flow limit is set at 0.1 m^3/s (i.e. 31% of MALF-7d). The default allocation amount specified in pNRP is 0.18 m^3/s for Wainuiomata River and tributaries and 0.095 m^3/s for Orongorongo River and tributaries, but the current actual allocation (below median flow for river allocation) is 0.8 m^3/s. The default allocation limit (Policy P13) for rivers with mean flows of less than 5 m^3/s is 30% of the MALF.

Minimum flows were predominantly based on an Instream Flow Incremental Methodology (IFIM) study carried out in the Wellington Region by Jowett (1993), although neither river was surveyed as part of the study. Both a subsequent IFIM study on the Wainuiomata River by Harkness (2003) and a review of that study by Hay (2011) recommend higher minimum flows based on regional habitat suitability models for brown trout; 0.42 m^3/s and 0.322 m^3/s, respectively. However, both suggest further on-site data from the Wainuiomata be collected to develop a river-specific model[3].

The Wainuiomata and Orongorongo rivers provide approximately 10% of the municipal water supply for the Wellington metropolitan area; 99% of surface water allocation in these catchments is for public water supply, which is abstracted from the river's headwaters (Keenan et al. 2019). In 1878 an earth dam was constructed on the Wainuiomata River, and a pipeline laid to Wellington. In 1912 the Morton Dam was constructed, and a water treatment plant installed in 1964. By the late 1980s this system had reached the end of its useful working life; Morton Dam was decommissioned and emptied in 1993 and a new treatment plant was built. River

[3] I note that the base IFIM survey data from 2002 could not be located for the Hay (2011) review but is now available for further analysis.

water is now collected by intakes in the Wainuiomata River and tributary George Creek (Lew et al. 2000b). A weir intake was commissioned on the Orongorongo River in 1921, with subsequent intakes added over the years on tributary rivers (Lew et al. 2000c).

Figure 4. Location of water quantity monitoring sites in the Wainuiomata and Orongorongo rivers. Recreational water quality site (yellow dot) and state of environment monitoring sites (orange dots) are also shown (adapted from LAWA; www.lawa.org.nz).

WWL are permitted to take a maximum of 60 megalitres per day (i.e. 0.69 m^3/s), with an instantaneous rate of no more than 0.8 m^3/s, from the 'Wainuiomata River' which includes combined abstraction from Wainuiomata and its tributaries (Upper George Creek and Lower George Creek) and Orongorongo River and its tributaries (Big Huia Creek, Little Huia Creek and Telephone Creek). This is not physically possible, and 0.46 m^3/s is the maximum amount available in the waterways (i.e. all the flow between minimum flow and median flow is consented to be abstracted). Further consent stipulations include maximum daily and instantaneous abstractions as outlined in Table 3.

Table 3. Consent conditions for Greater Wellington Water allocation from the Wainuiomata River (Consent No. WGN00201 [20552]) and Orongorongo River (Consent No. WGN00200 [20540]).

Location	Condition
All	Maximum daily abstraction rate is 0.69 m^3/s
	Maximum instantaneous abstraction rate is 0.8 m^3/s
Wainuiomata	Maximum daily abstraction rate is 0.46 m^3/s
Manuka Track	Up to 0.4 m^3/s can be abstracted when flow is between 0.1 and 0.5 m^3/s
	0.4 m^3/s plus 50% of the flow can be abstracted when flow is above 0.5 m^3/s (up to the maximum of 0.8 m^3/s)
Upper George Ck	Maximum daily abstraction rate is 0.116 m^3/s
	Maximum instantaneous abstraction rate is 0.12 m^3/s
Lower George Ck	Maximum daily abstraction rate is 0.174 m^3/s
	Maximum instantaneous abstraction rate is 0.175 m^3/s
Orongorongo	Maximum daily abstraction rate is 0.46 m^3/s
Big Huia Ck	Maximum daily abstraction rate is 0.23 m^3/s
	Maximum instantaneous abstraction rate is 0.232 m^3/s
Little Huia Ck	Maximum daily abstraction rate is 0.05 m^3/s
	Maximum instantaneous abstraction rate is 0.05 m^3/s
Telephone Ck	Maximum daily abstraction rate is 0.05 m3/s
	Maximum instantaneous abstraction rate is 0.05 m3/s

Current estimates are that abstraction currently reduces the MALF in the Orongorongo River at Truss Bridge by 56% (0.14 m^3/s current MALF and 0.32 m^3/s natural (no abstraction) MALF). In the Wainuiomata River at Leonard Wood Park abstraction is estimated to reduce MALF by 24% (0.38 m^3/s current MALF and 0.29

m^3/s natural (no abstraction) MALF). However, these estimates require further investigation (Keenan et al. 2019)[4].

