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ENVIRONMENTAL FLOWS AND ALLOCATION INVESTIGATIONS FOR SMALL STREAMS IN THE GREATER WELLINGTON REGION

ENVIRONMENTAL FLOWS AND ALLOCATION INVESTIGATIONS FOR SMALL STREAMS IN THE GREATER WELLINGTON REGION

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Prepared for Greater Wellington Regional Council

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EXECUTIVE SUMMARY

Greater Wellington Regional Council (the Council) commissioned Cawthron to provide advice on catchment-specific studies to determine sustainable ecological flow and allocation limits for small streams to support a proposed allocation change to the Regional Freshwater Plan in mid-2022.

A two-day site visit was undertaken to selected waterways in the Wellington region, and a review of existing hydrological and ecological material relating to those waterways. The waterways visited and assessed fell into two broad stream type categories—hill-fed streams (Wainui Stream, Turanganui and Tauanui rivers) and spring-fed streams (Parkvale Stream, Booths Creek, Dock Creek, Makoura Stream, Kuripuni Stream, 'Fleet Street' Stream, Tauherenikau Seepage Drain and Murphy's Drain). In hill-fed streams and spring-fed streams with little macrophyte growth, the channel morphology is the main characteristic that will control the hydrology. Spring-fed streams can be more hydrologically complex to assess where there is extensive instream growth of macrophytes across the channel. In these cases, flow is controlled by macrophyte biomass, i.e. the higher the biomass of macrophytes the greater the water resistance and the greater the control on water level.

This report provides a precis of information provided by the Council and observations made on the two-day visit to hill-fed and spring-fed catchments in the Greater Wellington region. We use these sources to identify hydrological information gaps to be addressed for meeting Council management objectives. In the report, each catchment is assessed with respect to the following key management questions:

- How sensitive are ecological values to change in flow regime at low flows?
- Is the current level of hydrological alteration (from abstraction) sustainable with respect to safeguarding ecosystem health?
- If not, what limits should be applied?

Secondary questions were:

- How sensitive are other instream values to change in flow regime at low flows?
- Is the current level of hydrological alteration (from abstraction) broadly consistent with the principles and hierarchy of requirements in the National Policy Statement for Freshwater Management 2020 and 'Te Mana o Te Wai'?

Advice is provided in the final section of this report, based on a stream type approach, to address hydrological and ecological information gaps.

For the Wainui Stream we recommend hydrological studies (proposed by Council staff and amended by us) that are necessary for understanding the degree of hydrological alteration due to current water abstraction. We also recommend studies on instream values, and on hydraulic geometry versus flow and instream habitat versus flow to help assess ecological

effects of current and future water allocation on fish populations in Wainui Stream and to inform minimum flow and allocation limits setting.

For the Turanganui and Tauanui rivers, we support the Council's initiatives to gain better information on the connectivity between surface water and groundwater for the Turanganui and Tauanui rivers. We also recommend studies on ecological values, hydraulic geometry versus flow and instream habitat versus flow

For the Wairarapa spring-fed streams with a low-moderate and high water allocation demand we recommend the Council obtains better estimates of flow statistics, current abstractions and longitudinal flow patterns, and better understanding of ecological values. Furthermore, for high allocation demand streams (i.e. Parkvale Stream/Booths Creek, Makoura Stream and Dock Creek) we recommend surveys and modelling to determine relationships between flow and hydraulic geometry (wetted width and mean depth) and dissolved oxygen.

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1. INTRODUCTION

1.1. Background

Greater Wellington Regional Council (GWRC) commissioned Cawthron to provide advice on catchment-specific studies to determine sustainable ecological flow[1] and allocation[2] limits for small streams to support a proposed allocation change to the Proposed Natural Resource Plan (PNRP) in mid-2022.

The work scope included a 2-day site visit to selected waterways in the Wellington region (Table 1) and a review of existing hydrological and ecological material relating to those waterways. The management objectives were the same for each catchment and revolve around answering the following primary questions:

- How sensitive are ecological values to change in flow regime at low flows?
- Is the current level of hydrological alteration (from abstraction) sustainable with respect to safeguarding ecosystem health?
- If not, what limits should be applied?

Secondary questions were:

- How sensitive are other instream values to change in flow regime at low flows?
- Is the current level of hydrological alteration (from abstraction) broadly consistent with the principles and hierarchy of requirements in the National Policy Statement for Freshwater Management 2020 (NPS-FM) and 'Te Mana o Te Wai'?

Table 1. Study streams in the Greater Wellington region requiring catchment specific studies to determine sustainable minimum flow and allocation limits.

Stream/River	Part of Wellington region	General description
Wainui Stream	Kapiti Coast	Hill fed, soft bottom
Tauanui/Turanganui rivers	Southern Ruamahanga Valley	Hill fed, gravel bed (hard bottom), significant groundwater exchange
Parkvale Stream/Booths Creek	Mid Ruamahanga Valley	Spring-fed, soft bottom, and water race exchange
Makoura/Kuripuni streams	Masterton	Spring-fed, soft bottom, urban/rural
South Featherston streams	Featherson/Lake Wairarapa	Spring-fed, soft bottom

[1] Focussed on minimum flows.
[2] Focussed on primary allocation.

In the NPS-FM, any freshwater management decisions must consider the concept of 'Te Mana o te Wai', i.e. the fundamental importance of water, and recognise that protecting the health of freshwater will protect the health and well-being of the wider environment (MfE 2020). There is a hierarchy of obligations under 'Te Mana O Te Wai' that prioritises:

a) first, the health and well-being of waterways and ecosystems,
b) second, the health needs of people
c) third, the ability of people and communities to provide for their social, economic, and cultural well-being, now and in the future (MfE 2020).

1.2. Considerations for assessing environmental flow and allocation limits for waterways

1.2.1. Environmental flow assessment and limits setting framework

Environmental flow assessment and the setting of minimum flow and allocation limits in New Zealand are guided by a well-documented framework based on values and risk (MfE 1998; Beca 2008; MfE 2008). The essence of the framework is that the greater the instream values and the greater the hydrological alteration, the greater the risk to instream habitat, ecosystem health and other instream values (e.g. mahinga kai and fishery amenity). When instream values are high and proposed minimum flow is low and/or allocation rate is high, greater effort should be spent on assessing environmental flow requirements. This requires the application of more complex ecological flow assessment methods that offer greater certainty in understanding ecological effects and greater precision in setting minimum flow and allocation limits (Beca 2008) (Appendix 1, Appendix 2). Conversely, when instream values are low, and/or the degree of flow alteration is low (relatively high minimum flow and low-moderate allocation rate) less complex methods can be justified for setting minimum flow and allocation rates—including default limits based on percentage of mean annual flow or other summary flow statistics. Default limits should be environmentally conservative to take account of uncertainty surrounding their potential ecological effects and to be consistent with Te Mana O Te Wai.

1.2.2. Default minimum flow and allocation limits

Default minimum flow and allocation limits serve two functions:

1. They provide a reference for assessing the degree of hydrological alteration that an abstraction regime presents and its risk of having more than minor effects on instream habitat, ecosystem health and other instream values.
2. They allow for environmentally conservative environmental flows and efficient water allocation where allocation demand is low to moderate and instream values are low to moderate. This allows abstractors to have access to modest quantities of water with minimal consenting costs.

The first function above can serve as a signpost for signalling when default limits can be safely applied and when more complex ecological flow assessment and limits setting methods should be applied—such as when high instream values and/or high allocation demand increases the risk of adverse effects on ecosystem health and other values.

Default minimum flow and allocation limits based on percentage of flow were recently reviewed and proposed for Otago (Hayes 2021; Hayes et al. 2021) (Appendix 1). We recommend these for GWRC for application to streams/rivers that have low to moderate instream values and/or low allocation demand.

1.2.3. Decision-making framework for environmental flow assessment and flow limits setting

A difficulty in values- and risk-based environmental flow assessments is determining where to start: how to determine the values of a waterway; what methods to apply to assess the flow requirements of the values; and then what level of environmental protection to employ in setting minimum flow and allocation limits.

In Figure 1, we present a high-level decision-making framework to guide thinking through the process towards setting environmental flow and allocation limits using stream types as our starting point (as set out in the River Environment Classification (REC) system (Snelder et al. 2010)). The framework is based on the values- and risk-based approach already mentioned and is relevant for addressing GWRC's management objectives for this project, presented to us as follows:

How sensitive are ecological values to change in flow regime?

The first consideration in assessing the sensitivity of ecological values to flow alteration is stream type (e.g. mountain, hill, lake, spring).

Shallow, gravel-bed streams (of hill source) with unconfined trapezoidal cross-sectional channel profiles are more sensitive to flow alteration than confined U-shaped spring-fed streams. The wetted width of U-shaped channels varies little with flow reduction until at very low flow it shrinks over the 'flat' bottom of the U. Furthermore, prolific growths of submerged and emergent macrophytes can control the water level in spring-fed streams, creating a back-water effect, resulting in wetted width, and depth, being even more insensitive to flow reduction, except in steeper gradient riffles and fast runs which do not have a downstream hydraulic control.

These characteristics mean that the same minimum flow and allocation limits applied to a spring-fed versus hill-fed stream are likely to deliver higher levels of protection for ecological values in the spring-fed stream.

The second consideration is the sensitivity of instream/ecological values to flow alteration. Habitat sensitivities to flow alteration vary among periphyton, benthic invertebrates, and fish taxa and life stages. Habitat for some benthic invertebrates can be highly sensitive to flow reduction over the median- to low-flow range in gravel-bed (hill-fed) rivers, and gravel riffles and fast runs, but unaffected by macrophyte back-water effects, in spring-fed streams. Among fish species, torrentfish, bluegill bully and adult trout habitat have the highest flow requirements and are most sensitive to flow reduction. Common smelt, īnanga and juvenile eel habitat has intermediate sensitivity to flow reduction, and large eel, common, upland and Cran's bully habitat is least sensitive to flow alteration.

Providing flow requirements of large eels shows the need to consider food requirements in addition to space (habitat) requirements of fish species. Deep water (in pools) and cover (large rocks and woody debris, and overhanging banks) are more important habitat considerations for large eels during daylight than water velocity (they prefer low water velocity and deep water). Hence, the diurnal flow-related habitat for large eels is usually found to be fairly insensitive to flow reduction. However, at night eels leave their diurnal refuge habitat and invade shallow runs and riffles in search of benthic invertebrate and small fish prey. Benthic invertebrate habitat in riffles and shallow runs is much more sensitive to flow reduction than large eel diurnal flow-related habitat. Therefore, it makes sense to take into account the flow requirements of benthic invertebrate habitat when assessing the flow requirements of large eels for informing minimum flow limits.

Ecosystem processes also have different sensitivities to flow alteration. Invertebrate drift flux can be very sensitive to flow reduction and is influenced by both the minimum flow and allocation limits (Hayes et al. 2016, 2018, 2020).

Is the current level of hydrological alteration (from abstraction) sustainable with respect to safeguarding ecosystem health?

In addressing this question, it is first important to consider definitions of 'sustainable', 'safeguarding' and 'ecosystem health'.

The Resource Management Act (1991) defines 'sustainable management' as managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic and cultural well being and for their health and safety <u>while</u>—

(a) Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonable foreseeable needs of future generations; and

(b) Safeguarding the life-supporting capacity of air, water, soil and ecosystems; and

(c) Avoiding, remedying, or mitigating an adverse effect of activities on the environment.

The concept of Te Mana O Te Wai in the NPS-FM stresses the original intent of the RMA (indicated by the insertion of 'while' in the above directive) that the life-supporting capacity of water and ecosystems, and the needs of future generations have primary importance in the management of water bodies. The RMA and NPS-FM provide no definition of life-supporting capacity and neither has one emerged from RMA case law. From an ecological perspective it could be argued that 'life-supporting capacity' refers to the capacity of a water body to support life in all its variety to survive and reproduce. The ultimate measures of the life-supporting capacity of water are the quality and quantity of life that it contains. In this respect life-supporting capacity is encompassed in the following definition of ecosystem health from the NPS-FM which is: suitable water quality, water quantity (extent and variability of water level or flow), habitat, aquatic life and ecosystem processes for sustaining indigenous aquatic life expected in the absence of human disturbance or alteration (before providing for other values); where 'aquatic life' means 'the abundance and diversity of biota …' and 'ecological processes' means 'the interactions among biota and their physical and chemical environment …'.

Words in provisions from the NPS-FM and RMA such as 'safeguard', 'protect', 'maintain' and 'sustain' used in the context of legal testing of environmental protection and effects are an awkward fit with how ecological attributes that are used to assess instream effects actually respond to flow alteration. 'Safeguard', 'protect', 'maintain' and 'sustain', without qualification, by definition, assume a binary or threshold relationship between an ecological response and the physical environment. For example, safeguarding literally means 'protecting' or 'keeping safe from harm'; it implies an element of 'precaution'.

While the above definitions fit comfortably with some aspects of water quality they do not with flow. Unlike lethal levels of toxicants, for example, which fail to safeguard/protect/maintain/sustain aquatic life, reduction in flow of small to moderate sized gravel-bed rivers inexorably diminishes instream life-supporting capacity, ecosystem processes, and habitat for some benthic invertebrates, some native fishes and trout, in a continuous manner over the median- to low-flow range. This diminishment of life-supporting capacity and ecosystem health continues with flow reduction until the river ceases flowing, or flows become so low that dissolved oxygen and/or temperature reach lethal levels, and life is extinguished in the affected locations.

The key point is that the responses of most ecological attributes to flow change are continuous, not binary or threshold, relationships. This means for instance that in any river there is no single minimum flow that provides for life-supporting capacity or ecosystem health, including the flow requirements of fish.

In respect of flow, decision makers are faced with the challenging task of setting minimum flow and allocation limits that maintain percentages of ecosystem health components (i.e. flow, habitat, life-supporting capacity, ecosystem processes and related values such as mahinga kai/fisheries). And, because of large uncertainties in ecology–flow and fishery–flow relationships, there is a low degree of precision in the environmental protection that a percentage of flow or a flow-related ecological attribute (including habitat indices) might actually provide for the instream value (e.g. a fish population or fishery). Consideration of uncertainty and low precision in ecological flow assessment, and in monitoring the effectiveness of environmental flow limits, requires caution to be exercised in setting minimum flow and allocation limits.

Now, back to the question: Is the current level of hydrological alteration (from abstraction) sustainable with respect to safeguarding ecosystem health?

In the absence of studies determining responses between flow and habitat and ecosystem processes that could inform an assessment of effects of current flow alteration for any given stream or Fisheries Management Unit, the default limits presented in Appendix 1 can serve as a first-cut filter for assessing whether current flow alteration is likely to be having less than minor effects and therefore be considered to be environmentally 'sustainable'. When current flow alteration exceeds those default limits, this should trigger instream flow investigations to determine non-linear responses of hydraulic geometry, habitat and perhaps ecological variables, with the complexity of the studies increasing with the importance of instream values and the degree of current, and potential future, hydrological alteration (Figure 1). Such relationships can provide a better (more accurate and precise) basis for assessing instream flow requirements, and the magnitude of effects of current flow alteration. Depending on the level of current flow alteration, they may reveal scope for reducing the minimum flow and/or further allocation; or they may confirm overallocation and justify management action to reduce overallocation over time. The greater precision offered by non-linear hydraulic geometry, habitat and ecological flow responses allows for more precise limits setting for more efficient apportioning of flow between the river (for maintaining a high level of ecosystem health) and water users.

Traditional assessments of the effects of hydrological alteration on ecosystem health have usually focussed on responses of hydraulic geometry variables (usually wetted width, but reach-averaged water velocity is also relevant) and physical habitat (suitable depths and velocities for various taxa and life stages) to reduction in flow. Periphyton, aquatic invertebrates and fish species/life stages have differing water depth, velocity and substrate habitat preferences, and habitat suitability curves/models have been developed for most of these. These suitability curves/models can be married with reach-scale hydraulic models to estimate non-linear responses of habitat to flow change to assist in assessing flow requirements of instream life/values to inform setting minimum flow limits. However, consideration of flow requirements of instream life/values should not necessarily be limited to hydraulic geometry variables and habitat; other flow-related attributes relevant to ecosystem health mentioned in the NPS-FM include water quality and ecological processes. An example of the latter is the seston and invertebrate drift transport capacity, which declines with flow reduction with adverse consequences for filter feeding invertebrates and drift-feeding fish (Hayes et al. 2016, 2018).

If not, what limits should apply?

Following from above, if current minimum flow and allocation limits exceed the default limits in Appendix 1, then minimum flow limits should be informed by desktop and/or instream investigations of instream values and responses of relevant flow-related variables to reduction in flow and flow variability. The investigations and limits setting process should follow the framework set out in Figure 1.

As already mentioned, the sensitivity of instream values depends on stream type and size (Beca 2008; and see Appendix 1). By starting the instream flow assessment and limits-setting process with water source stream types we are stratifying ecological flow assessments and limits-setting among streams with broadly different sensitivities to flow alteration in respect of channel geometry, instream habitat, physical and ecological processes. For example, spring-fed streams have stable flows throughout the year, often have U-shaped channels which render wetted width relatively insensitive to flow reduction—except at very low flows, and prolific emergent aquatic plants—which can have more control on water level than the longitudinal bed profile.

Once the values of a waterway have been determined, the next step is to prioritise the values and establish an overall value for the waterway (high, medium, low). For example, a small urban stream may be deemed to have some value for fish and water birds (e.g. eels, ducks), or aesthetics, in places, but because it has been highly modified (culverts, straightening, floodbank protection), and those modifications are unlikely to be reversed, its overall value may be deemed lower than otherwise (e.g. medium/low).

The effort in assessing habitat and ecological flow requirements and setting limits should reflect the values of the in-stream resources—the next step in the process (Figure 1) (i.e. more ecological assessment effort for limits setting where values are high).

Examples of desktop investigations of flow-related variables include modelling with NIWA's eFlows Explorer to assess the effects of flow alteration on hydraulic-geometry variables, generalised habitat and flow duration curves for ungauged streams/rivers. Examples of instream investigations include assessing effects of flow alteration on reach-specific flow duration curves, hydraulic geometry variables, habitat, dissolved oxygen and temperature, fish passage and ecosystem processes (e.g. drift flux). Studies may include simple observations and measurements (e.g. confirmation of whether a stream is flowing at low flow and its wetted width) or more usually, quantitative data gathering and modelling (e.g. hydraulic-habitat modelling with SEFA (System for Environmental Flow Analysis (Jowett et al. 2015)). These studies may be complemented with investigations of the diversity and abundance of species present to inform instream values assessment, assessment of ecosystem health at low flow, and whether fish populations, in particular, are likely to be space and food limited at low flow and hence sensitive to flow alteration.

When information from habitat and/or ecological flow responses is available, percentage change limits can be based on these rather than on the default percentage change in flow limits presented in Appendix 1. In these cases, minimum flows (or residual flows) that retain 90% of habitat available at the naturalised 7-day MALF in rivers with mean flows < 5 m^3/s, and 80% of habitat at the MALF in larger rivers, for benthic invertebrates and the most flow-demanding fish (such as native torrentfish, smelt and galaxiids, and introduced trout) are likely to be environmentally precautionary, consistent with Te Mana O Te Wai.