It is difficult to assess the actual versus allocated water takes for the eastern catchments because the WWL consent specifies a maximum combined rate for the take from both rivers. The relationship between the minimum flows in the mainstem rivers and their tributaries is unknown. As such, it is possible that considerable extraction could occur from tributaries. Further, Keenan et al. (2019) state that "the actual abstraction from the Wainuiomata River sometimes, but not always, exceeds the allocation amount in the pNRP" based on an analysis of the 2000 to 2018 abstraction data.

2.3.3. Stream water quality and ecology

In their overview of stream water quality and ecology of the Whaitua Te Whanganui-a-Tara, Greer and Ausseil (2018) analysed a limited amount of data from the eastern catchments. Data were collected by GWRC as part of the River Water Quality and Ecology (RWQE) monitoring programme (3 sites), the GWRC Recreational Water Quality monitoring programme (1 site), and Hutt City Council's (HCC) *E. coli* monitoring programmes (2 sites). Variables were the same as those measured in the Hutt River, including water quality (i.e. temperature, dissolved oxygen concentrations, nutrient concentrations, faecal containment levels and total suspended solid concentrations), periphyton, cyanobacteria, macrophyte and fine sediment cover data, and macroinvertebrates.

Greer and Ausseil (2018) concluded that ecosystem health in the very lower reaches of both the Orongorongo and Wainuiomata rivers was slightly degraded as indicated by periphyton and macroinvertebrate assessments. These indicators probably reflect local agricultural impacts via nutrient and sediment pollution, particularly in the Wainuiomata River. It is difficult to determine the relative effects of agricultural or urban influences (from Wainuiomata township) given only one monitoring site. Greer and Ausseil (2018) conclude that recreational values are not impaired in either river, with low faecal contamination or cyanobacteria proliferation. However, Wainuiomata River at Richard Prouse Park often has public warnings in place due to *E. coli* levels (Mark Heath, GWRC, pers. comm). Most of both catchments are forested upstream and expected to be in excellent condition as reflected by monitoring results from the Wainuiomata River at Manuka Track site.

No native fish monitoring has been routinely undertaken in the Wainuiomata and Orongorongo rivers by Greater Wellington Regional Council. A summary of data from the New Zealand Freshwater Fish Database notes that six species of native fish have been found in the eastern rivers (between 2000 and 2017), four of which are classified as at risk or threatened (Greer & Ausseil 2018). Suitable inanga spawning habitat has

[4] I understand that GWRC are currently refining estimates of naturalised flows for these rivers.

also been found in the lower reaches of the Wainuiomata River, which is available sporadically when the river mouth is open. There is no suitable inanga spawning habitat in Orongorongo River. The Wainuiomata and Orongorongo rivers are both identified as important trout fishery rivers in Schedule I of the pNRP, and the Wainuiomata is identified as an important spawning water (Greer & Ausseil 2018). On average, 1277 angler days per annum are spent on the Wainuiomata River, based on four national angler surveys conducted between 1994 and 2015 (Unwin 2016), making it the third most popular trout fishing river in the region.

2.3.4. Wellington Water consent monitoring

Assessment of effects from water discharge into George Creek

Data were collected to assess the potential effects of discharging water from the Orongorongo River into George Creek which is a tributary of the Wainuiomata River. Water from the Orongorongo is gravity fed via a 5.6-km pipeline to a mini-hydro turbine and then to the Wainuiomata WTP. When the WTP is not operating the water is discharged into George Creek below the turbine. Habitat and macroinvertebrate community composition were measured above and below the discharge point from 2009-2017. The 2017 survey results show no difference in metrics and generally excellent ecosystem health in George Creek, as has been observed since 2009 (Stantec 2017).

Assessment of effects of discharge from the Wainuiomata WTP

Data were collected from 1998–2018 to assess the intermittent discharge of supernatant, partially and fully treated water from the Wainuiomata WTP to the Wainuiomata River. In 2018, macroinvertebrates metrics (e.g. MCI) indicated generally excellent ecosystem health, above and below the WTP discharge (at a total of 3 sites), which has generally been observed since 1998 (Stantec 2018b). Periphyton cover was relatively low in 2018 but has varied dramatically since monitoring began (e.g. 5–80% cover) and cyanobacteria is always present. There are no apparent trends in metrics associated with river flow at time of sampling.

Further, fish sampling was undertaken between 2002 and 2012 to assess the effects of discharge from the Wainuiomata WTP into Wainuiomata River (Death 2012). The non-migratory dwarf galaxias dominated fish populations observed at 3 sites. Other species often found included longfin eel and brown trout, and species rarely found included redfin bully, koaro, lamprey and shortfin eel. There was no effect of the discharge on fish populations, but the physical barriers imposed by two dams present appear to restrict access for some species. For example, trout are absent or in very low numbers above the upper dam and present below, whereas dwarf galaxias are in very high numbers above the upper dam and rare or absent below the lower dam.

3. SUMMARY AND RECOMMENDATIONS

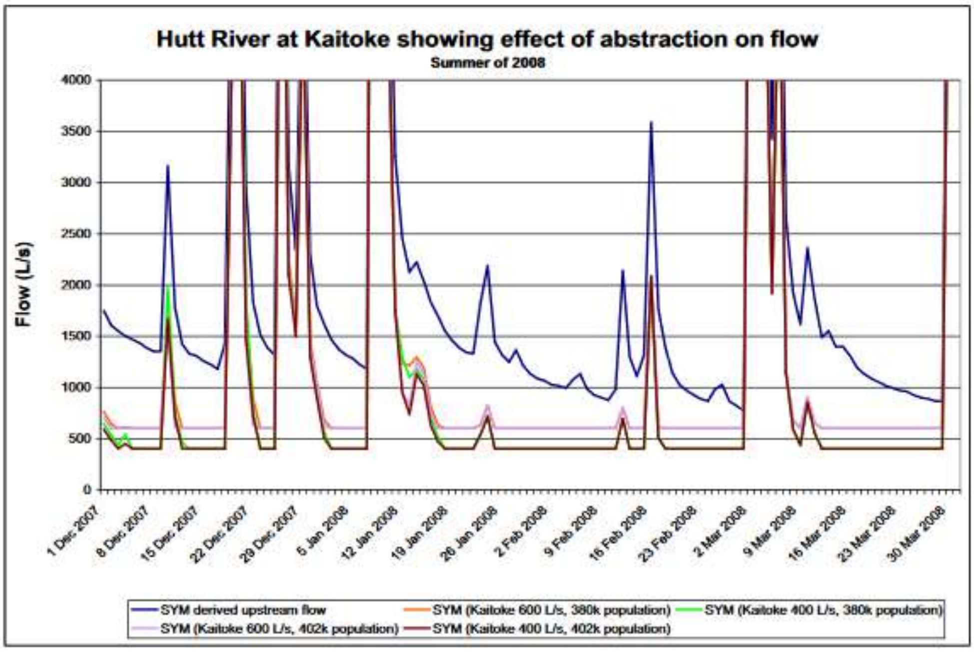
3.1. Hutt River

3.1.1. State of the Hutt River

Long term datasets are invaluable for characterising the ecology of rivers. In the Hutt River, 50-yr flow records show no systematic or significant change or trends over that period. However, the influence of broad-scale climatic patterns on river hydrology is apparent with higher rainfall and flow during positive Interdecadal Pacific Oscillation (IPO) and more frequent, longer and lower low flow periods during negative phases of the IPO. Likewise, 18-yr trout survey records show the similar effects (i.e. flood effects) of broad-scale climatic patterns on total abundance in the Hutt and other rivers in the region. More recent datasets, from the last 10-15 years, show spatial variation in water quality and ecology in the Hutt River and tributaries with very good condition in the headwaters and increasing degradation (moderate to poor condition) downstream associated with agricultural and urban land use. Land-use effects on stream health are most likely via increased nutrient loading and faecal contamination from livestock and stormwater, as well as significant habitat modification via flood control. However, it is also likely that the modified flow regime, due to land use and water abstraction from both surface and groundwater, is confounding the effects of pollutants. It is difficult to partition the effects of interacting stressors using existing datasets; however, cumulative effects are likely to be greatest during periods of low flow (i.e. during negative IPO phases).