The minimum flow is the primary management lever for maintaining instream habitat at low flow. The allocation rate has less relevance to instream habitat, other than influencing the duration of habitat levels which become a less important consideration when the minimum flow has been set high enough to maintain a high level of low-flow habitat assumed to be naturally limiting fish populations. The allocation rate has more influence on benthic productivity (of periphyton and benthic invertebrates), though its influence on flood/fresh variability and duration of biomass accrual, and ecosystem processes such as invertebrate drift flux (drift transport capacity), which can reduce with flow over the median- to low-flow range and so is diminished by abstraction.

The proposed National Environmental Standard for Flows and Water Levels (MfE 2008) provides guidance on the flow duration effects of allocation, to complement the default limits presented in Appendix 1: A high degree of hydrological alteration is assumed to occur when abstraction increases the duration of low-flow conditions to 30 days or more, with moderate and low levels of hydrological alteration corresponding to increases of about 20 days and 10 days, respectively.

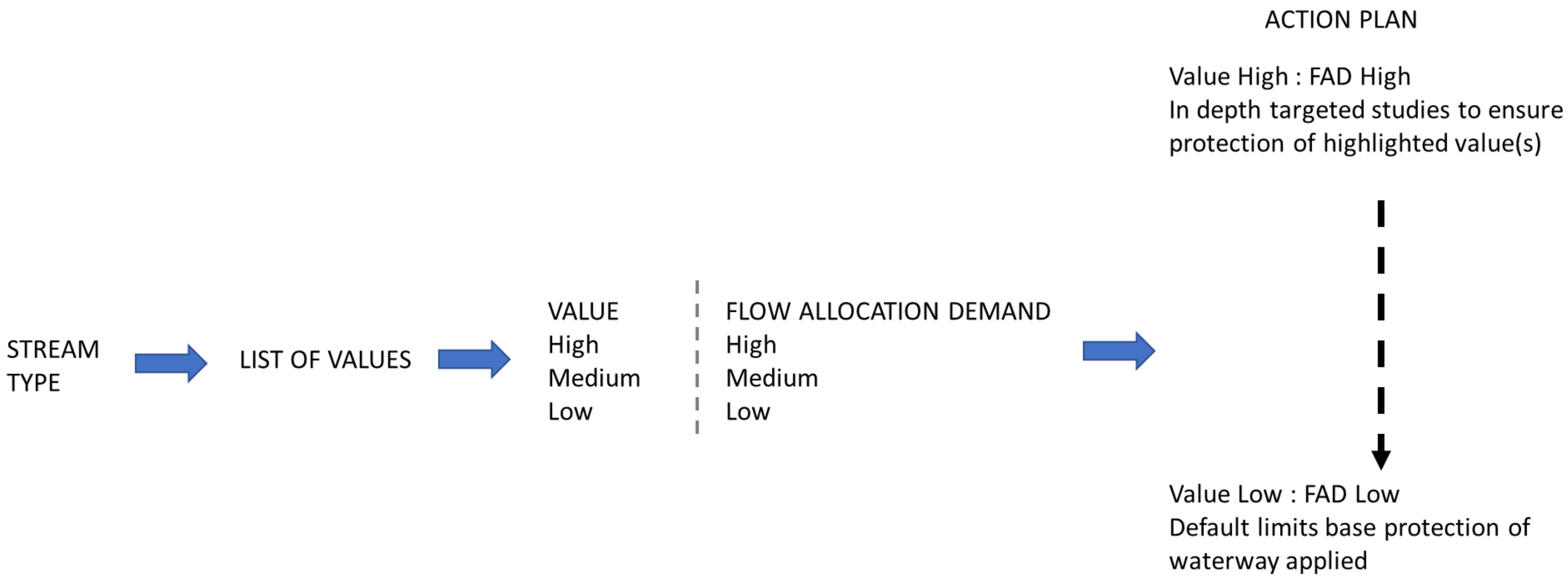

Figure 1. High-level decision pathway for guiding the process of ecological flow assessment and minimum flow and allocation limits setting founded on a values- and risk-based framework stratified by source-of-flow stream type (i.e. spring, hill, lake, mountain, wetland). FAD = Flow allocation demand.

2. APPLYING FLOW ASSESSMENT PATHWAYS TO WELLINGTON REGION WATERWAYS

The streams visited during the 2-day site visit can be classified into hill-fed and spring-fed waterways (see Table 1). The characteristics of these stream types under the River Environment Classification system (Snelder et al. 2004) are as follows:

Hill - Strong seasonal pattern: low flows in late summer, high flows in spring due to rainfall and snow melt. High to medium sediment loads depending on catchment geology and land use. Where the valley is broad so that the river channel is unconstrained, the channel morphology is characterised by unstable substrates and wide, active gravel bed flood plains.

Spring-fed - Stable flow regime with no or negligible flood flows. Low suspended solids and sediment load. High nutrient status from catchments draining pastoral areas, otherwise low nutrient status in hill and mountain areas.

2.1. Hill-fed waterways

In Figure 2 a decision pathway (based on Figure 1) is provided for setting flow limits for hill-fed streams. Although the main management objectives being addressed in this report are related to ecological values, the flow diagram has been set up such that two secondary objectives listed in Section 1.1 are considered (i.e. how sensitive are other values to change in flow regime at low flows, and is the current level of hydrological alteration (from abstraction) broadly consistent with the principles and hierarchy of requirements in the National Policy Statement for Freshwater Management 2020 (NPS-FM) and Te Mana o Te Wai).

When the overall value and flow allocation demand for hill-fed streams range from medium: medium to high: high (see Figure 2), targeted studies on specific values and flow-dependent attributes may include:

1. better defining values, i.e. their spatial and temporal extent
2. identifying flow dependent attributes and their relative importance, e.g. hydraulic geometry (wetted width, average depth and velocity), instream habitat (periphyton, invertebrates and fish), dissolved oxygen and temperature, invertebrate drift transport capacity, critical depths and widths for fish passage
3. assessing flow responses of the above attributes.

Hill-fed streams

List of values to be considered (not exhaustive)*

1. Mauri of the waterway
    - Safeguarding ecosystem health: water quality, water quantity (variability), habitat, aquatic life (abundance and diversity), ecosystem processes.
    - Protecting taonga species (aquatic & terrestrial) & threatened species

2. Needs of people
    - Water quantity & quality (drinking)
    - Mahinga Kai/fishing/harvesting for non-profit human consumption

3. Social, economic, & cultural well being:
    - Wāhi tapu
    - Fisheries (cultural/recreational/commercial)
    - Contact recreation (swimming, rafting/kayaking, fishing)
    - Abstraction for economic use

* Each value is ranked from 1 (high) to 5 (low) based on its importance

Value : FAD options	Action Plan
High : High	Targeted studies to determine habitat and ecological flow responses to inform minimum flow and allocation limits, or apply recommended default allocation limit (see detail in body of text below this figure)
Medium : Medium	Consider targeted studies to determine hydraulic geometry and habitat flow responses to inform minimum flow limits, or apply recommended default minimum flow limits; and apply recommended default allocation limit
Low : Low	Lowest level of protection, flows set so they do not breach national bottom limits (none available yet for flows) and/or apply recommended default flow limits

Figure 2. Decision pathway for guiding the process of ecological flow assessment and minimum flow and allocation limit setting founded on a values- and risk-based approach for hill-fed streams. FAD = Flow allocation demand. MALF is the naturalised 7-day mean annual low flow.

2.1.1. Wainui Stream

Catchment description

The Wainui Stream is 5.6 km long, and begins its journey from Mt Wainui. The upper catchment is covered in regenerating native forest, the middle third in exotic forest and farmland and the lower third is alluvial outwash fans and sand dunes as it reaches the sea (Hughes 2014). The lower catchment is being replanted in indigenous forest.

Table 2 summarises the low-flow hydrology of Wainui Stream and an ecological values assessment by GWRC.

Hydrology

Continuous monitoring of stream flow upstream of the Kapiti Coast District Council (KCDC) water intake was carried out for a short period in 1998/99. A synthetic flow record was derived by Keenan (2009), and the 1-day and 7-day mean annual low flows were estimated to be 14 L/s and 15 L/s, respectively (Table 2).

Several concurrent gaugings carried out since 1999 (with some accounting for the KCDC water take) have indicated that the stream loses flow as it emerges from the foothills, frequently dries out completely in the reach upstream of SH1, and then regains flow between SH1 and the beach (Figure 3).

These concurrent gaugings have been used to derive adjusted MALF estimates for the Wainui Stream at its mouth:

1. 22 L/s (1 day duration)
2. 25 L/s (7 day duration).

Median flow cannot be calculated with certainty due to a lack of measurement record. A generalised model estimate (from NIWA River Maps[3]) for the lower campground reach is 140 L/s.

Thompson (2019) provides further discussion about the flow characteristics, in particular the ephemeral reach adjacent to the KCDC take (just upstream of SH1).

[3] https://niwa.co.nz/freshwater-and-estuaries/management-tools/new-zealand-river-maps

Table 2. Summary of hydrology, hydrological and ecological values assessment, current abstraction pressures and predicted future pressures for the Wainui Stream. MALF estimates MALF estimates are naturalised. KCDC = Kapiti Coast District Council.

Wainui Stream	
Low flow hydrology	
Median flow (L/s)	Could not be calculated with certainty due to a lack of measurement record. Generalised model estimate (from NIWA River Maps) for the lower campground reach is 140 L/s.
7-day MALF (L/s) upstream KCDC water intake [a]	15 (25 at stream mouth - unverified)
1-day MALF (L/s) upstream KCDC water intake [a]	14 (22 at stream mouth - unverified)
Values assessment	
Ecological value	Very High
Fishery value (sport)	Low
Māori cultural value	High
Abstraction pressure	Moderate to High
Out of stream value (water use)	High
Abstractions [b]	
Current maximum allowable take (L/s)	25
Future prediction (L/s)	Possible increased demand or allocation expected if township of Paekākāriki grows

[a] The 1- and 7-day MALF are based on continuous flow monitoring data collected upstream of the KCDC water intake for a short period in 1998/1999. A synthetic flow record was derived by Keenan (2009), and the 1-day and 7-day mean annual low flows were estimated to be 14 L/s and 15 L/s, respectively. An updated assessment by Keenen (2021) concurred with the 7-day MALF of 15 L/s.
[b] The only consented current and future water take on the Wainui Stream is by KCDC for the Paekākāriki water supply. These are primarily bore water takes but have shallow ground-water connection to the stream.

Allocation and current abstraction regime

There is only one consented abstraction—the KCDC groundwater take upstream of SH1 for water supply to the town of Paekākāriki (Figure 4). With an estimated depletion of approximately 12 L/s (assuming pumping of 14 hours/day (Keenan 2021)), this equates to about 48% of naturalised 7-day MALF at the stream mouth, and 9% of naturalised median flow. Actual use is likely to be significantly less than consented, but the analysis of records has not yet been completed. Drying of the mid reaches in summer is accepted to be a natural event, although the effect of KCDC bore takes on the extent and magnitude of the drying is not well understood. Overall abstraction pressure is difficult to characterise owing to uncertainty over the actual use and depletion rate, but a precautionary view is one of moderate to high allocation. Under current plan provisions there is no further water available to allocate.

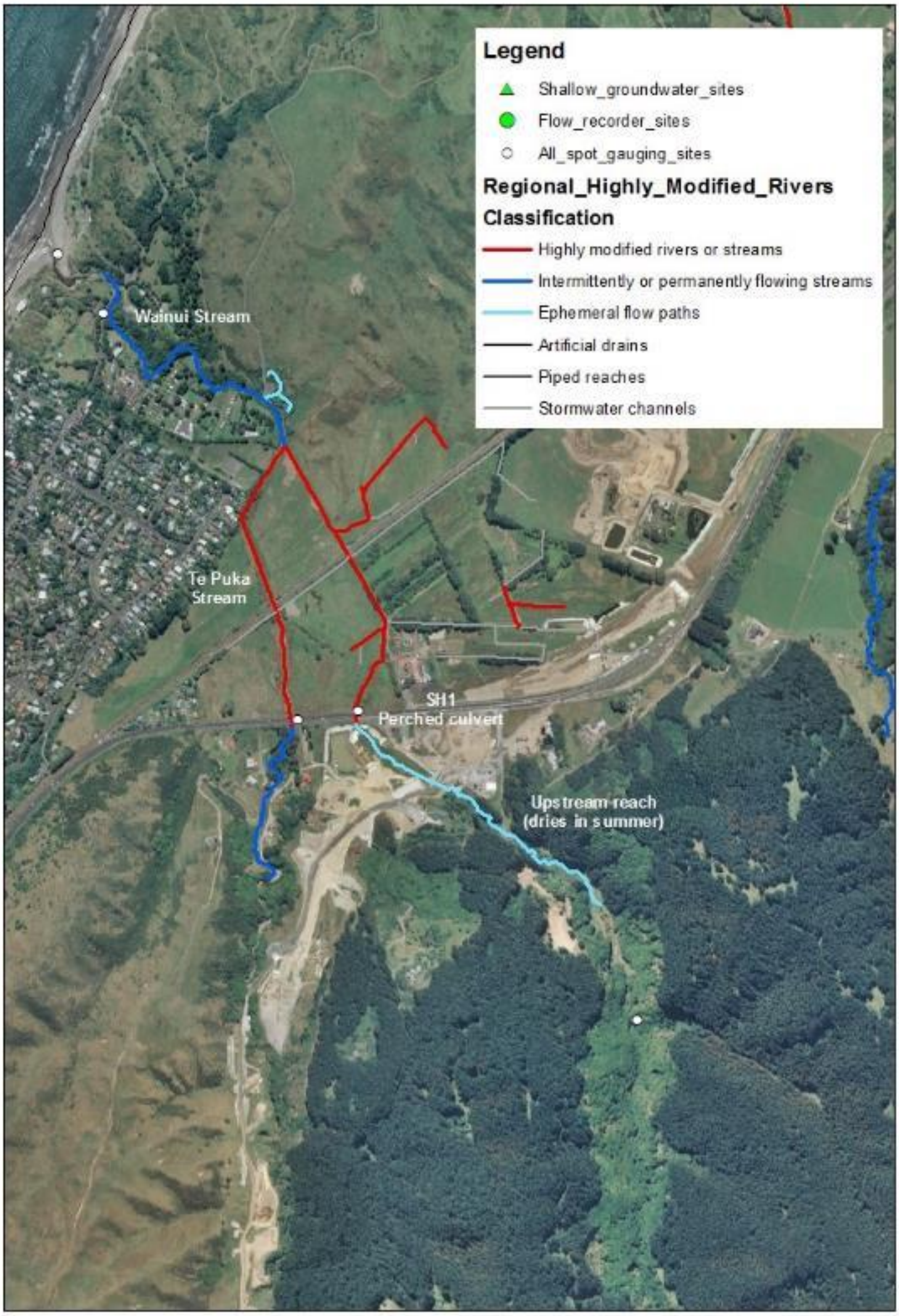

Figure 3. Stream channels and hydrological monitoring sites on the Wainui Stream (source material supplied by GWRC).

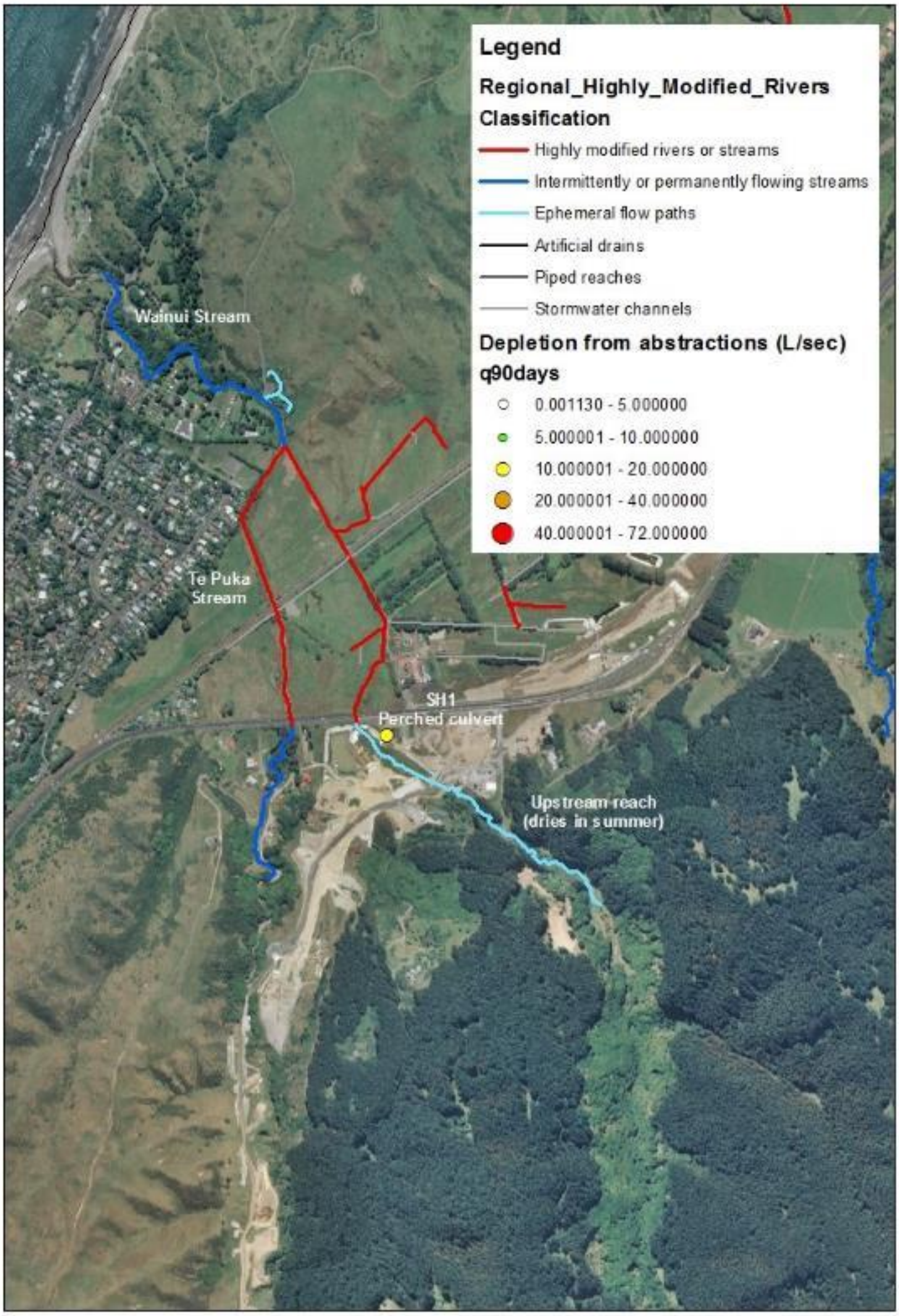

Figure 4. Location of consented abstraction (yellow dot) in the Wainui Stream catchment (source material supplied by GWRC).

Instream values

Anecdotally, the Wainui Stream catchment is often described as being highly valued in the Wellington region for diversity and abundance of indigenous fish. This is related to its short length and accessibility for diadromous (sea-migratory) fish species. The following species have been recorded in the catchment: banded kōkopu, common bully, giant kōkopu, kōaro, longfin eel, redfin bully, shortfin eel and torrentfish; and īnanga have also been observed. The habitat quality is generally very good through the lower reaches with abundant riparian vegetation providing shade and cover, and organic debris and bank refugia also providing cover.