3.1.2. Short-term reduction in minimum flow (2011-2014)

The summer of 2012/13 was towards the end of a 15-yr long negative phase of the IPO with preceding years having below average annual rainfall. As such, any effect of flow reduction would be expected to be amplified in these conditions mainly by increased duration of low flows—which is an effect of the large flow allocation. However, in the context set above, it is not surprising that “the increased water take at the Kaitoke weir in the 2012/13 summer did not result in any significant deviation from the patterns observed in other years” (Tonkin & Taylor 2016), because it occurred for a relatively short time during a period of naturally low flows. Flow naturally recedes and very rarely falls below the minimum flow (Kaitoke consented minimum flow being very low at < 100 y return period). The allocation steepens the rate of flow recession and holds the flow at the minimum flow (flat lining) for various lengths of time, depending on the frequency of natural floods/freshes. In naturally dry years (e.g. negative IPO) flows are naturally lower for longer (lower frequency of floods/freshes in summer) and the low minimum flow and large allocation exacerbate the hydrological and potential ecological effects. However, the reduction in residual flow below the Kaitoke weir from 0.6 m^3/s to 0.4 m^3/s occurred for only about 21 days between 11 March and 12 April, punctuated by a 6-day rain event (McCarthy 2013). Also, the reduction was relatively small in comparison to flow alteration as a result of existing takes (e.g. Figure 5). As noted earlier by Goldsmith et al. (2010), this magnitude of reduction was not anticipated to significantly affect habitat suitability for trout, native fisheries, nor periphyton proliferation over and above that potentially caused by the 0.6 m^3/s minimum flow and allocation rate. As such, it is fair to conclude that the 2012/13 short-term reduction in low flow had no immediate significant effects on measured environmental variables.



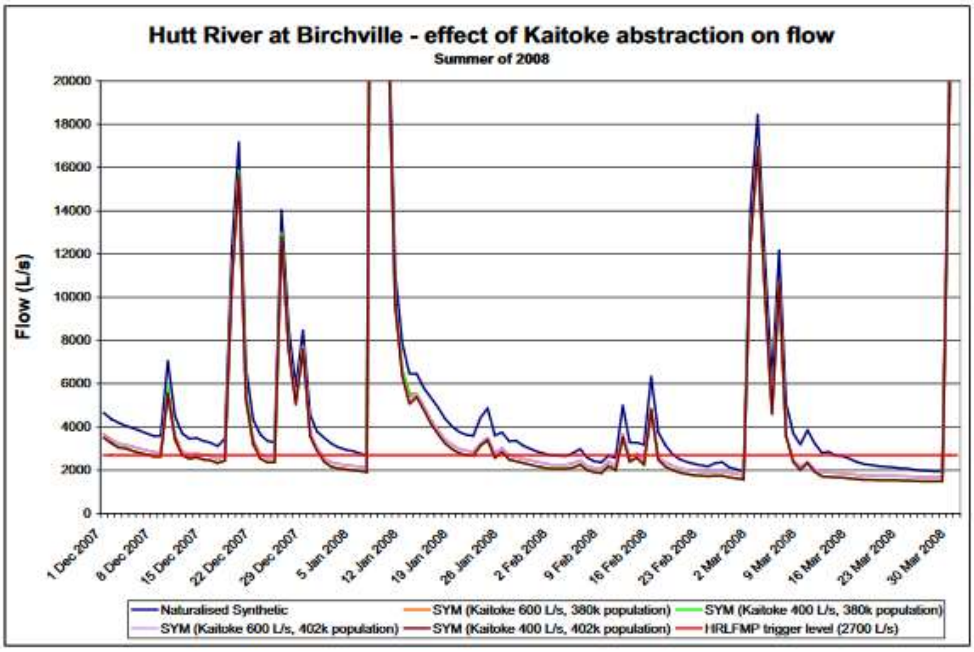


Figure 5. Upstream or naturalised flow, flow after current abstraction with 600 L/s and 400 L/s residual flow, and flow after abstraction to supply the future population for Kaitoke and Birchville (from Goldsmith et al. 2010).