2.1.2. Assessment of the sustainability of current hydrological alteration and recommendations for studies to inform ecological flow and allocation limits in Wainui Stream

How sensitive are ecological values to change in flow regime?

The Wainui Stream supports a diverse native fish fauna, comprising entirely diadromous species: banded kōkopu, common bully, inānga, giant kōkopu, kōaro, longfin and shortfin eel, redfin bully, and torrentfish. The species list includes several with high conservation significance: giant kōkopu (declining), kōaro (declining), longfin eel (declining), torrentfish (declining), and īnanga (declining) (Dunn et al. 2018). While Wainui Stream is unlikely to support significant fisheries (and mahinga kai) within its confines and mouth, owing to the stream's small size, it will export juvenile galaxiids (inānga, banded kōkopu, giant kōkopu) that may contribute to whitebait runs in other rivers along the south-west coastline of the North Island, and mature eels which will contribute to eel recruitment back to New Zealand. Fish species richness will be highest in the lower segment of the stream below the KCDC takes and State Highway 1, declining with distance inland and altitude/gradient. This lower segment of the stream also possesses the best riparian vegetation, providing good cover/shading and terrestrial invertebrate food supply for fish. Hence, the footprint of the water allocation demand overlays the most important segment for native fish.

The most flow-sensitive fish species are torrentfish and kōaro, which prefer fast, shallow cobble-boulder cascade, riffle and run habitat. However, torrentfish appear to be rare in Wainui Stream, because their preferred habitat (fast riffles and cascades) is uncommon in the lower segment. The same point applies to kōaro, but also this species migrates well inland so most of the population will be in the upper catchment. The more critical issue for kōaro, in respect of flow management, is maintenance of fish passage in the form of continuous flow throughout the stream, especially in spring when juveniles are migrating upstream. Juvenile eels also migrate over spring and throughout summer to autumn, and adult eels migrate back to the ocean in autumn. Fortunately, none of the native fish species require much flow for upstream passage, providing riffles are flowing, and adults usually migrate downstream during floods. Exacerbation of the spatial and temporal extent of drying in the stream by abstraction should be minimised to facilitate fish passage.

The other native fish species have low to moderate flow requirements. Īnanga, banded kōkopu and giant kōkopu are moderately flow sensitive, because they are drift-feeders and so require current to transport aquatic and terrestrial invertebrates for them to intercept. Juvenile eels and redfin bullies are also moderately flow sensitive because they prefer to live among the gravels and cobbles of riffles and fast runs. Adult eels are the least flow-sensitive, but as previously mentioned, they rely on benthic invertebrates and small fish in riffles and runs for their food, and invertebrate habitat is sensitive to flow reduction. Minimum flow options that sustain a high percentage (≥ 80%) of benthic invertebrate habitat relative to the habitat level sustained by the naturalised 7-d MALF will likely maintain adequate food supply for eels and other native fish, and high levels of habitat for the various fish species.

Is the current level of hydrological alteration sustainable with respect to safeguarding ecosystem health?

Before any real progress can be made in answering this question, the degree of hydrological alteration needs to be better understood. The present estimate for the depletion for the KCDC groundwater take of about 12 L/s (assuming pumping is 14 hours/day) (Keenan 2021), equates to perhaps about 48% of naturalised 7-day MALF at the stream mouth. We are uncertain whether the maximum allowable take of 25 L/s, would result in a greater depletion rate in the steam, given that actual use is likely to be significantly less than consented. If the KCDC take was directly connected to the stream's flow, or was from surface water, it would be considered to be a large abstraction, likely to have more than minor adverse effects on instream habitat and ecological values. However, the hydrological effects of the KCDC groundwater take on Wainui Stream will be muted by the storage effect of the aquifer, delaying and smoothing out spikes in takes. Therefore, understanding depletion rates of the groundwater takes on surface flow in Wainui Stream is crucial for quantifying the degree of flow alteration.

Hydrological studies

The following hydrological studies proposed by GWRC staff and amended by us are necessary for understanding the degree of hydrological alteration due to current water abstraction, and to provide the foundation for assessing habitat and ecological effects:

- Further review and analysis of the groundwater take data to establish a firm view on the most likely depletion curves.
- Undertake summer flow gaugings in the lower stream reaches.
- Target flow gaugings to periods of pumping and no pumping to determine whether any measurable stream response can be detected. This would depend on whether KCDC have any ability to manipulate pumping.
- Combine analysis of the surface gauging data and analysis of the groundwater depletion data to predict hydraulic response of current groundwater takes and different restriction regimes.

- Verify whether the stream dries naturally in places, and the spatial and temporal extent of drying, and any exacerbation of drying attributable to KCDC's groundwater abstraction.

Ecological values, hydraulic geometry and instream habitat studies

We recommend the following studies on instream values, hydraulic geometry and instream habitat to help assess ecological effects of current and future water allocation in Wainui Stream to inform limits setting:

- Verify the spatial distribution of native fish populations, including species presence and density, versus the spatial footprint of flow alteration from water allocation. Existing records of fish species distributions are likely to be dominated by presence absence data. Density data would be very useful to complement hydraulic habitat modelling results below, and help to ascertain whether fish populations are likely to be limited by low flow. If densities are actually frequently relatively low, then predicted habitat reduction will overestimate adverse effects on fish, and minimum flow and allocation limits could be relaxed.
- The high diversity of native fish species coupled with large allocation demand justifies a cross-sectional hydraulic-habitat survey targeted at the lower segment of the stream, between the KCDC take and the bridge above the beach. This will provide relationships between flow and hydraulic geometry variables (wetted width, average depth and velocity) and habitat (for benthic invertebrates and the range of fish species known from the stream). Modelling analysis to be done with SEFA.

The habitat modelling results may show that current water allocation from Wainui Stream is having more than minor adverse effects on habitat for benthic invertebrates and some fish species, and that allocation restriction options have limited scope to substantially mitigate effects. Nevertheless, habitat modelling, and running abstraction scenarios on the results, will provide transparent communication of habitat, and potential ecological effects of allocation to iwi and the wider community. Collaborative decision making on minimum flow and allocation limits can then proceed with shared knowledge.

If not, what limits should apply?

Further abstraction from the Wainui Stream to service future growth potential of Paekākāriki is unlikely to be an option under the NPS-FM policy 11 '….future over-allocation [of freshwater] is avoided', given that current allocation appears to represent a high degree of hydrological alteration. Furthermore, climate change predictions for hill-fed streams on the North Island's west coast are for drier conditions, and lower flows, in summer (MfE 2018). It is likely that the future needs of Wainui Stream and local residents will require improvements in water use efficiency and water storage options to be considered to meet the management and policy objectives of the NPS-FM and PNRP, respectively.

As mentioned in response to the previous question, habitat modelling may show that even current allocation and actual abstraction have adverse effects on instream habitat. Potential risks of habitat reduction on fish might be shown to be lower if density data are available. This might provide some scope to settle for more permissive limits and reduce the management challenges of reducing overallocation.

In Section 1.2.3 we commented on definitions of 'sustainability' and 'safeguarding' in the context of continuous non-linear habitat and ecosystem responses to flow reduction. We pointed out that there is no single minimum flow that provides for life-supporting capacity and ecosystem health, including the flow requirements of fish. Furthermore, instream values vary in importance, depending on the species present, their conservation status and their local importance for mahinga kai / fisheries / harvesting. This means there is some scope to vary minimum flow and allocation limits, tailoring them to values and risk of adverse ecological effects, whilst also considering the importance of water allocation for human consumptive water supply and economic use in the context of Te Mana O Te Wai.

The KCDC water take is largely for human consumptive water supply, so it fits in the second tier of importance, after the primary concern of safeguarding the mauri and ecosystem of Wainui Stream, in the context of Te Mana O Te Wai considerations. Once iwi and the wider community are presented with the results of the values assessment, hydrological, habitat and ecological studies on Wainui Stream they may collaboratively choose to accept more permissive limits, to secure current allocation (or close to it), but which maintain a percentage of naturalised flows and instream habitat acceptable to them, given an understanding of risk to naturalised and status quo ecosystem health and other values.

2.1.3. Turanganui and Tauanui rivers

Catchment description

The Turanganui and Tauanui rivers are located in the southern part of the Wairarapa Valley, and originate in the Aorangi Range with confined bedrock channels within indigenous and forestry headwater catchments. They transition to gravel bed rivers as they emerge from the hills onto the Pirinoa Terrace valley floors and then run in a westerly directly for about 15 km through farmland before discharging to the Ruamahanga River and Lake Onoke.

Being fed from the eastern hills in the Wairarapa, both rivers are prone to prolonged very low summer flows; freshes are much rarer in summer months than for rivers originating from the western ranges that pick up prevailing westerly rainfall. In the lower catchment the predominant land use is dairy.

Because the two rivers are close together geographically and connected hydrologically, they are considered together in the assessment below. Table 3 summarises the low-flow hydrology of Turanganui and Tauanui rivers and an ecological values assessment by GWRC.

Turanganui River hydrology

No long term continuous water level/flow data are available for this catchment. However, hydrology data collected over the past five years has involved the deployment of several flow sensors and numerous spot gauging runs (Figure 5). There is (since 2018) a permanent flow site in the headwaters ('Turanganui at Gorge') which provides a measure of natural flow before losses to groundwater and abstraction occur in the lower catchment.

Concurrent gaugings show a consistent longitudinal pattern of loss and gain at low flows with complete drying in at least one reach common in summer (Figure 6). The overall spatial pattern is considered to be largely natural although the magnitude and extent of loss could be influenced further by abstraction. There are several groundwater abstractions that are thought to potentially influence river flow although the level of connection to surface water remains uncertain and the subject of ongoing investigations (see allocation section).

MALF has not yet been estimated at any locations. Preliminary analyses suggest a natural MALF of around 125 L/s at the Gorge (Table 3). MALF is obviously highly variable and likely to be zero in the reach adjacent to the QEII-covenanted swamp forest on Te Rata Road, and possibly elsewhere.

Table 3. Summary of hydrology, hydrological and ecological values assessment, current abstraction pressures and predicted future pressures for the Turanganui and Tauanui rivers. MALF estimates are naturalised.

Turanganui and Tauanui rivers	
Low flow hydrology	
Median flow (L/s) – Turanganui (from NIWA River Maps natural median flow in lower reaches)	1000
Median flow (L/s) – Tauanui (from NIWA River Maps natural median flow in lower reaches)	800
7-day MALF[2] (L/s) for the Turanganui River (estimated by correlating the 'Turanganui at Gorge'[1] flow record with the flow site Ruakokopatuna River at Iraia (which flows north from the Aorangi Range))	125 (at Gorge) 155 (at Te Rata Rd bridge)
7-day MALF[2] (L/s) for the Tauanui River (estimated by correlating the 'Tauanui at Gorge'[1] flow record with the flow site Ruakokopatuna River at Iraia (which flows north from the Aorangi Range))	100 (at Gorge and Lake Ferry Rd bridge)
1-day MALF (L/s)	Not available
Values assessment	
Ecological value	Very High
Fishery value (sport)	Low?
Māori cultural value (mahinga kai)	High?
Abstraction pressure	High
Out of stream value (water use)	High
Abstractions	
Turanganui River current maximum allowable take (L/s)	82 (excluding seepage drain and category C consents)
Tauanui River current maximum allowable take (L/s)	23.7 (excluding the seepage drain consents and a large deep groundwater take of 90 L/s)
Future prediction (L/s)	Not available

[1]The 'Tauanui at Gorge' and 'Turanganui at Gorge' flow recorders (established in 2018) provide a measure of natural flow before losses to groundwater and abstraction in the lower catchment.
[2] Note: MALF in this case is highly variable and likely to be zero in several reaches.

Median/mean flow is unknown as the continuous gauge record is too short and incomplete across the seasons to derive a reasonable estimate. A cursory look at NIWA River Maps suggests a natural median flow in the lower reaches of about 1000 L/sec (Table 3).

There have been concerns raised as to the effect of groundwater abstractions potentially exacerbating summer low flows in the Turanganui River. Preliminary results from a monitoring survey being undertaken by GRWC suggest that during peak irrigation periods the shallow water aquifer is undergoing a degree of induced drainage.

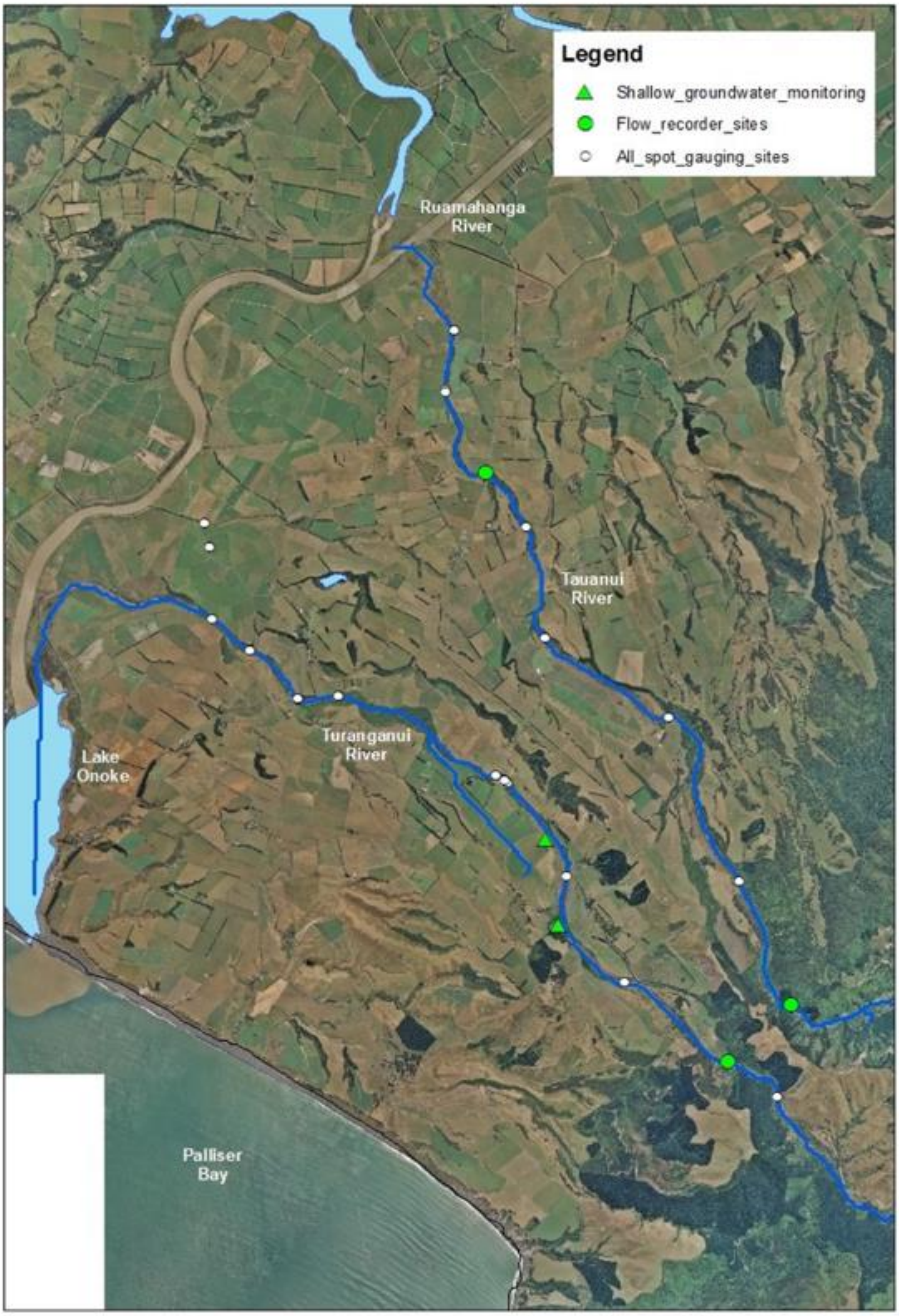

Figure 5. Hydrological monitoring sites in the Turanganui and Tauanui rivers (source material supplied by GWRC).

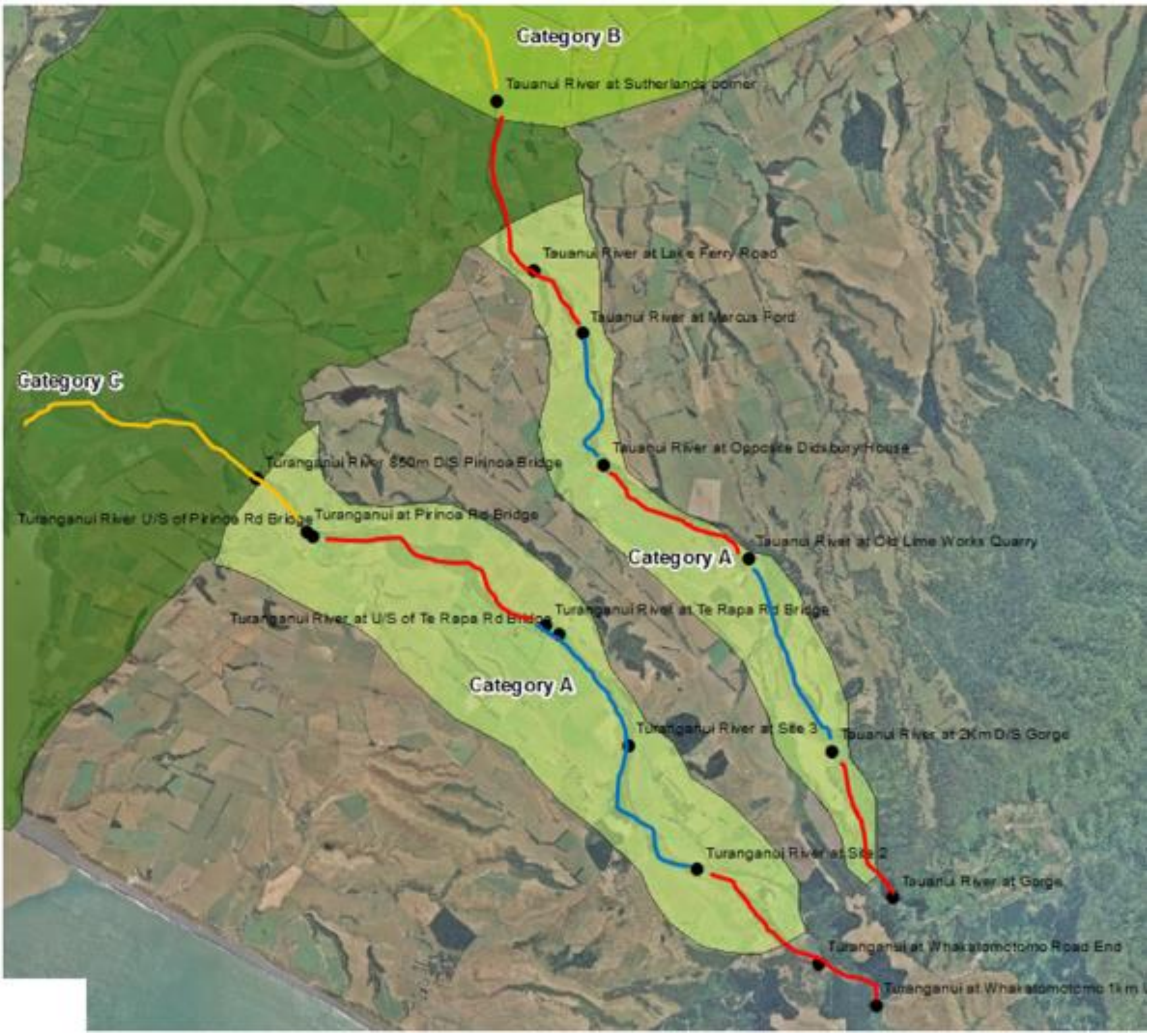

Figure 6. Spatial pattern of losing (red), gaining (blue) and neutral (orange) flows in the Turanganui and Tauanui rivers (source material supplied by GWRC).