3.1.3. The long-term effect of reduced minimum flows

Water abstraction under the current regime directly affects the flows between the median and minimum flows including the frequency, duration and magnitude of low flows in the Hutt and eastern rivers studied in this report (Figure 5). As previously identified by an expert panel, the main issues to consider from reduced low flows include a) reductions in habitat availability, b) low flow barriers to fish passage, c) water quality and risk of periphyton proliferation, and d) status of macroinvertebrates (Hudson 2010). Another issue to consider is the transport capacity of the river, in terms of fine sediment and organic matter (seston and macroinvertebrates).

Habitat availability

Hydraulic models have been used to illustrate the changes in habitat in the Hutt River associated with flow; at a minimum flow of 1.2 m^3/s at Birchville compared to MALF, wetted perimeter is reduced by 13% (18.1 m retained), mean depth by 10% (0.37 m retained), and mean water velocity by 27% (0.24 m/s retained) (Hudson 2007). Habitat suitability models have been used to predict the influence of such changes on food-producing habitat (general benthic invertebrate), native fish, trout and cyanobacteria. In most cases, the maximum amount of habitat available to species is predicted to be available at proposed minimum flows (Hudson 2007). This is because the preferences of native fish species present in the Hutt River basically span the range of depth and velocity conditions available. Likewise, *Microcoleus* grow in a wide range of conditions and decreasing flow is unlikely to be a key driver during accrual periods (Heath & Greenfield 2016). Habitat suitability models suggest that food-producing habitat and adult brown trout feeding are most sensitive to further flow reduction. However, it is worth noting that habitat suitability models are based on generic suitability curves (i.e. developed using data from other rivers) and adopt the assumption that low flow is the limiting factor. This is a reasonable assumption for assessing base life supporting capacity (i.e. habitat quantity) but does not consider the importance of other parts of the flow regime (such as freshes; particularly important in flashy rivers such as the Hutt), which determine habitat quality.

Habitat suitability models could be improved by refining hydraulic models for rivers in the Whaitua te Whanganui-a-Tara to provide better estimates of habitat quantity available at low flows for key sites. Refined hydraulic models could then also be used to develop benthic process-based models which consider multiple aspects of the flow regime and provide estimates of habitat quality.

To date, no surveys have been conducted to validate habitat suitability models in the Hutt River. Trout drift-diving surveys, while not designed to examine the effects of reduced flow, provide results which show a positive trend in trout numbers from 1999-2016, which suggests low flow is not driving the high spatial and temporal variability observed in trout abundance throughout the Hutt River (although this does not preclude a potential shift in mean abundance or growth rate associated with the long standing allocation rate, i.e. there are no pre-impact trout data). However, as noted by Hay (2007), it is uncertain whether a carefully designed and well-funded monitoring programme would detect any effects of a 20-30% reduction in habitat on fish populations.

Fish passage

Hudson and Harkness (2008) modelled contiguous and total passage for native fish and trout, and concluded it is unlikely that barriers to fish passage would occur under proposed minimum flows. Their conclusions were supported by a survey of fish passage at low flows in 2013 (Tonkin & Taylor 2013).

Water quality and periphyton proliferation

There are downstream patterns in water chemistry and temperature regimes in the Hutt River, but no evidence to suggest that these are influenced by low flow (Wellington Water 2018). Water temperature increases downstream as one would expect in a river continuum, although from 2012–2018 the average difference between Kaitoke and Taita Gorge in mean temperature was 3.1 °C and the maximum temperature difference was 5.7 °C, which seems large given the groundwater interaction present. Careful quality control of continuous logger data is needed to ensure this temperature variance is valid. Meanwhile, summer water temperatures are also increasing over time in relation to increases in average annual air temperature ($R = 0.595$; correlation between maximum water temperature at Taita Gorge and annual average air temperature in Wellington 2012–2018). Observed temperatures at Taita Gorge are likely to be causing thermal stress on some biota (Rutherford et al. 2015).

Spatial and temporal patterns in continuous dissolved oxygen (DO) saturation probably reflect benthic productivity, but periphyton is not measured at the same sites so there are no data to support this hypothesis. Regardless, DO concentration does not fall below critical levels (i.e. 7-day mean minimum of 5 mg/L). Nutrient concentrations also increase longitudinally down the river with no measurable link to low flow. However, Heath and Greenfield (2016) suggested that reduced low flows may reduce the capacity of the river to dilute nutrient inputs, which may contribute to periphyton proliferation. A better understanding of water quality and temperature relationships with low flow probably requires a better understanding of the interaction with groundwater along the length of the river.