Tauanui River hydrology

No long-term continuous water level/flow data are available for the Tauanui River catchment. However, hydrology data collected over the past five years have involved the deployment of several flow sensors and numerous spot gauging runs (Figure 5). There is (since 2018) a permanent flow site in the headwaters ('Tauanui at Gorge') which provides a measure of natural flow before losses to groundwater and abstraction occur in the lower catchment. A semi-permanent sensor is also now located at the main road bridge and reinstated each summer.

Concurrent gaugings show a consistent longitudinal pattern of loss and gain at low flows with complete drying in some reaches common in summer (Figure 6). The overall spatial pattern is considered to be largely natural, although the magnitude and extent of loss could be influenced further by abstraction. There is only one abstraction that is thought to potentially influence surface flow (Didsbury – upstream of the road bridge) although it is a deep groundwater take and the level of connection to the surface is uncertain and the subject of ongoing investigations (see allocation section). Several of the gaugings were undertaken before this take began in about 2017.

MALF has not yet been estimated at any locations. However, preliminary analyses by Keenan (2021) suggests a natural MALF of around 100 L/s at the Gorge (Table 3). This estimate is based on correlations with the Ruakokoputuna River, which flows north from the Aorangi Range. MALF is obviously highly variable and likely to be zero in several reaches.

Median/mean flow is unknown as the continuous gauge record is too short and incomplete across the seasons to derive a reasonable estimate. A cursory look at NIWA River Maps suggests a natural median flow in the lower reaches of about 800 L/s (Table 3).

Turanganui River allocation and current abstraction regime

In the Turanganui River there are nine consented takes: two directly from either the river or seepage drains at the bottom of the catchment, four from connected groundwater (Category A[4]) and three from Category C groundwater in the lower catchment (Onoke Groundwater Zone) (Figure 7).

[4] A, B and C categories are based on the degree of connection with surface water environment, category A being in direct connection and category C having no significant connection.

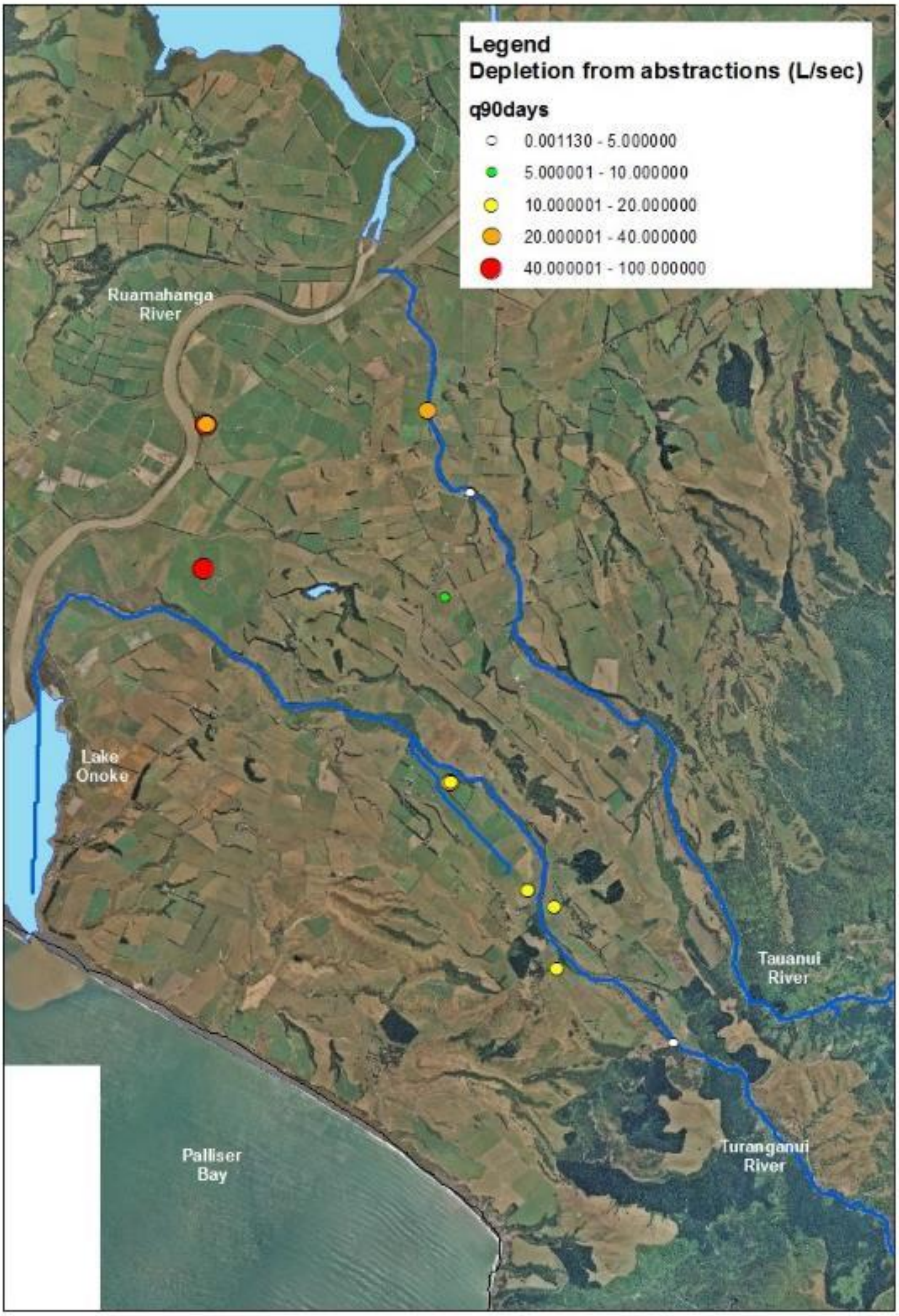

Figure 7. Estimated maximum potential depletion from consented surface and highly connected groundwater abstractions in the Turanganui and Tauanui rivers (source material supplied by GWRC).

Excluding the seepage drain and Category C consents, paper allocation relating to the Turanganui River is about 82 L/s. Estimating the depletion rate is difficult because there is a high level of uncertainty around one take in particular (that is 20 L/s); calculations suggest very minor depletion, but conceptual understanding of the side valley geology suggests much higher (Category A) connection, and depletion, is more likely. Excluding this particular take, total river depletion can be estimated as about 65 L/s. Taking a more cautious approach and assuming full connection then depletion would be closer to paper allocation (around 80 L/s). Either way, total abstraction is likely to represent a 'high' degree of alteration at low flows, equating to between 75 and 120% of estimated MALF at the Lake Ferry Road Bridge (noting this is an un-naturalised estimate and uncertainty is again high due to lack of long-term flow data). Keenan (2021) considered that flow depletion from full utilisation of consented abstractions would be 'high' mid-river, and 'moderate' to 'very high' in the mid- to lower river (depending on the methodological approach used for calculating estimates of streamflow depletion due to groundwater abstraction).

The level of abstraction is likely to be much more modest when compared to median flow, equating probably to less than 10%.

Like the Tauanui, interpreting the degree of allocation pressure in the catchment is difficult for several reasons related to spatial variability in flow (falling to zero in some reaches) and uncertainty of connection of Category A takes.

Restrictions on any of the takes have historically been applied infrequently or inconsistently.

Tauanui River allocation and current abstraction regime

There are five consented takes in the Tauanui catchment: three direct surface takes from either the river or seepage drains at the bottom of the catchment, one from connected groundwater (Category A) and one from what is currently thought to be deep Category C groundwater (Figure 7).

Excluding the seepage drain consents and the large deep groundwater take, paper allocation is 23.7 L/s. If a nominal amount of 10 L/s is added for the WAR180071 take, then maximum depletion may be around 35 L/s. This may equate to around 50 to 100% of estimated MALF at the Lake Ferry Road bridge (which is likely to be a largely natural flow). Uncertainty is high due to lack of flow data but either way abstraction is likely to equate to a 'high' degree of alteration at low flows in the lowest reaches of the river. The level of abstraction is likely to be much more modest when compared to median flow, probably less than 5%. Interpreting the degree of allocation pressure in the catchment is difficult for several reasons:

- flow in some reaches is known to fall to zero

- the largest take of known depletion (22.7 L/s) is near the bottom of the catchment which, arguably, mitigates some potential impacts (at least in terms of spatial extent)
- there remains significant uncertainty about the very large deep groundwater take; small changes in the understanding of depletion rates from this take could have significant implications for understanding overall catchment allocation pressure.

Restrictions on any of these takes have historically been applied infrequently or inconsistently.

Instream values

The Turanganui and Tauanui rivers support a diverse native fish fauna, comprising diadromous species: longfin and shortfin eel, kōaro, īnanga, giant kōkopu, banded kōkopu, common bully, redfin bully, and torrentfish, and two non-migratory species: upland bully, black flounder and common smelt (although smelt and flounder have been found in only the Turanganui River and are likely to be restricted to the lower reaches close to Lake Onoke). Brown trout have also been recorded in the rivers.

The loss of flow connection in drying reaches during low flows creates a barrier for fish passage. However, the severity of disruption to fish passage will depend on the fish species present and timing of migrations (i.e. juvenile native fish travelling upstream to rearing and adult habitat and adults of some species travelling downstream to spawn; adult lamprey and trout travelling upstream to spawn and juveniles moving downstream as they grow to adult habitat).

The migration patterns of some fish species recorded from the Turanganui River are shown in Table 4. It should be noted that migration periods of native fish are often cued by temperature and floods as well as season, lunar cycles and tides. As a result, peak migration periods may vary from year to year depending on these conditions, and the peaks listed in Table 4 should be treated as a guide only. Moreover, the upstream migration periods are somewhat misleading because pelagic[5] fish in particular will continue to penetrate upstream for feeding unless they encounter barriers. For example īnanga, which feed in shoals through the juvenile whitebait stage to maturity in autumn—moving up and down streams/rivers to feed.

The native species listed in Table 4 considered to have a conservation status of ‘At risk, declining’ are, longfin eel, giant kōkopu, kōaro, and īnanga.(Dunn et al. 2018). The shortfin eel, banded kōkopu, common bully, upland bully, redfin bully, black flounder and smelt have a ‘Not threatened’ status.

[5] ‘Pelagic’ refers to fish that are free swimming in the water column, by contrast with ‘benthic’ species that live on the stream bed.

Table 4. Migration and spawning calendar of freshwater fish species (modified from Smith 2014) found in the Turanganui and Tauanui rivers.

Common name	Upstream migration period	Peak upstream migration period	Downstream migration period	Spawning period
Brown trout	December–May (adult)	March–May	Year-round (juvenile)	Autumn/winter (peak May–June)
Longfin eel[a]	November–April (juveniles (elvers))	December–March	March-May (adult)	Not applicable as migrates to sea to spawn
Shortfin eel[b]	November–April (juveniles (elvers))	December–March	February–March (adults)	Not applicable as migrates to sea to spawn
Kōaro	September–November (juvenile)	September–October	May–September (larvae)[c]	April to August (peak from April-May)
Īnanga	March–November (juvenile)	April–November	October–August (larvae)[d]	Almost year round (peak from March–June)
Giant kōkopu	October to December (juvenile)	November	May to September [e]	April to August (peak from May to June)
Banded kōkopu	August to December (juvenile)	September to October	April to September (larvae)[f]	March to August (peak from May to June)
Common bully	December–March (juvenile)	Not known	September–March (larvae)[g]	August to February
Upland bully[h]	None	None	None	August to February (peak from October-December)
Redfin bully	November–March (juvenile)	Not known	September–February (larvae)	Late winter through spring August – November
Torrentfish	April to November (juvenile)	May to August	December–June[1] (larvae)	November to May (peak from January to April)
Common smelt	August to November (juvenile and some adult lake fish)	September to November	January to August (larvae)[j]	December to July (sea-run) (peak from March to May)

[a] Glass eels migrate up from the estuary from July–November (peak period: August–October).

[b] Glass eels migrate up from the estuary from August–December (peak period: September–November).

[c] The peak downstream migration is May–June.

[d] The peak downstream migration is March–July. Larvae of īnanga are present only within the lower reaches of rivers and streams.

[e] The peak downstream migration is June–July.

[f] The peak downstream migration is June–July.

[g] The peak downstream migration is October–November.

[h] Upland bullies are a non-migratory species.

[i] The peak downstream migration is April–June.

[j] The peak downstream migration is February–May.

2.1.4. Assessment of the sustainability of current hydrological alteration & recommendations for studies to inform ecological flow and allocation limits in the Turanganui and Tauanui rivers

How sensitive are ecological values to change in flow regime?

Neither catchment is specifically mentioned in the Natural Resources Plan (or listed in schedules) for significance to mana whenua. However, it is safe to assume that cultural values will be commensurate with the high ecosystem and indigenous species values. Specific locations of cultural interest to Maori are currently unknown to GWRC but should be established for this project if possible.

Anecdotally, concerns have been raised about the role of abstraction in generally reducing the quality of recreational opportunities (compared with past generations), although again specifics are unknown.

Drying in some sections of the Turanganui and Tauanui rivers during summer may be a naturally occurring event, but if current abstractions are increasing the extent and duration of these events, it is likely that fish migration and access to upstream spawning areas will be adversely affected. Invertebrates will be less affected providing there is a source of colonisers (either upstream or from nearby tributaries) to repopulate the previously dry lower sections of the rivers.

The most flow-sensitive fish are kōaro; they prefer fast, shallow cobble-boulder cascade, riffle and run habitat. Kōaro migrate well inland so most of the population will be in the upper catchment. The more critical issue for kōaro, in respect of flow management, is maintenance of fish passage in the form of continuous flow throughout the stream, especially in spring when juveniles are migrating upstream. Juvenile eels also migrate over spring and throughout summer to autumn, and adult eels migrate back to the ocean in autumn. Exacerbation of the spatial and temporal extent of drying in the stream by abstraction should be minimised to facilitate fish passage.

The other native fish species have low to moderate flow requirements. Īnanga and banded kōkopu are moderately flow-sensitive because they are drift feeders and so require current to transport aquatic and terrestrial invertebrates for them to intercept. Juvenile eels and redfin bullies are also moderately flow-sensitive because they prefer to live among the gravels and cobbles of riffles and fast runs. Adult eels are the least flow-sensitive, but as previously mentioned, they rely on benthic invertebrates and small fish in riffles and runs for their food, and invertebrate habitat is sensitive to flow reduction.

Because the Turanganui and Tauanui rivers support high fish biomass (particularly īnanga in the lower reaches of the Turanganui, authors per obs.), space and food (invertebrates and small fish) may be limiting at low flow, so fish populations are more likely to be sensitive to flow reduction. Minimum flow options that sustain a high percentage (≥ 80%) of benthic invertebrate habitat relative to the habitat level sustained by the naturalised 7-d MALF will likely maintain adequate food supply for eels and other native fish, and high levels of habitat for the various fish species.

Is the current level of hydrological alteration sustainable with respect to safeguarding ecosystem health?

Current abstraction pressure for the Turanganui River (at Lake Ferry Road bridge) and Tauanui River (at Lake Ferry Road bridge) are roughly estimated to be 55% and 15% of MALF, respectively (Keenan 2021). The Turanganui estimate represents a high degree of hydrological alteration, likely to be having more than minor adverse effects on instream habitat and ecological health, when compared with the default allocation limit of 20% of MALF for small rivers presented in Appendix 1.

The high instream values and high allocation/abstraction rates warrant investigations to improve understanding of the hydrology, flow alteration and effects on hydraulic geometry and instream habitat to inform the minimum flow and allocation limit setting.

Hydrological studies

The following hydrological studies proposed by GWRC staff and amended by us are necessary for understanding the degree of hydrological alteration due to current water abstraction, and to provide the foundation for assessing habitat and ecological effects.

Better information on the connectivity between surface water and groundwater is essential. The Council has been working towards gaining this knowledge through:

- installing flow recorders and sensors to determine the effect of abstraction on naturalised flow (Figure 5)
- concurrent longitudinal gaugings to determine water loss and gain at low flows (Figure 6)
- a targeted study to understand the hydrogeology and connectivity between surface water and groundwater to address:
    - rural community concerns on summer low flows and speculation that abstraction may be a central cause for die-back of native trees in a high value QEII-covenanted forest remnant that bounds the Turanganui River.
    - effects of abstraction on surface flow reduction and spatial extent and duration of stream drying.

Ecological values, hydraulic geometry and instream habitat studies
We recommend the following studies on instream values, hydraulic geometry and instream habitat to help assess ecological effects of current and future water allocation in Turanganui and Tauanui rivers to inform limits setting:

- Verify the spatial distribution of native fish populations, including species presence and density, versus the spatial footprint of flow alteration from water allocation. Existing records of fish species distributions are likely to dominated by presence/absence data. Density data would be very useful to complement hydraulic habitat modelling results below, by helping to ascertain whether fish populations are likely to be limited by low flow. If densities are actually frequently relatively low, then predicted habitat reduction will overestimate adverse effects on fish, and minimum flow and allocation limits could be relaxed.
- The high diversity and biomass of native fish species coupled with large allocation demand justifies a cross-sectional hydraulic-habitat survey targeted at the mid and lower segments of both rivers. This will provide relationships between flow and hydraulic geometry variables (wetted width, average depth and velocity) and habitat (for benthic invertebrates and the range of fish species known from the stream). Modelling analysis to be done with SEFA.

The habitat modelling results may show that current water allocation from the Turanganui and Tauanui rivers is having more than minor adverse effects on habitat for benthic invertebrates and some fish species, and that allocation restriction options have limited scope to substantially mitigate effects. Nevertheless, habitat modelling, and running abstraction scenarios on the results, will provide transparent communication of habitat, and potential ecological, effects of allocation to iwi and the wider community. Collaborative decision making on minimum flow and allocation limits can then proceed with shared knowledge.

If not, what limits should apply?

Further abstraction from the Turanganui and Tauanui rivers to service future irrigation is unlikely to be an option under the NPS-FM policy 11 '… future over-allocation [of freshwater] is avoided', given that current allocation appears to represent a high degree of hydrological alteration. Furthermore, climate change predictions for the Wairarapa are for greater risk of drought. On average, 15% more water will be required by mid-century and 30% more by late century to maintain soil moisture levels assuming current land uses. Hill-fed rivers such as the Turanganui and Tauanui will, therefore, probably experience lower summer flows more often[6] (MfE 2018). It is likely that the future needs of Turanganui and Tauanui rivers and people will require improvements in water use efficiency and water storage options be considered to meet the management and policy objectives of the NPS-FM and PNRP, respectively.