Macroinvertebrates

Macroinvertebrate monitoring to date shows either the effects of seasonal change throughout the summer or the influence of pollutants. The data are not useful for assessing effects of water abstraction. This is because methods and metrics have focussed on riffle flow habitats and metrics designed to indicate 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. Exploring benthic and drifting invertebrate data at trout drift-diving sites, as well as temperature and periphyton dynamics, would help in determining why trout are differentially distributed throughout the Hutt River, and would help in understanding the effects of flow modification on macroinvertebrate and trout distribution.

3.1.4. Recommendations

Life supporting capacity

In a hierarchy of flow effects on river biota, floods dominate long-term patterns (e.g. Hayes et al. 2018). While water abstraction in the Hutt River currently has very little influence on flood magnitude (although I note the pNRP provides opportunity for significant supplementary allocation—50% of volume above median flow, providing flushing flows are preserved), current abstraction does directly affect the flows between the median and minimum flows including the frequency, duration and magnitude of low flows. Median to low flows provide the life supporting capacity of rivers (in terms of space (habitat) and food supply—they ensure contiguous wetted habitats for biota and key ecological processes). Currently it is estimated that minimum flows retain 87% of wetted perimeter (relative to MALF at Birchville), then this is probably a relatively minor effect on community and population biomass and hence life supporting capacity. The effect, of course, also needs to be defined in terms of duration as well as magnitude (i.e. the portion of an average year, or dry year, that the wetted area (or flow) is reduced by X%). This then needs to be interpreted with respect to the recovery time of benthic communities (i.e. time taken to (re)colonise channel following floods/freshes).

BITHABSIM or the benthic process model in SEFA (System for Environmental Flow Analysis; Ian Jowett's environmental flow assessment computer package) could be used to model the effects of the Hutt River water abstraction and minimum flow regime on the productivity of benthic invertebrates. It receives input from an example hydrograph and a habitat (weighted usable area (WUA)) vs flow relationship for a target invertebrate taxon (e.g. *Deleatidium*) and tracks the effects of floods (bed disturbance and wetting) and drying on benthic habitat; it also takes account of accrual to predict average habitat productivity (a modified WUA index interpreted as 'realised WUA' versus 'potential WUA'). The model can be run on a naturalised hydrograph and an abstracted hydrograph, and the difference between average WUA between these scenarios is an estimate of the effect of abstraction on benthic invertebrate productivity (or on productive invertebrate habitat).

A coarser assessment of effects of abstraction on invertebrates could be achieving by comparing benthic invertebrate WUA sustained by the naturalised median flow (or summer median flow) and an abstracted median flow. This is commonly done with benthic invertebrate habitat represented by the 'food producing' and '*Deleatidium*' habitat suitability criteria.

Potential risk versus realised effects

I disagree that the effect of the Kaitoke water abstraction on benthic communities of the Hutt River is well characterised. Detecting anthropogenic effects against the background of high natural, stochastically varying data is challenging. For example, Hayes et al. (2018) demonstrated how a minimum of 10 years of biannual quantitative fish sampling in relation to continuous abiotic data is needed to detect a > 20% change in species abundance, or 20–30 years of data would be needed to detect annual changes of 10% or less. Hence, based on sampling to date there is no evidence to suggest that the adverse effects are any more than minor because there are insufficient data to analyse the effects of reduced low flows on benthic communities in the Hutt River.

I think a significant long-term monitoring investment would be required to detect the effects of flow modification in the Hutt River. It would need to focus on flow-sensitive environments and metrics. The location of monitoring sites may need to be revised to consider groundwater interactions. Detecting the effects of low flows on benthic communities at the river scale will take considerable investment.

A more beneficial immediate investment may be to gain greater certainty around the potential risk of effects in the light of climate change predictions and water demand forecasts. Developing a benthic process-based model and collecting and analysing the data required to refine a groundwater-surface water model to include temperature and nutrient dynamics will help answer the question 'How far can the flow regime be modified before there is a risk of impact?' Ideally a groundwater-surface model would identify the predicted range in primary drivers (flow, nutrients, temperature) resulting from various allocation and climate change scenarios to help inform sustainable allocation limits in the face of cumulative effects. At a minimum, an improved aquifer model will help determine the optimal water abstraction regime to meet current and future water needs for public supply with least impact on river ecosystems.