[6] https://wwl.net.nz/climate-change

As mentioned in response to the previous question, habitat modelling may show that even current allocation and actual abstraction has adverse effects on instream habitat. Potential risks of habitat reduction on fish might be shown to be lower if density data are available and show that densities are low to moderate. This might provide some scope to settle for more permissive limits and reduce the management challenges of reducing overallocation.

2.2. Spring-fed streams

2.2.1. Decision pathway for ecological flow assessment and limits setting for spring-fed streams

In Figure 8, a decision pathway (based on Figure 1) is provided for setting flow limits for spring-fed streams. Although the main management objectives being addressed in this report focus on ecological values, the flow diagram has been set up such that two secondary objectives listed in Section 1.1 are considered, namely the sensitivity of other instream values to flow reduction at low flows, and consistency with the principles and hierarchy of requirements in the NPS-FM related to 'Te Mana o Te Wai'.

Spring-fed streams

List of values to be considered (not exhaustive)*	Value : FAD options	Action Plan
1. Mauri of the waterway • Safeguarding ecosystem health: water quality, water quantity (variability), habitat, aquatic life (abundance and diversity), ecosystem processes. • Protecting taonga species (aquatic & terrestrial) & threatened species	High : High	Targeted studies to determine DO pathways in stream (accounting for groundwater effects) to inform setting of stream specific minimum flow and allocation rates (see detail in body of text below this figure)
2. Needs of people • Water quantity & quality (drinking) • Mahinga Kai/fishing/harvesting for non-profit human consumption	Medium : Medium	Consider targeted studies to specific value(s) and flow dependent attributes, and/or apply recommended default flow limits
3. Social, economic, & cultural well being: • Wāhi tapu • Fisheries (cultural/recreational/commercial) • Contact recreation (swimming, rafting/kayaking, fishing) • Abstraction for economic use	Low : Low	Lowest level of protection, flows set so they do not breach national bottom limits (none available yet for flows) and/or apply recommended default flow limits

* Each value is ranked from 1 (high) to 5 (low) based on its importance

Figure 8. Decision pathway for the process of ecological flow assessment and minimum flow and allocation limits setting founded on a values- and risk-based approach for spring-fed streams. FAD = Flow allocation demand. MALF is the naturalised 7-day mean annual low flow.

When the overall value and flow allocation demand for spring-fed streams range from medium: medium to high: high (see Figure 8), targeted studies on specific values and flow-dependent attributes will depend on whether macrophytes are present.

Stable flow regimes and high biomass of macrophytes, a common feature of spring-fed streams, can confound interpretation of flow reduction effects using conventional instream flow assessment approaches (see Allen & Hay 2011).

Macrophyte absent or biomass low

In spring-fed streams (and reaches) that are relatively clear of macrophyte growth, flow is controlled by the channel geometry, i.e. the presence of fast-flowing shallow riffles acting as hydraulic controls below runs or pools. This is a scenario typical of hill-fed streams, so, depending on the importance of instream values, targeted studies could include:

- better defining values i.e. their spatial and temporal extent
- better defining hydrological alteration, including spatial and temporal extent
- identifying groundwater inflows and their spatial extent
- identifying flow-dependent attributes and their relative importance, e.g. hydraulic geometry (wetted width, average depth and velocity), instream habitat (periphyton, benthic invertebrates, fish), dissolved oxygen and temperature, invertebrate drift transport capacity, critical depths and widths for fish passage
- assessing flow responses of the above attributes.

Macrophyte growth present and extensive

In spring-fed streams where extensive instream growth of macrophytes across the channel, flow is controlled by macrophyte biomass, i.e. the higher the biomass of macrophytes the greater the water resistance and the greater the control on water level. This makes it challenging, or impossible, to undertaken channel geometry and instream habitat modelling studies, because these rely on accurate measurements of water levels and stable water-level rating curves.

In reaches where macrophytes control the water level, the backwater effect usually keeps the channel wet to the U-shaped banks, and maintains sufficient water depth for most fish and other life. The cover needs of fish (e.g. eels, banded and giant kōkopu, and trout) and kōura are provided by the abundant macrophytes and fully wetted undercut banks. The benthic invertebrate community reflects one suited to grazing in depositional habitats and on epiphytic algae growing on macrophytes (e.g. communities dominated by snails, caddisflies and flies). Biomass of such invertebrates can be high in such habitats, providing a good food supply for fish. These features contribute to spring-fed streams being less sensitive to flow reduction than mountain-fed, gravel bed streams.

Often, a feature of spring-fed streams of more concern than flow-related habitat is dissolved oxygen. High biomass of macrophytes in spring-fed streams has a strong influence on the daily DO cycle, owing to photosynthesis (oxygen-producing daytime phase) and respiration (oxygen-depleting night-time phase). A reduction in flow (water level) can increase the amplitude of the daily DO cycle in spring-fed streams, potentially reducing overnight (pre-dawn) DO to levels that compromise the life-supporting capacity of a stream. Oxygen-poor groundwater upwellings, which are common in spring-fed streams—because they are supplied by groundwater—can exacerbate this effect especially near the stream bed.

2.2.2. Potential specific studies for spring-fed streams

Depending on the instream values and degree of hydrological alteration, specific studies for macrophyte dominated spring-fed streams could include:

- better defining values i.e. their spatial and temporal extent
- better defining hydrological alteration, including spatial and temporal extent
- identifying ground water inflows and their spatial extent
- identifying flow dependent attributes, e.g. hydraulic geometry (wetted width, average depth and velocity) and habitat where these can be adequately measured and modelled, dissolved oxygen
- assessing flow responses of the above attributes.

Hydraulic geometry measurements for modelling using the WAIORA method involve measuring the following at two or more flows: flow, wetted width and depth at 5 representative runs or 3 riffles, runs and pools. Depth is measured at 5 locations over the cross sections to estimate mean depth. The mean stage (depth) change is best estimated by installing temporary staff gauges (e.g. rebar or waratah) to measure water level at the measured flows. The modelling provides estimates of wetted width and average depth and velocity versus flow. Generalised habitat versus flow relationships for fish and benthic invertebrates are optional add-ons. The last step may be most efficiently performed by NIWA using their coding for the eFlows Explorer or a variant of it. Predictions of percentage change in wetted width, mean depth and velocity (and generalised habitat) can be made for any flow within the range of confidence of the model and expressed as a percentage of these variables predicted for the naturalised 7-d MALF—to inform assessment of effects of current and future flow alteration scenarios to inform minimum flow limits. Predictions of allocation effects on mean velocity can also inform allocation limits, through rules of thumb on the influence of water velocity on fine sediment and periphyton flushing and invertebrate drift transport.

Where hydraulic geometry versus flow modelling cannot be performed due to macrophytes controlling water level, hydraulic geometry measurements alone may nevertheless be useful. Measurements of wetted width and depth made at low flows (with abstraction occurring) will confirm whether flows are sufficient to wet the channel to the U-shaped margins, to maintain benthic invertebrate habitat in riffles and runs and maintain sufficient depth for fish.

Dissolved oxygen (DO) is critical for supporting aquatic life and low concentrations can cause death, particularly for sensitive fish and aquatic organisms. As Davies-Colley and Wilcock (2004) explain, the DO concentration at any point in time is a balance between several processes, including:

1. oxygen being consumed by aquatic life through respiration
2. oxygen being produced through photosynthesis by aquatic plants and cyanobacteria
3. exchanges between the water and the atmosphere. The re-aeration process in water is mostly controlled by the degree of turbulent mixing. A swift-flowing river is well re-aerated, whereas a sluggish stream has poor exchange of atmospheric oxygen.

Dissolved oxygen can vary widely over a 24-hour period. As photosynthesis is light-dependent, the DO peaks during daylight hours and declines at night. Lowest levels of DO are normally at dawn just before photosynthesis resumes. Flow reductions may reduce DO concentration and saturation by reducing the air/surface water interchange (see Young & Doehring (2010)).

The NPS-FM states daily DO minima levels > 7.5 mg/L[7] are the highest numeric attribute for rivers whereby there is no stress caused by low DO on any aquatic organisms in rivers. Conversely, the national bottom line for DO is a daily minimum of 4 mg/L, below which there is a significant, persistent stress on a range of aquatic organisms caused by DO exceeding tolerance levels.

Applying currently available DO–flow models to spring-fed streams is problematic because they do not account for the influence of groundwater, which is potentially low in DO (Allen & Hay 2011). The confounding influence of groundwater on DO–flow modelling was identified as a limitation of a previous study of flow alteration on spring-fed streams in the Wairarapa, including Parkvale Stream and Dock Creek (Young & Doehring 2010); oxygen saturation of Parkvale Stream generally ranged from 80-115% and Dock Creek occasionally had DO concentrations less than 40% saturation and regularly below 50% saturation.

We support the following recommendations of Young and Doehring (2010):

[7] 1-day minimum for the summer period: 1 November to 30 April. The 1-day minimum is the lowest daily minimum across the whole summer period (MfE 2020).

- Undertake more DO–flow monitoring and modelling in Wairarapa spring-fed streams at very low flow to determine if their predicted changes in DO with flow are realistic.
- Determine the concordance of flow minima, influenced by abstraction, and DO minima and maxima—and consider controls on the timing of abstraction to ensure that DO minima and flow minima do not coincide.
- Undertake two station (upstream-downstream) oxygen logging and shallow groundwater monitoring in two reaches in each spring-fed stream, one with little groundwater input and one with a known input of groundwater. This also requires flow and water level in the study reaches to be gauged/recorded over the monitoring period, and water temperature to be continuously logged (15 min intervals) along with DO saturation and concentration. [We suggest modifying this slightly as shown in Section 3.3.2].

2.2.3. Parkvale Stream/Booths Creek

Catchment description

The Parkvale Stream has a catchment area of 73 km² and rises as a series of springs at the base of the Tararua foothills, adjacent to the Atiwhakatu Stream and Waingawa River. It runs south past Carterton, picking up numerous small spring-fed tributaries, plus the more substantial Taratahi Water Race inflows, before discharging to an old oxbow of the Ruamahanga River (known as Te Para Stream).

Booths Creek occupies a smaller catchment running directly adjacent to the Parkvale Stream catchment and discharging to Te Para Stream just downstream.

Land use is predominantly dry stock grazing in the upper catchments and dairy in the lower catchments.

Table 5 summarises the low-flow hydrology of Parkvale Stream and Booths Creek and an ecological values assessment by GWRC.

Parkvale Stream hydrology

Greater Wellington continuously monitors flow in the Parkvale Stream at Renalls Weir. The site has been operating since January 2002 and is located approximately 2 km upstream from where Parkvale Stream and Booths Creek join, before entering the Ruamahanga River (Figure 9).

Numerous spot gaugings have been made since the mid-1990s and indicate summer low flows upstream of SH2 are generally in the range 20–60 L/s. Several small spring-fed tributaries between SH2 and Park Rd cause the low flow to increase by two to four times and approximately 15% of flow is subsequently lost to groundwater in the reach between Park Rd and the flow recorder at Renalls Weir.

The mean annual low flows (MALF) at Renalls Weir for the period 2002–2009 (omitting years where low flow data are missing) are 44 L/s (1-day duration) and 61 L/s (7-day duration). The flow records are significantly impacted by abstraction (see next section). Nevertheless, naturalised MALF estimates have been derived in the past (Keenan 2009) by predicting the path of natural base flow recessions (to discount the effect of likely abstraction) (see Table 5).

Table 5. Summary of hydrology, hydrological and ecological values assessment, current abstraction pressures and predicted future pressures Parkvale Stream and Booths Creek. MALF estimates are naturalised.

Parkvale Stream and Booths Creek	
Low flow hydrology	
Median flow (L/s) - Parkvale	221 (naturalised median flow is between 399-400)
Median flow (L/s) - Booths	Not available
7-day MALF (L/s) at Parkvale Stream at Renalls Weir	140
7-day MALF (L/s) at Booths Creek at Anderson Line	80
1-day MALF (L/s) at Parkvale Stream at Renalls Weir	120
1-day MALF (L/s) at Booths Creek at Anderson Line	70
Values assessment	
Ecological value	Low to moderate with the odd high area (brown mudfish)
Fishery value (sport)	Medium? (no known angling but possible spawning)
Māori cultural value	High
Abstraction pressure	High
Out of stream value (water use)	High
Abstractions	
Parkvale current maximum allowable take (L/s)	200
Booths current maximum allowable take (L/s)	144
Future prediction (L/s)	No increased demand or allocation expected

Figure 9. Parkvale Stream and Booths Creek stream channels and hydrological monitoring sites (source material supplied by GWRC).

The observed summer median (November–April) at Renalls Weir is 221 L/s and a crude preliminary estimate of naturalised median is in the range 300 to 400 L/s (based on the potential maximum allocation and constraints to that in most summers).

Being mainly spring-fed, Parkvale Stream exhibits relatively stable flow over time and is not prone to large fresh events. During extended dry periods, base flow recedes relatively quickly (e.g., compared to larger river systems rising from deep within the Tararua Range), as a result of a reduction in support from groundwater discharge.

Booths Creek hydrology

Greater Wellington continuously monitors flow in Booths Creek at Andersons Line. The site has been operating since 2011 and is located approximately 5 km upstream from the mouth of the catchment. Three years of record were previously collected at the bottom of the catchment (Old Mill Rd) between 2002 and 2005.

Low flow longitudinal patterns have been reasonably well characterised in Thompson (2012) and are summarised in Figure 10.

Keenan (2009) estimated MALF for Booths Creek near its confluence with Parkvale Stream by correlating spot flow gaugings from the Booths at Old Mill site with those at Parkvale at Renalls Weir. Her estimates, summarised in Table 5, cannot be considered truly representative of natural MALF as some abstraction will have been occurring in both catchments during some of the gaugings (while cease-take orders will have been in force during others) and variable inflows from the Taratahi Water Race affected the MALF calculations (Keenan 2021). GWRC advise that some refinement may be possible with additional data collected since 2009 including actual metering data since about 2014 (pers. comm. Mike Thompson, GWRC). Since the 2009 report Keenan (2021) has calculated a naturalised 7-day MALF at Andersons Line (representative of flows in the mid-reaches of the Creek and upstream of Renalls weir and the Taratahi Water Race) of 15 L/s.

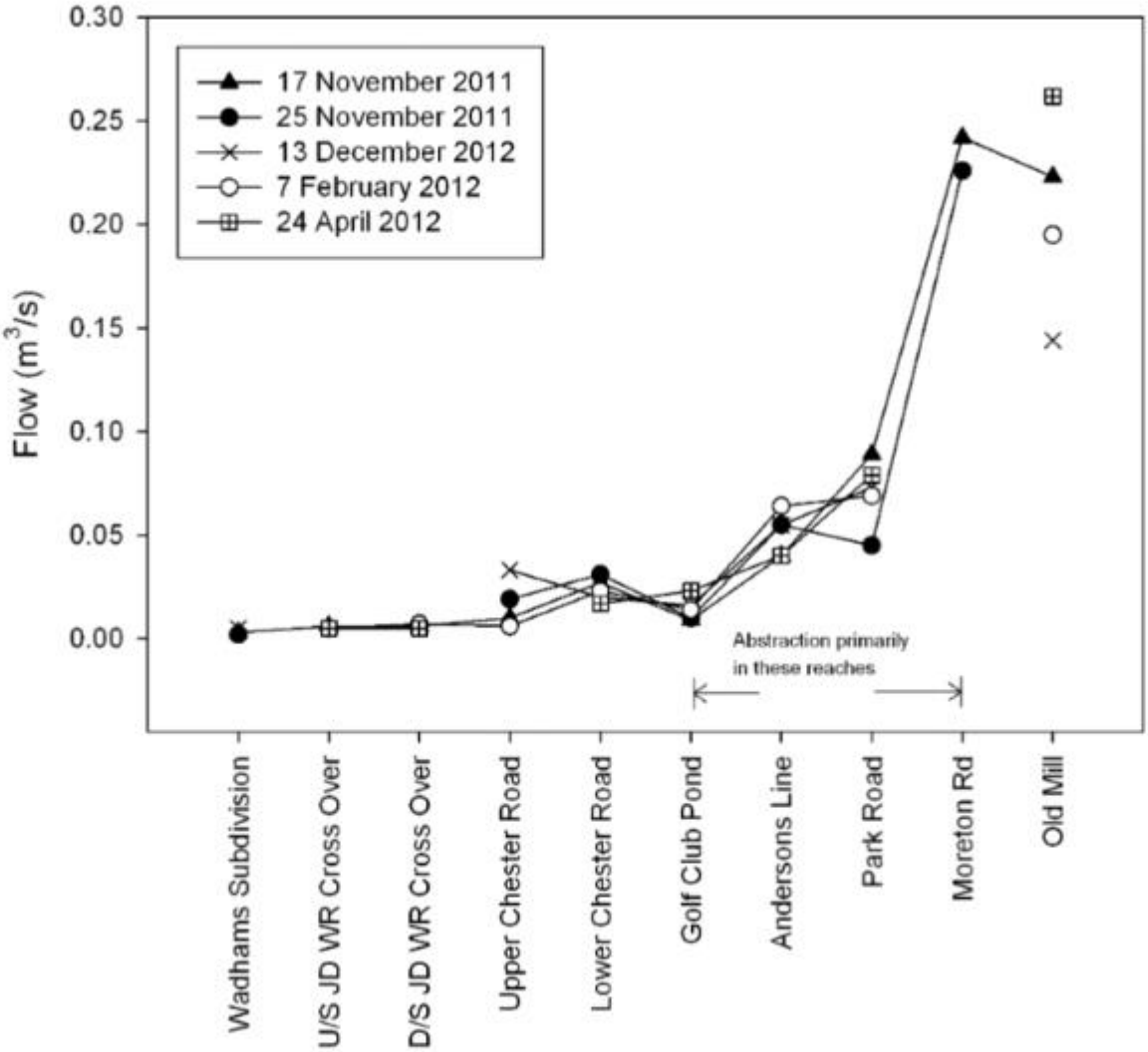

Figure 10. 'Corrected' Booths Creek concurrent flow gaugings (summer 2011/12) (source material supplied by GWRC).

Allocation and current abstraction management regime

There are twelve consented takes in the Parkvale catchment: seven surface water takes and four from Category B groundwater. In Booths Creek there are eight consented takes: four surface water takes, and four from Category B groundwater (Figure 11).

Current paper allocation from both catchments is high, equating to between about 130% and 180% of natural 7-d MALF in the Parkvale and Booths catchments, respectively, and about 60% of the natural summer median. There is an acknowledgement among water users of full, if not over-allocation so no increased demand (or allocation) is expected.

Almost all takes are restricted by a ‘bottom of catchment’ flow (150 L/sec at Renalls Weir) equating to just over-estimated natural 7-d MALF (140 L/s) and most cease take at a flow (100 L/s) equating to about 70% of natural 7-d MALF. Reliability for users is low in summer relative to other catchments.

Generally, in the Wellington region volumes of cumulative catchment actual water use over prolonged periods (several consecutive weeks to months) is significantly lower than paper allocation. GWRC staff consider that it may be possible to better quantify this gap for the Parkvale and Booths catchments (M Thompson, GWRC, pers. comm.).