Hence, in the absence of quantified flow-ecology relationships (realised effects), precautionary standards (based on the potential risk of effects) should be applied. Beca (2008) outline how the risk of abstraction depends on stream size and the species present in the stream, with higher risks of deleterious effects in small streams than in larger streams and rivers. However, an abstraction of more than 40% of MALF is considered a high degree of hydrological alteration irrespective of stream size, region or source of flow. When such a high degree of hydrological alteration is present then there is a high risk of deleterious effects and Beca (2008) recommend methods to determine ecological flow requirements for high risk rivers (e.g. 1D and 2D hydraulic habitat models, dissolved oxygen and temperature models, fish bioenergetics model, groundwater model, connectivity/fish passage assessment, periphyton biomass model).

The Beca (2008) recommended methods are contained within the Proposed National Environmental Standard on Ecological Flows and Water Level (MfE 2008). The proposed NES provides interim limits on alterations to flows and water levels to protect instream values, and these were used to inform default allocation limits in the proposed Natural Resources Plan (pNRP) for the Wellington region. There is a strong scientific and practical basis to the default limits outlined in MfE (2008)—until enough evidence is accrued to determine effects, then interim limits provide precautionary, expedient, and cost-effective guidelines.

Further, Richter et al. (2012) propose precautionary levels of flow alteration for environmental flow protection. Their presumptive flow standard was based on the ‘natural flow’ paradigm (so taking more than just low flows into account), supported by an international review of flow setting approaches and expert judgement based on retaining a percentage of natural flow. They advised that a high risk of moderate to major changes in natural structure and ecosystem functions accompanies daily flow alteration > 20%. High and moderate levels of ecological protection will be provided by limits that restrict daily flow alterations to < 10% and 11–20%, respectively. The Richter et al. (2012) presumptive flow standards may be overly precautionary, but with 40% of current MALF-7d at Taita Gorge already allocated and a possible 20% reduction in naturalised MALF-1d at Taita Gorge already realised, it is likely that the Hutt River is already experiencing moderate to major changes in ecology.

In the case of the Hutt River, some methods to determine ecological flow requirements for high risk rivers have been applied (e.g. hydraulic habitat models, groundwater model, connectivity/fish passage assessment, periphyton biomass model). It is my opinion that further effort could be made to gain greater certainty around the potential risk of effects in the light of climate change predictions and water demand forecasts (e.g. benthic process model, updated groundwater-surface water model).

3.2. Wainuiomata and Orongorongo rivers

Limited data for the eastern rivers make it difficult to partition the potential effects of flow allocation. However, these rivers provide the perfect opportunity to explore the relative effects of flow modification because abstraction occurs within a forested landscape. Current allocation is very high in relation to MALF and if any effects of flow modification are detectable, it would be during low flow periods in the catchments.

There is little evidence to suggest water abstraction has adverse effects on the water quality and ecology of the eastern rivers based on the limited range of variables monitored; however, there is also limited evidence that effects are minor. Not enough data have been collected and analysed to sufficiently characterise the ecological effects of the abstraction activities in these rivers. Fundamental gaps in information to draw conclusions include instream habitat modelling for these rivers; that is, it has not been undertaken on the Orongorongo River and there are questions around the data quality for the Wainuiomata modelling data. Further continuous water quality data will help place potential flow effects in the context of other key drivers of biotic patterns and ecological processes and at a minimum signal potential biotic stress.

In the absence of enough data, default limits are most suitable for application in these rivers and provide a buffer for future environmental changes, e.g. climate change predictions of longer drought episodes.

3.3. Conclusions

In respect of the specific questions asked in this report:

1. I do *not* consider that the effect of the Kaitoke water abstraction on benthic communities of the Hutt River is well characterised despite the intensive Hutt River Ecological Monitoring Programme (HREMP) through seven consecutive summers to 2017/18. This is because benthic communities in the Hutt River are determined by a hierarchy of effects where the natural habitat and flow template (i.e. braided gravel bed river with a flashy hydrograph and high groundwater interaction) has been subject to the cumulative stressors of land use and water abstraction (i.e. channelisation from flood protection works, nutrient and faecal contamination, and reduced flows). There are no measurements of the state of the river prior to anthropogenic modification, so there is no baseline to assess the magnitude of water abstraction effects. Attempts have been made to characterise the primary drivers through which cumulative stressors affect benthic communities, for example, hydrograph and habitat availability modelling, temperature, dissolved oxygen and nutrient/contaminant monitoring. Differences between upstream and immediately downstream of the Kaitoke water abstraction are evident in some of these drivers. The immediate effect of reduced flow due to surface water abstraction becomes less evident further downstream because of the buffering effects of increased run-off and groundwater interactions as well as a change in river morphology.