Takes are located mainly downstream of SH2 in the lower half of the catchments. No attempt has been made in the past to assess flow alteration (with reference to MALF) at individual points of take, which would be helpful for assessing hydrological and ecological effects assessment.

Instream values

The following assessment of instream values was provided by Alton Perry, GWRC. The Masterton streams are typical of pastoral spring-fed streams, widespread habitat modification and little riparian planting. The water quality is likely to be poor. Monitoring has shown that DO saturation drops below 80% regularly in places.

Management of streams/races for drainage may also be an issue in some locations, and anecdotally people perceive some reaches of the ‘natural’ Parkvale would be dry if not for the water race inputs.

Parkvale Stream and Booth Creek support a moderate diversity of native fish including: longfin and shortfin eels, īnanga, brown mudfish, Cran’s bully, upland bully and common bully. Brown trout and rudd are also present. The native fish that have a conservation status of ‘At risk, declining’ are, longfin eel, īnanga and brown mudfish (Dunn et al. 2018). The shortfin eel, Cran’s bully, upland bully and common bully, have a ‘Not threatened’ status.

Kōura (freshwater crayfish) are also fairly common. The ‘rare’ aquatic moss (*Fissidens berteroi*) and freshwater sponges have been found in Parkvale Stream under a bridge.

There are pockets of mudfish around Lowes Reserve so maintaining hydraulic connectivity between wetlands, springs, streams is believed to be important.

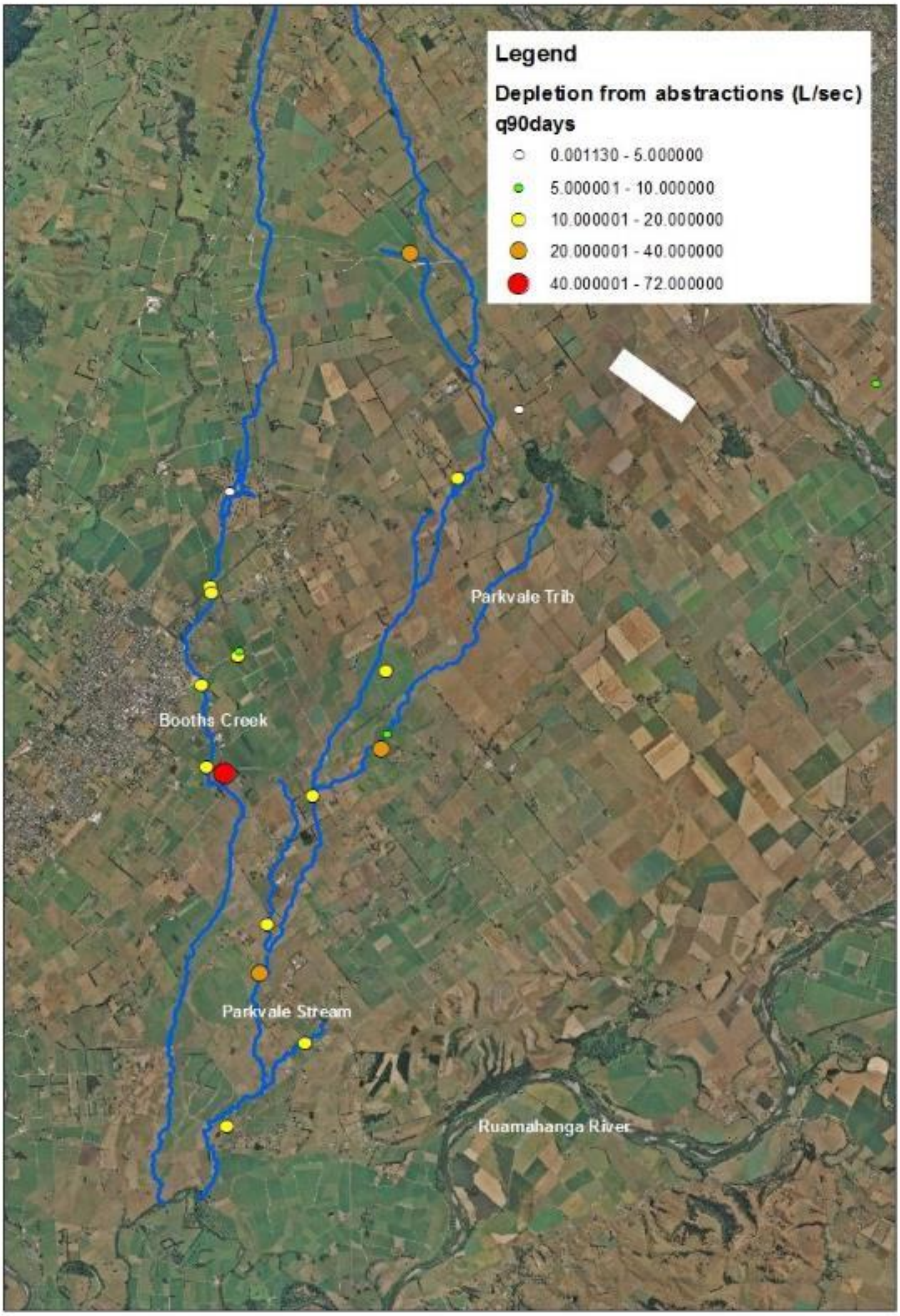

Figure 11. Consented surface and groundwater abstractions in the Parkvale Stream and Booths Creek catchments (source material supplied by GWRC).

A report on Māori cultural values associated with several Wairarapa waterways, including Parkvale Stream and Booths Creek (Royal 2011), found that:
Parkvale Stream and Booths Creek are both highly valued by Kahungunu ki Wairarapa and Rangitane o Wairarapa;

- Tuna (eels) are still supported by, and harvested from, Booths Creek by local iwi, although not in the numbers or condition as in the past.
- Both Parkvale Stream and Booths Creek support substantial amounts of watercress. This continues to be valued by tangata whenua who harvest significant quantities.
- Instream values deteriorate from upstream to downstream reaches; of particular note is a change from a gravel bed to a silt-covered bed and encroachment of willows.

Kākahi (freshwater mussel) have been observed[8] but their mahinga kai value was not specifically described in by Royal (2011).

2.2.4. Masterton streams

Catchment description

The Masterton streams network comprises several watercourses, primarily the Makoura and Kuripuni streams (Figure 12). Fleet Street Stream (and its tributary Solway Stream) join the lower reaches of the Kuripuni Stream. All streams rise to the northwest of Masterton as a series of springs along a fault line. Upper reaches are heavily modified through the Masterton urban area, with piping, culverting and straightened open concrete channels being commonplace. Stormwater inflows are widespread and there may also be some diversion of flow from the Makoura Stream to the Waipoua River north of Masterton, although the nature and extent of any diversion is unknown.

The streams revert to largely natural channels to the south of Masterton before discharging directly to the Ruamahanga River. Land use in the lower catchments is a mix of lifestyle blocks and both irrigated and non-irrigated farm land. The Masterton wastewater treatment plant occupies land adjacent to the lowest reaches of the Makoura Stream.

Table 6 summarises the low-flow hydrology of the Makoura, Kuripuni, Solway and Fleet Street streams and an ecological values assessment by GWRC.

[8] Notes from 15 March 2011 fieldtrip for Parkvale Stream at Chester Rd; field trip participants included GWRC staff, Wellington Fish & Game and DoC staff, and Cawthron staff.

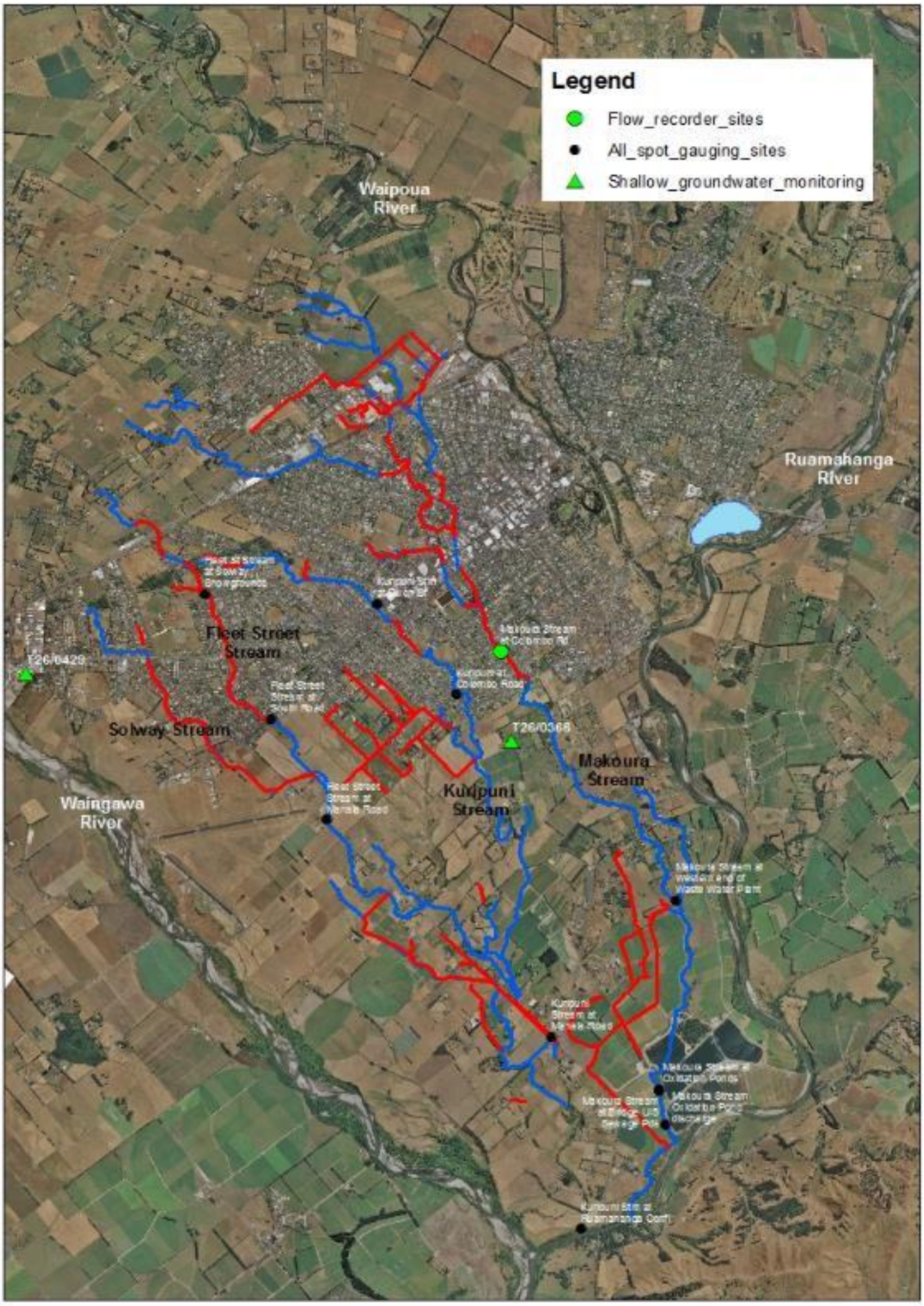

Figure 12. Stream channels and hydrological monitoring sites for the Masterton streams (blue = natural channel, red = highly modified channel) (source material supplied by GWRC).

Table 6. Summary of hydrology, hydrological and ecological values assessment, current abstraction pressures and predicted future pressures for Makoura, Kuripuni, Solway and Fleet Street streams. MALF estimates are based on the status quo flow regime (i.e. include abstractions).

Makoura and Kuripuni streams	
Low flow hydrology	
Median flow (L/s) at Makoura/ Kuripuni/ Solway/ Fleet St streams	No reliable median flow estimates exist for these streams
7-day MALF (L/s) at Makoura at Colombo Rd	60-70
7-day MALF (L/s) at Kuripuni at Colombo Rd	50
7-day MALF (L/s) at Fleet St/ Solway at Manaia Rd	50
1-day MALF (L/s) at Makoura/ Kuripuni/ Solway/ Fleet St streams	No reliable mean annual flow estimates exist for these streams
Values assessment	
Ecological value	Low to moderate with the odd high area (brown mudfish)
Fishery value (sport)	Medium? (no known angling but spawning habitat)
Māori cultural value	High
Abstraction pressure	Low (Fleet) to High (Makoura)
Out of stream value (water use)	Moderate
Abstractions	
Makoura current maximum allowable take (L/s)	53
Kuripuni current maximum allowable take (L/s)	3
Fleet St/Solway current maximum allowable take (L/s)	27.9
Fleet St current maximum allowable take (L/s)	1.4
Future prediction (L/s)	No increased demand or allocation is expected

Hydrology of Masterton streams

Greater Wellington continuously monitors flow at only one site on the stream network, the Makoura Stream at Colombo Road (see Figure 12). The site is located approximately 5 km upstream of the Ruamahanga River, where the stream emerges from the Masterton urban area. It has only been operating since January 2019.

Spot gauging data are scarce, especially for the Fleet Street/Solway stream complex that is frequently dry through the upper reaches in summer. While more data are available for the Kuripuni and Makoura streams, these have been collected largely at the Colombo Road sites. No comprehensive concurrent gauging assessments have been completed so the longitudinal pattern of flow from headwater springs to the Ruamahanga River is largely unquantified. However, the streams are considered to be largely gaining from groundwater, and in the lower reaches (downstream of Masterton) they generally maintain fairly stable flows and reasonable depths throughout summer.

Spot gaugings at Colombo Road suggest summer base flows of 40-70 L/s in the Kuripuni Stream while the gaugings and short-term continuous record for the Makoura Stream suggest a range of around 40–120 L/s.

No reliable MALF estimates exist for these streams. Nevertheless Keenan (2021) provided some preliminary estimates of abstracted 7-day MALF (Table 6), and in her 2009 report suggested naturalised 7-day MALF for the lowest reaches of the Makoura Stream is likely to lie between 100-200 L/s but that further data would be needed to improve any estimates.

Seasonal change in flow does not appear to be large, with winter base flows in 2019 and 2020 being around 200-400 L/s in the Makoura Stream and the largest freshes being around 1 m^3/s. The observed summer median flow (November-April) for the short record available at Colombo Road, is only about 100 L/s.

Allocation and current abstraction management regime

There are five consented takes in the Makoura Stream (3 surface water and 2 Category B), and four takes in the Kuripuni Stream, including Fleet Street and Solway streams (2 surface water and 2 Category B) (Figure 13).

Current paper allocation from both catchments (assuming a 90-day pumping duration for depletion by abstracted takes) is relatively low in the Fleet Street/Solway Stream (about 7 L/s), moderate in the Kuripuni (around 12 L/s) and higher in the Makoura (around 50 L/s—although 80% of this occurs in the lowest reach). There is an acknowledgement among water users of at least full allocation so no increased demand (or allocation) is expected (Table 6).

Almost all takes are restricted (to half volumes) at a flow of 100 L/s at the Colombo Road site on the Makoura Stream. This probably equates to a flow exceeding MALF and close to summer median since the large majority of abstraction from the Makoura occurs downstream of Colombo Road. There is currently only one cease take and it applies to one of the smallest takes on the Fleet Street system. More minimum flows can be expected to be applied under Greater Wellington's 'Natural Resources Plan' at the next round of consent renewals, starting in 2023.

The large bulk of the take volume occurs in the lower half of the catchments. No attempt has been made in the past to assess flow alteration (with reference to MALF) at individual points of take.

Generally in the Wellington region, volumes of actual cumulative catchment water use over prolonged periods (several consecutive weeks to months) are significantly lower than paper allocation. On the other hand, in these catchments unconsented/permitted take (especially in the lower catchments) is likely to be higher than average due to the high density of small holding blocks and accessibility of the stream network.

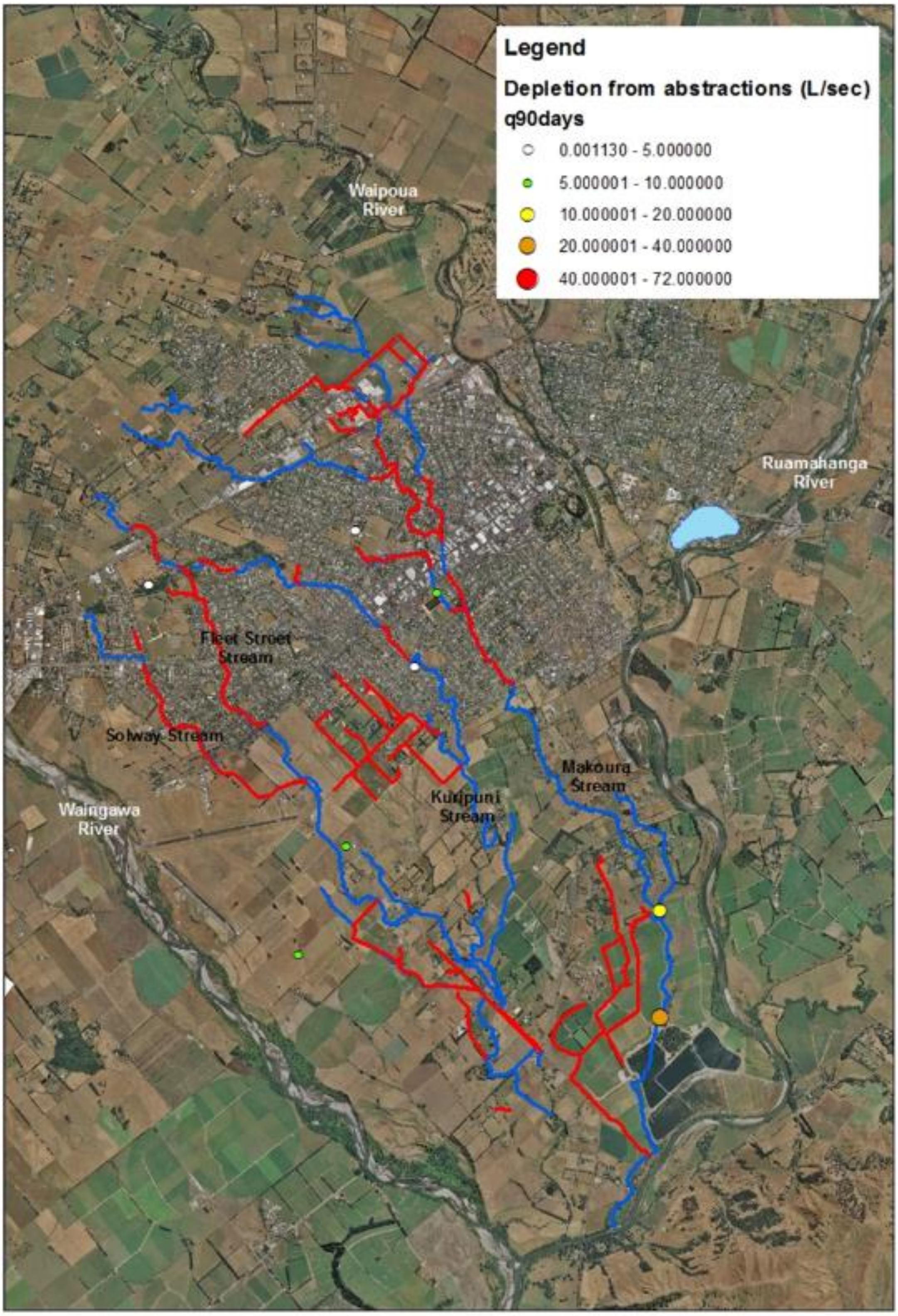

Figure 13. Consented surface and groundwater abstractions in the Masterton stream catchments (source material supplied by GWRC).

Instream values

The following assessment of instream values was provided by Alton Perry, GWRC.

The Masterton streams are typical of urban streams, being straightened and confined, with sections of concrete banks, providing little hydraulic habitat diversity. The water quality is likely to be poor.

Flows in the Makoura and Kuripuni (through the town) typically seem to be sustained at levels that adequate for the aquatic values that are persisting.

The Masterton streams support a moderate diversity of native fish including: longfin and shortfin eels, inanga, brown mudfish and common bully. Brown trout are also present. The native fish that have a conservation status of 'At risk, declining' are, longfin eel, īnanga and brown mudfish (Dunn et al. 2018). The shortfin eel and common bully have a 'Not threatened' status.

People feed longfin eels along the streams and value their presence. Shortfin and longfin eels, non-migratory common bully, and brown and rainbow trout are common and the inanga are also present.

Kōura (crayfish) are also fairly common. The 'rare' aquatic moss (*Fissidens berteroi*) is common in the Kuripuni and Makoura streams.

Populations of brown mudfish are persisting in some of the springheads in remnant kahikatea forest.

There have been reports of sections of the Fleet Street stream system drying up and eels needing to be rescued, mainly during droughts.

2.2.5. South Featherston streams

Catchment description

The South Featherston stream system comprises several watercourses, including Dock Creek[9], the Tauherenikau Seepage Drain and Murphy's Drain (Figure 14).

Dock Creek rises as a series of springs in what was once the original channel of the Tauherenikau River before it was diverted 50 years ago for flood management purposes to take a more direct route into Lake Wairarapa. The springs emerge (see Figure 14) in approximately the same area as the river loses a significant volume of flow to groundwater and becomes perched (i.e. stream flow is driven by river loss and re-emergence). Dock Creek and its primary tributaries run for about 10 km through farmland as incised, macrophyte dominated channels before joining Otakura Stream and then discharging to Lake Wairarapa.

[9] Sometimes referred to as Stonestead Creek.

The Tauherenikau Seepage Drain and Murphy's Drain (including Ashby's Drain) rise on the other side of the river and are driven primarily by the same process of river flow loss and re-emergence. These drain channels are highly modified (e.g. straightened) compared with the more natural Dock Creek but overall have similar form in being relatively incised and dominated by macrophytes.

Both Dock Creek and the drains have connections to the tail end of water races (Longwood and Moroa) although there is no information to better characterise these points of connection.

Land use in the Masterton stream catchments is predominantly dairy.

Table 7 summarises the low-flow hydrology of the Makoura, Kuripuni and Fleet Street streams and an ecological values assessment by GWRC.

Figure 14. Stream channels and hydrological monitoring sites for the Masterton stream sites including Dock Creek Tauherenikau Seepage Drain and Murphy's Drain (including Ashby's Drain) (source material supplied by GWRC).

Table 7. Summary of hydrology, hydrological and ecological values assessment, current abstraction pressures and predicted future pressures for South Featherston streams (Dock Creek, Tauherenikau Seepage Drain and Murphy's Drain). MALF estimates are natural.

Dock Creek, Tauherenikau Seepage Drain and Murphy's Drain	
Low flow hydrology	
Median flow (L/s) – Dock Creek	Estimate between 700–800[a]
Median flow (L/s) – Tauherenikau Seepage Drain and Murphy's Drain	Not available
7-day MALF (L/s) at Dock Creek	Estimate 560[b]
7-day MALF (L/s) at Tauherenikau Seepage Drain and Murphy's Drain	Not available
1-day MALF (L/s) at Dock Creek	Not available
1-day MALF (L/s) at Tauherenikau Seepage Drain and Murphy's	Not available
Values assessment	
Ecological value	Low to medium?
Fishery value (sport)	Medium? (no known angling but possible spawning)
Māori cultural value	Medium?
Abstraction pressure	Moderate to High
Out of stream value (water use)	High
Abstractions	
Dock current maximum allowable take (L/s)	380
Tauherenikau current maximum allowable take (L/s)	198
Murphy's current maximum allowable take (L/s)	84
Future prediction (L/s)	Not available

[a] Based on relationship between Dock and neighbouring flow sites.
[b] Naturalised MALF estimate for the period 2014–2020.

Dock Creek hydrology

A continuous water level monitoring site has been operating in Dock Creek since late 2016. However, it is difficult to maintain a stable rating in the stream due to excessive macrophyte growth and thus the record is somewhat patchy. In addition, estimating MALF is complicated by the fact that flow at the site is affected, to a relatively large degree, by abstraction. While surface takes are telemetered and can therefore be accounted for, it is more difficult to estimate the cumulative effects of groundwater takes (see more in Allocation section below).

Keenan (2021) undertook a preliminary analysis of Dock Creek hydrological information using the continuous record for 2016–2020. The flow data were naturalised using metering data and a cumulative groundwater depletion estimated using two methodological approaches.

The naturalised 7-day MALF estimate for the period 2014–2020 is 560 L/s (Keenan 2021). These estimates are considered to be preliminary estimate because (1) the 7-day MALF calculations are based on only a short period of hydrological record, and (2) there is an underlying assumption that method used to predict the streamflow depletion estimate best represents the actual effects on Dock Creek.

Median/mean flow is unknown as the continuous gauge record is too short and incomplete across the seasons to derive a reasonable estimate. A cursory look at the relationship between Dock Creek and neighbouring flow sites with better records suggests a median natural flow in the range 700–800 L/s is likely.

Tauherenikau Seepage Drain and Murphy's Drain hydrology

There has never been a permanent flow monitoring site on any part of the Tauherenikau Seepage Drain (TSD) or Murphy's Line Drain network, so no continuous flow data exists. Characterisation of the hydrology (most recently by Thompson 2014) therefore relies solely on spot gauging data that have been collected sporadically since the early 1990s by both GWRC and Greg Butcher on behalf of consent holders.

Unfortunately, there has never been a set of comprehensive concurrent (same day) low flow gaugings at all points of interest on the drains. However, available gaugings suggest a general pattern in the main stem TSD is one of substantially increasing flow in a downstream direction from an average (from existing gaugings) of 60 L/s at Vollebregts to 230 L/s at Rayners to just over 400 L/s as the Seepage Drain enters Barton's Lagoon. The flow gain downstream of Vollebregt is likely due to seepage input from groundwater and re-emergence of the Tauherenikau River losses; while downstream of Rayners, dry weather flow is doubled by input from Murphy's Drain (average 210 L/s). Flow in the Seepage Drain tributary is much lower, averaging 37 L/s on the occasions it has been gauged. While the numbers just given are based on only a handful of gaugings per site and will not reflect flow conditions across years, they are a starting point.

No estimate of MALF (or other flow statistics) has been made to date. A rough estimate of MALF might be possible with further analysis of existing data, and more likely with further data collection and analysis.

Allocation and current abstraction management regime

There are ten consented takes affecting flow in Dock Creek: five direct surface takes and five takes from connected (Category A and Category B) groundwater. There are a further ten consented takes from the TSD and other drains on the western side of the river. Four of these are surface water takes and the remainder Category A groundwater takes (Figure 15).

Current paper allocation from consents is 380 L/s although the estimated maximum potential depletion rate from the stream is closer to 250 L/s (as several of the groundwater takes are considered to have low levels of hydraulic connection with the stream). This depletion rate equates to about 45% of estimated natural 7-day MALF at the bottom of the catchment (a 'high' degree of alteration) (see also Keenan 2021), and probably around a third of median flow. Most of the takes are currently restricted (to half their daily allowance) when flow in Dock Creek upstream of the Otakura Stream confluence is less than 500 L/s (equating to about 90% of MALF). Cease takes have not been required in the past but are now under the new Natural Resources Plan.

There are a further ten consented takes from the TSD and other drains on the western side of the river. Four of these are surface water takes and the remainder Category A groundwater takes. Current paper allocation from these consents is about 200 L/s and the maximum potential depletion rate is estimated to be around 135 L/s. This depletion rate equates to about 35% of an 'average' dry weather summer flow at the bottom of the catchment (a 'moderate' to 'high' degree of alteration) before the drains discharge to Barton's Lagoon. Most of the takes are currently restricted (to half their daily allowance) when flow in the nearby Otakura Stream falls below 50 L/s. It is not known how this flow relates to MALF, as this statistic has not been estimated. Cease takes have not been required in the past but are under the new Natural Resources Plan.

Generally in the Wellington region, volumes of cumulative catchment actual water use over prolonged periods (several consecutive weeks to months) is significantly lower than paper allocation.

Takes are located mainly downstream of SH522 in the lower half of the catchments. Some attempt has been made in the past to assess flow alteration at individual points of take in the TSD catchment (see Thompson 2014), but data were limited.

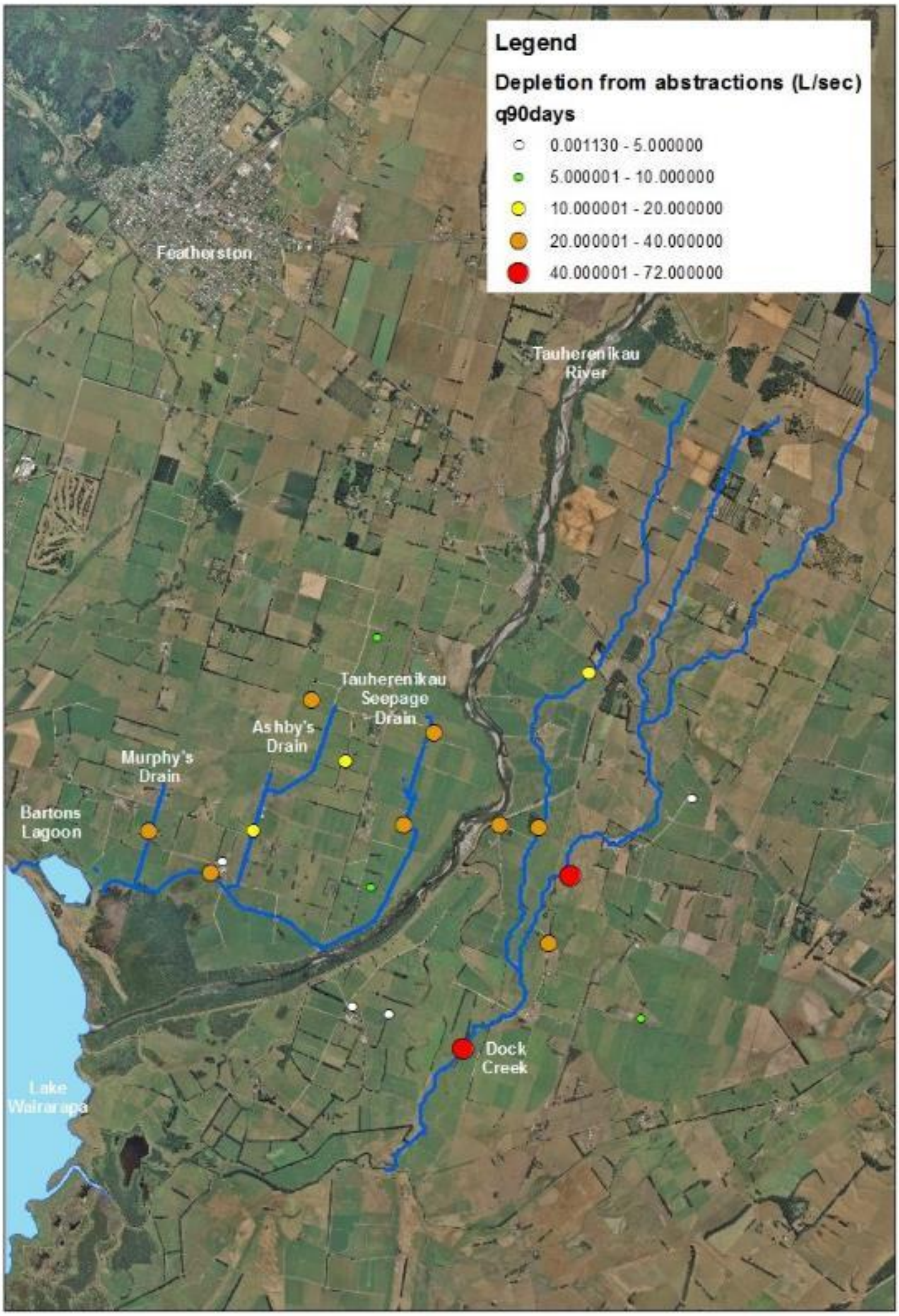

Figure 15. Consented surface and groundwater abstractions for the South Featherston streams (source material supplied by GWRC).

Instream values

A report on Maori cultural values associated with several Wairarapa waterways, including Dock Creek was undertaken by Royal (2011). Observations pertinent to the assessment of abstractions at low flow included:

- Dock Creek is part of Wairarapa Moana; the lake and its wider freshwater environment, including marginal wetlands and tributary waterways, is of very high cultural significance to Ngati Kahungunu ki Wairarapa.
- Wairarapa Moana and the Otakura Stream catchment (of which Dock Creek is a primary tributary) has been important in the past as a source of food, particularly tuna (eels) and watercress, but also flounder, īnanga and kōkopu. However, in recent years the mahinga kai value of these streams has declined due to low eel numbers and poor water quality.

2.2.6. Assessment of the sustainability of current hydrological alteration & recommendations for studies to inform ecological flow and allocation limits in spring-fed streams

How sensitive are ecological values to change in flow regime?

The instream values of the spring-fed streams included in present project (Parkvale Stream and Booth Creek, Masterton Streams, South Featherston Streams) are longfin and shortfin eels, common bully, brown and rainbow trout, and kōura.

Eels and common bully in spring-fed streams have low to moderate flow requirements. Eels are less reliant on benthic invertebrate food production from stony riffles and shallow runs than in hill-fed streams, having plenty of alternative invertebrate prey associated with macrophytic depositional habitats in slower runs and pools. Kōura are not flow-dependent, as evidenced by their abundance in lakes and slow, deep macrophyte dominated reaches of spring-fed streams. Trout are the most flow-dependent of the above species, because they feed on flow-dependent invertebrate drift[10] as well as invertebrates on the stream bed and macrophytes. However, it is unlikely that trout are numerous enough, to support valued fisheries within the above spring-fed streams, although they will contribute to the Lake Wairarapa and Ruamahanga trout fisheries by exporting recruits.

Benthic invertebrates colonising stony riffles and runs will have the highest flow requirements of the instream values in these spring-fed streams. Many of the species occupying these habitats have moderate to fast water velocity preferences. Moreover, they prefer open, unconsolidated gravel-cobble substrate. These habitats are sensitive to adverse effects of fine sediment deposition and periphyton proliferation, both of which increase with reduced flow. These effects will add to loss of benthic invertebrate habitat area if flow reduction also substantially reduces the wetted width of stony riffles and runs.

[10] Invertebrate drift concentration and flux can decline with flow reduction; flux being the total number of invertebrates drifting past a stream cross section.

All aspects of ecosystem health are sensitive in varying degrees to reduction in DO. However, flow-related declines in DO below critical levels for instream life usually occur at quite low flows.

For the above reasons, there is scope for minimum flow and allocation limits for the spring-fed streams reviewed in this report to be more permissive than would be appropriate for hill-fed streams.

Is the current level of hydrological alteration sustainable with respect to safeguarding ecosystem health?

Current paper allocation from Parkvale Stream and Booth Creek is high, equating to between about 130% and 180% of naturalised 7-d MALF, respectively. Of the Masterton spring-fed streams, allocation is relatively low in the Fleet Street/Solway Stream, moderate in the Kuripuni and high in the Makoura Stream. Of the South Featherson Streams, allocation from Dock Creek is high (about 45% of naturalised 7-day MALF) and from Tauherenikau Seepage Drain and Murphy's Drain is moderate (about 35% of an 'average' dry weather summer flow at the bottom of the catchment).

Given the low-moderate instream values in these streams, and their relative insensitivity to flow reduction, concerns over the ecological sustainability of current allocation fall mainly on those streams currently experiencing a high degree of hydrological alteration (i.e. Parkvale Stream and Booth Creek, and Makoura Stream and Dock Creek). Comparison with the default allocation limit of 20% of MALF in Appendix 1 suggests that that the 'high' allocation rates reported for these streams is likely to be having more than minor adverse effects on instream habitat and other aspects of ecosystem health.

If not, what limits should apply?

For the above Wairarapa spring-fed streams estimated to have low to moderate allocation demand (< 30% or 35% of naturalised 7-d MALF), we recommend that default minimum flows and allocation rate limits be applied. The default limits in Appendix 1 could be relaxed somewhat to accommodate current allocation in these streams, given their low-moderate instream values and their relative insensitivity to flow reduction.

For the other streams estimated to be experiencing high allocation demand, we recommend that limits be informed by results of the specific studies outlined below.

2.2.7. Recommended specific studies for Wairarapa spring-fed streams

Streams with current low-moderate allocation demand (< 35% of naturalised 7-d MALF)

Hydrological studies

- Better estimate flow statistics (naturalised & status quo 7-d MALF, median flow)
- Better estimate current abstraction versus paper allocation

- Better estimate longitudinal low flow patterns with concurrent gaugings.

Ecological values, hydraulic geometry and instream habitat studies

- Better estimate instream values and their spatial distribution.

Streams with current high allocation demand (< 35% of naturalised 7-d MALF)

Given the low to moderate importance of instream values identified for the spring-fed streams with high allocation demand (Parkvale Stream/Booths Creek, Makoura Stream and Dock Creek), and the relative insensitivity of the instream values to flow reduction, a low to moderate investigation effort is justified.

Moreover, default minimum flow and allocation limits are unlikely to accommodate current high allocation demand on Parkvale Stream and Booth Creek, and Makoura Stream and Dock Creek, further justifying some stream specific instream flow investigations to inform the scope for sustainable water allocation. We recommend that studies on these streams be confined to the following:

Hydrological studies

- Better estimate flow statistics (naturalised & status quo 7-d MALF, median flow)
- Better estimate current abstraction versus paper allocation
- Better estimate longitudinal low flow patterns with concurrent gaugings.

Ecological values, hydraulic geometry and instream habitat studies

- Streams/reaches where water level is not controlled by macrophytes
    - Hydraulic geometry measurements for modelling (using the WAIORA method (Jowett et al. 2003)
    - DO versus flow measurements and modelling covering one or more reaches affected, and unaffected, by groundwater inflows
- Streams/reaches where water level is controlled by macrophytes
    - Hydraulic geometry measurements at low flow
    - DO versus flow measurements and modelling covering one or more reaches affected, and unaffected, by groundwater inflows.