   There is evidence that benthic communities are affected by anthropogenic stressors along the Hutt River. However, data collected during the HREMP are unable to determine the relative influence of water abstraction (compared to other stressors) on benthic communities because the sampling methods and community metrics used focus on detecting the effects of eutrophication. I note that eutrophication is exacerbated by the flow-dependent flux of nutrients.

2. Considering the broader set of monitoring and investigation information available for the Hutt, Wainuiomata and Orongorongo rivers and the nature of the abstraction activity (in the context of other catchment pressures):
    a. I do not consider that enough data have been collected and analysed to reasonably characterise the ecological effects of the abstraction activities on these rivers, in particular the eastern rivers.
    b. There is evidence of sensitivity to the cumulative effects of abstraction and other land use stressors in ecological metrics along the length of the Hutt River, but not specifically to abstraction alone other than immediately below the Kaitoke weir. Evidence includes elevated nutrients and contaminants, increased temperature (although further data quality control is required to validate patterns), algal proliferation (including cyanobacteria) and poor macroinvertebrate community health.
    c. There are significant gaps in the type of information available (including spatial/temporal resolution) that I consider fundamental to drawing conclusions about the effect of the abstractions. These gaps are addressed in my recommendation below.

3. Based on conclusions relating to the questions above, I recommend the following:

- Targeted investigations:
    - Improved estimation of naturalised flows to provide a benchmark to determine the magnitude of flow change due to water abstraction (I understand GWRC are currently undertaking this modelling).
    - Development of a benthic process model (e.g. Ian Jowett's SEFA) using the naturalised hydrograph and an abstraction hydrograph; the difference between the two provides an estimate of the effect of abstraction on benthic invertebrate productivity in addition to invertebrate habitat. This modelling would provide greater understanding of the effects of flow alteration on the life supporting capacity of the river.
    - Refining a groundwater-surface water model to take into account nutrients and temperature to provide greater understanding of the effect of surface or groundwater abstraction on primary drivers of benthic communities [I understand that GWRC and WWL are currently revising the Hutt Aquifer Model (HAM3), which incorporates flux between the Lower Hutt River and Waiwhetu aquifer system, to incorporate improvements in the 3D conceptual geological model and allow for water quality modelling and uncertainty analysis (HAM5)]. Ideally the model will be useful for both water quality and quantity modelling, including climate change predictions.
    - Undertake hydraulic habitat characterisation to validate and refine hydraulic habitat models, particularly in the eastern rivers. In the absence of long-term datasets characterising the distribution and abundance of biota throughout the

rivers (e.g. native fish), habitat suitability models are the best tool available to estimate the effects of water abstraction on habitat.

- Ongoing monitoring:
    - Continue the monitoring of primary drivers with a focus on continuous data where possible (e.g. hydrology, temperature, dissolved oxygen, nutrients). This will support water quality and water quantity model development and provide a greater characterisation of the flow and habitat template. Consideration should be given to sites in the eastern rivers.
    - Continue benthic community monitoring, where feasible, to maintain/provide a long-term dataset that could then be explored in relation to drivers. A minimum of 10 years of data (and more likely 20 years) is recommended to begin to detect the influence of flow modification compared to broad climatic influences. Monitoring could be in a reduced capacity, for example a targeted site(s) once a year for macroinvertebrates and restricted to periods of low flow for periphyton.
    - Consider introducing weighted habitat sampling of macroinvertebrates in addition to riffle sampling. This will allow detection of overall change in abundance/diversity rather than focussing on flow-insensitive habitats. Likewise, explore flow-sensitive metrics as well as pollution-sensitive community metrics to help elucidate the relative influence of stressors on benthic communities.

Finally, there needs to be some long-term planning into how future water demands will be managed. If more water is needed for public water supply, then a scenario model needs to be developed to understand what the best water take scenario is (i.e. the combined extraction from eastern and Hutt river surface and groundwaters) to minimise the environmental effects on these river systems. From a policy perspective, the relevance of the concept of Te Mana o te Wai needs to be considered.

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