3. SUMMARY OF RECOMMENDATIONS

3.1. Wainui Stream

3.1.1. Hydrology

In the Wainui Stream, the following hydrological studies are necessary for understanding the degree of hydrological alteration due to current water abstraction, and to provide the foundation for assessing habitat and ecological effects:

- further review and analysis of the groundwater take data to establish a firm view on the most likely depletion curves
- summer flow gaugings in the lower stream reaches
- target flow gaugings to periods of pumping and no pumping to determine whether any measurable stream response can be detected. This would depend on whether KCDC have any ability to manipulate pumping.
- combine analysis of the surface gauging data and analysis of the groundwater depletion data to predict hydraulic response of current groundwater takes and different restriction regimes
- verify whether the stream dries naturally in places, and the spatial and temporal extent of drying, and any exacerbation of drying attributable to KCDC's groundwater abstraction.

3.1.2. Ecological values, hydraulic geometry and habitat

We recommend the following studies on instream values, hydraulic geometry and instream habitat to help assess ecological effects of current and future water allocation in Wainui Stream to inform limits setting:

- better determine the spatial distribution of native fish populations, including species presence and density, versus the spatial footprint of flow alteration from water allocation
- undertake a cross-sectional hydraulic-habitat survey and modelling exercise targeted at the lower segment of the stream, between the KCDC take and the bridge above the beach. This moderately intensive instream flow assessment is justified by the high diversity of native fish species coupled with large allocation demand. The modelling will provide relationships between flow and hydraulic geometry variables (wetted width, average depth and velocity) and habitat (for benthic invertebrates and the range of fish species known from the stream).

3.2. Turanganui and Tauanui rivers

3.2.1. Hydrology

For the Turanganui and Tauanui rivers we support the following Council's initiatives to gain better information on the connectivity between surface water and groundwater for the Turanganui and Tauanui rivers through:

- installing flow recorders and sensors to determine the effect of abstraction on naturalised flow
- concurrent longitudinal gaugings to determine water loss and gain at low flows
- a targeted study to understand the hydrogeology and connectivity between surface water and groundwater to address:
    - rural community concerns on summer low flows and speculation that abstraction may be a central cause for die-back of native trees in a high value QEII-covenanted forest remnant that bounds the Turanganui River.
    - effects of abstraction on surface flow reduction and spatial extent and duration of stream drying.

3.2.2. Ecological values, hydraulic geometry and habitat

We recommend the following studies on instream values:

- hydraulic geometry and instream habitat survey to help assess ecological effects of current and future water allocation and to inform limits setting. Also to better determine the spatial distribution of native fish populations, including species presence and density, versus the spatial footprint of flow alteration from water allocation
- undertake a cross-sectional hydraulic-habitat survey and modelling exercise targeted at the mid- and lower-segments of both rivers to provide relationships between flow and hydraulic geometry variables (wetted width, average depth and velocity) and habitat (for benthic invertebrates and the range of fish species known from the stream).

3.3. Wairarapa spring-fed streams

3.3.1. Hydrology

For Wairarapa spring-fed streams with a low-moderate and high allocation demand we recommend GWRC focus on gaining better estimates of:

- flow statistics
- hydrological alteration caused by current abstractions (spatial and temporal extent)
- ground water inflows and their spatial extent.

3.3.2. Ecological values, hydraulic geometry and dissolved oxygen

For high allocation demand streams (i.e. Parkvale Stream/Booths Creek, Makoura Stream and Dock Creek) we recommend surveys be undertaken to determine the spatial distribution of native fish populations, including species presence and density, versus the spatial footprint of flow alteration from water allocation.

We recommend the following physical and water quality surveys and modelling be undertaken depending on whether macrophytes are controlling water level in the stream/reach.

Streams/reaches where water level is not controlled by macrophytes

- survey and modelling to determine relationships between hydraulic geometry variables (wetted width, mean depth) and flow
- survey and modelling to determine relationships between dissolved oxygen and flow, covering one (or more) reach or reaches affected, and unaffected, by groundwater inflows..

Streams/reaches where water level is controlled by macrophytes

- hydraulic geometry measurements (wetted width and mean depth) at low flow
- survey and modelling to determine relationships between dissolved oxygen and flow, covering one (or more) reaches affected, and unaffected, by groundwater inflows.

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5. REFERENCES

Allen C, Hay J 2011. Minimum flow setting in spring-fed streams: issues and recommendations. Prepared for Environment Southland. Cawthron Report No. 1905. 25 p. plus appendices.

Beca 2008. Draft guidelines for the selection of methods to determine ecological flows and water levels. Report prepared by Beca Infrastructure Ltd for MfE. Ministry for the Environment, Wellington, New Zealand.

Davies-Colley R, Wilcock B 2004. Water quality and chemistry in running waters. In: Freshwaters of New Zealand. Harding J, Mosley P, Person C, Sorrell B (eds.) Chapter 11. New Zealand Hydrological Society and New Zealand Limnological Society.

Dunn NR, Allibone RM, Closs GP, Crow SK, David BO, Goodman JM, Griffiths M, Jack DC, Ling N, Waters JM, Rolfe JR 2018. Conservation status of freshwater fishes, 2017. Published by Department of Conservation.

Hayes JW 2021. Evidence presented to the Environment Court on ecological flow assessment as it relates to Plan Change 7. In the matter of a notice of motion under section 149T(2) to decide proposed Plan Change 7 to the Regional Plan: Water for Otago. Dunedin.

Hayes JW, Goodwin E, Shearer KA, Hay J, Kelly L 2016. Can WUA correctly predict the flow requirements of drift-feeding trout? Comparison with a drift-net rate of energy intake model incorporating drift-flow processes. Transactions of the American Fisheries Society 145: 589-609.

Hayes J, Hay J, Gabrielsson R, Goodwin E, Jellyman P, Booker D, Wilding T, Thompson M 2018. 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 J, Goodwin E, Shearer K, Bind J, Hoyle J, Stecca G, Measures R, Haddadchi A, Walsh J, Willsman A 2020. Ecological flow regime assessment for the Aparima River at Anderson's Beach: Complementing hydraulic-habitat modelling with drift-feeding trout net energy intake modelling. Prepared for Environment Southland. Cawthron Report No. 3457. 129 p. plus appendices.

Hayes J, Booker D, Singh S, Franklin P 2021. Default minimum flow and allocation limits for Otago. Cawthron Advice Letter 2157 to Otago Regional Council, dated 17 September 2021. 19 p.

Hughes P 2014.Friend of Paekākāriki streams. Wainui Catchment (Draft Version 3). 28 p.

Jowett IG, Kingsland S, Collier K 2003. WAIORA User Guide - Version 2.0. NIWA Client Report HAM2003 - 163.

Jowett IG, Payne T, Milhous R, Hernández JMD 2015. System for Environmental Flow Analysis (SEFA), Software package. http://sefa.co.nz.

Keenan L 2009. Mean annual low flow statistics for rivers and streams in the Wellington region. Unpublished technical report, WGN_DOC#715651-V1. Greater Wellington Regional Council.

Keenan L 2021. Low flow characteristics and flow depletion in selected small rivers and stream. Hydrological advice for Greater Wellington Regional Council. Awanui Science. 56 p.

Ministry for the Environment (MfE) 1998. Flow guidelines for instream values (2 volumes). Ministry for the Environment, Wellington.

Ministry for the Environment (MfE) 2008. Proposed national environmental standard on ecological flows and water levels: discussion document. Publication number: ME 868. 61 p.

Ministry for the Environment (MfE) 2018. Climate change projections for New Zealand: atmosphere projections based on simulations from the IPCC fifth assessment, 2nd Edition. Wellington: Ministry for the Environment. 131 p.

Ministry for the Environment (MfE) 2020. National policy statement for freshwater management 2020. Published by Ministry for the Environment. 70 p.

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

Royal C 2011 Cultural values for Wairarapa waterways report. Prepared for Greater Wellington Regional Council. 102 p.

Smith J 2014. Freshwater fish spawning and migration periods. NIWA Report prepared for the Ministry of Primary Industries. NIWA Client Report No: HAM2014-101. 84 p.

Snelder T, Biggs B, Weatherhead M 2004 (updated 2010). New Zealand River Environment Classification user guide. Ministry for the Environment. 144 p.

Thompson M 2012. Booths Creek low flow hydrology: Technical advice to assist with abstraction management. Greater Wellington Regional Council, internal memorandum.

Thompson M 2014. Advice on Tauherenikau Seepage Drain consent renewals. Greater Wellington Regional Council, internal memorandum.

Thompson M 2019. Wainui Stream – review of hydrology and influence of KCDC groundwater takes. Greater Wellington Regional Council, internal memorandum.

Young RG, Doehring KAM 2010. Relationship between low flow and dissolved oxygen and in selected rivers and streams in the Wairarapa: preliminary findings from 2009/10 summer monitoring. Prepared for Greater Wellington Regional Council. Cawthron Report No. 1865. 28 p.

6. APPENDICES

APPENDIX 1. RATIONALE FOR SETTING DEFAULT MINIMUM FLOW AND PRIMARY ALLOCATION LIMITS FOR NEW ZEALAND STREAMS/RIVERS BASED ON A VALUES AND RISK BASED FRAMEWORK.

The following is based on a rationale for setting default minimum flow and allocation limits for Otago streams/rivers proposed by J. Hayes and supported by NIWA staff (Hayes 2021; Hayes et al. 2021).

A1.1 Default minimum flow and allocation limits based on percentage of MALF

The default minimum flows and allocation limits below have been derived from consideration of information from the following sources:

- The 2008 proposed National Environmental Standard for Flows and Water Levels (NES) (MFE 2008)
- The support document for the NES on selection of methods to determine ecological flows (Beca 2008)
- An international presumptive standard for environmental flow protection (Richter et al. 2012).

The NES recommended a default minimum flow limit of 90% of naturalised 7-day (7-d) MALF, and allocation rate of 30%, for rivers with mean flow less than 5 m^3/s. For rivers with mean flow greater than 5 m^3/s, it recommended a minimum flow limit of 80% of naturalised 7-d MALF and an allocation rate of 50% of 7-d MALF. However, the support document to the draft standard advised that "Abstraction of more than 40% of naturalised 7-d MALF, or any flow alteration using impoundments, would be considered a high degree of hydrological alteration, irrespective of region or source of flow". The support document further advised that even a total allocation of 20–30% of naturalised 7-d MALF could be considered a high degree of hydrological alteration in rivers and streams with mean flow less than 5 m^3/s, depending on the instream values and baseflow characteristics.

The support document for the NES Beca (2008) includes Appendix Tables A1.1 and A1.2 below, which were intended to guide the selection of methods for assessing ecological flow requirements; the approach being to apply more complex methods offering greater certainty in determining effects the higher the instream values and hydrological alteration. The guidance in the tables is also relevant to the degree of risk of deleterious effects on instream values. Hence, the tables are relevant for informing environmentally conservative minimum flow and allocation limits.

Table A1.1 Assessment of risk of deleterious effects on instream habitat according to fish species present and natural mean stream flow (and generic application to other values/management objectives). The data in the column for ‘Salmonid spawning and rearing, torrentfish, bluegill bully’, may be generically applied to invertebrates and riverine bird feeding (e.g. wading birds, blue duck, black fronted tern). Table reproduced from Beca (2008). Longfin and shortfin eels were not included in Beca’s table, but probably would fit in column 2, with Inanga etc, because eel habitat is fairly insensitive to flow; cover (coarse substrate, bank overhangs, and woody debris and other debris) is more critical for eel habitat.

Mean flow (m^3/s)	Inanga*, upland bully, Crans bully, banded kopopu*	Roundhead galaxias, flathead galaxias, lowland longjaw galaxias, redfin bully*, common bully*	Salmonid spawning and rearing, torrentfish*, bluegill bully*	Adult trout+
<0.25	High	High	High	High
< 0.75	Moderate	High	High	High
< 5.0	Low	Moderate	High	High
< 15.0	Low	Low	Moderate	High
15–20	Low	Low	Low	Moderate
> 20	Low	Low	Low	Low

* Access to and from the sea is necessary
+ Access to spawning and rearing areas is necessary
* Actual degree of impact will depend on the degree of hydrological alteration whether or not the level of risk is high or low

Table A1.2. Relationship between degree of hydrological alteration and total abstraction expressed as percentage of 7-day mean annual low flow for various risk classifications (Appendix Table A1) based on stream size (baseflow1 and species composition. Table reproduced from Beca (2008).

Risk of deleterious effect						Degree* of hydrological alteration
Low risk and high baseflow	Low risk and low baseflow	Moderate risk and high baseflow	Moderate risk and low baseflow	High risk and high baseflow	High risk and low baseflow	
<20%	<15%	<15%	<10%	<15%	<10%	Low
20–40%	15–30%	15–30%	10–25%	15–30%	10–20%	Medium
>40%	>30%	>30%	>25%	> 30%	>20%	High

Table A1.1 assesses the risk of deleterious effects on instream habitat according to the species and life stage present and naturalised mean stream flow. Risk of deleterious effect is related to stream size; the smaller the mean flow, the greater the risk presented by flow alteration. Risk is also related to fish size interacting with stream size. For example, large (adult) trout, which need deep, fast water, are more at risk in moderate to small rivers than small fish. Finally, risk is also related to conservation status of the instream values; rare, threatened non-migratory galaxiids deserve more care in maintaining habitat and flows because they have greater risk of extirpation than more common, widespread species.

Table A1.1 can then be used with Table A1.2 to determine the degree of hydrological alteration which is related to the risk of adverse effect on instream habitat, ecosystem health and other instream values. Table A1.1 characterises the sensitivity of instream values to flow alteration, and the risk to them of flow alteration, depending on mean flow, fish size/life stage and conservation status. Table A1.2 determines how the total abstraction (in terms of percentage of naturalised MALF) affects the degree of hydrological alteration for the stream and its risk category and its baseflow characteristics.

Richter et al.'s (2012) presumptive flow standard was derived by expert judgement based on an international review of scientific research. The standard states that minimum flows and allocation limits that ensure that naturalised mean daily flows are altered by no more than 10% 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% (i.e. there may be some measurable changes in structure and minimal changes to ecosystem function). "Structure" in this context could refer to flow-related habitat, species composition and abundance of instream communities, abundance. Greater flow alteration will have increasing risk of adverse effects.

Compared to Richter et al.'s (2012) presumptive standard, the NES limits for allocation of up to 30% and 50% of naturalised 7-d MALF in rivers with mean flow less than and greater than 5 m^3/s, respectively, seem insufficiently precautionary. Allocation limits of 20% and 30% for rivers with mean flow less than and greater than 5 m^3/s, respectively, are considered to be more appropriate to give effect to Te Mana O Te Wai (Hayes 2021, Hayes et al. 2021).

Table A1.3 summarises the default minimum flow and allocation limits that proposed by Hayes et al. (2021) for Otago, and recommended by us for Greater Wellington streams/rivers. The limits are based on percentage of naturalised 7-d MALF. The table is derived from Hayes' (2021) evidence presented to the Otago PC7 hearing, but revised to be read as minimum flow limits for ceasing water takes and primary allocation limits not to be exceeded.

Table A1.3. Proposed default minimum flow and primary allocation limits, expressed as % of naturalised 7-d mean annual low flow (MALF), for maintain flows that present a low risk of more than minor effects on ecosystem health and wellbeing of Otago's streams/rivers, including their instream habitat, life-supporting capacity, mahinga kai and fisheries amenity.

Limit	**Surface water body with mean flow ≤ 5 m³/s**	**Surface water body with mean flow > 5 m³/s**	**Abstraction from permanently flowing reaches of intermittent streams**	
			Containing threatened indigenous species; **or** **Significant spawning and juvenile rearing habitat for regionally or nationally important salmonid fisheries downstream**	**Not containing threatened indigenous species;** **or** **significant salmonid spawning and juvenile rearing habitat**
Minimum / residual flow	90% of naturalised 7-day MALF	80% of naturalised 7-day MALF	90% of naturalised 7-day MALF	80% of naturalised 7-day MALF
Allocation rate	20% of naturalised 7-day MALF	30% of naturalised 7-day MALF	20% of naturalised 7-day MALF; or > 15% of instantaneous flow at point of take if naturalised MALF estimates are zero or are unavailable	25% of naturalised 7-day MALF; or > 20% of instantaneous flow at point of take if naturalised MALF estimates are zero or unavailable

The above default minimum flow and allocation limits assume that naturalised 7-d MALF can be estimated for a freshwater management unit of appropriate length for flow management. This is straightforward for gauged streams/rivers with flow recorders installed, but more challenging for ungauged streams. NIWA's recently developed eFlows Explorer webtool (https://shiny.niwa.co.nz/eflowsexplorer/) is a recent innovation worth considering for estimating MALF and other flow statistics (and flow duration curves) for ungauged streams. The app is intended to aid understanding of how minimum flow and total allocation can be set, by demonstrating how they interact with reliability of water supply and an example environmental outcome such as total area of aquatic habitat (wetted width at minimum flow) or availability of habitat for a chosen fish species. The app builds on the National Digital River Network. The predictions for MALF and other flow statistics are less accurate than for gauged rivers with good periods of record. However, they provide an pragmatic interim solution for setting default minimum flow and allocation limits based on the best available estimates of naturalised MALF where gauged flow records do not exist. Limits can be revised in future as more flow data are gathered and naturalised MALF estimates become more accurate.

Minimum flow and allocation limits set as proportions of historical flow statistics, such as the default limits proposed here, assume linear reductions in habitat or ecological responses with flow reduction. However, flow-related habitat and ecological–flow relationships are known to respond non-linearly to flow. This results in default minimum flow and allocation limits delivering different habitat and ecological protection levels in different rivers and for different species/size classes (Snelder et al. 2011; Booker et al. 2014). On the other hand, they are simpler to apply than more complex methods of assessing environmental flows and setting limits, and some guidance exists on percentage flow alteration limits likely to pose low risk of adverse ecological effects (e.g. the 2008 proposed NES and Richter et al.'s (2012) presumptive standard).

The above minimum flow and allocation limits are considered to be environmentally conservative whilst allowing for modest levels of water abstraction (Hayes et al. 2021; Hayes et al. 2021). Environmentally conservative limits:

- give effect to the NPS-FM directive of Te Mana O Te Wai to put the health and wellbeing of water bodies first, and
- take account of uncertainty in naturalised 7-d MALF estimates and the need to reduce the risk of over allocation in the event that the MALF has been overestimated.

Minimum flows can later be revised downward, and allocation rates revised upward, if MALFs are found to be underestimated. However, it is much more difficult to claw back water for rivers after flow has been overallocated.

A1.2 Minimum flow and allocation limits based on percentage of channel geometry variables or instream habitat

Minimum flow and allocation limits set as proportions of historical flow statistics, such as the default limits proposed above, assume linear reductions in habitat or ecological responses with flow reduction. However, flow-related habitat and ecological–flow relationships are known to respond non-linearly to flow. This results in default minimum flow and allocation limits based on percentages of flow statistics delivering different habitat and ecological protection levels in different rivers and for different species/size classes (Snelder et al. 2011; Booker et al. 2014). On the other hand, they are simpler to apply than more complex methods of assessing environmental flows and setting limits, and some guidance exists on percentage flow alteration limits likely to pose low risk of adverse ecological effects (e.g. the 2008 proposed NES and Richter et al.'s (2012) presumptive standard).

More complex environmental flow assessment methods usually require investigations at the reach scale (e.g. to assess relationships between channel geometry variables (wetted width, average velocity and depth) and flow); and they are usually undertaken on gauged rivers where there is a flow record or where a synthetic flow record can be developed. However, it is now also possible to apply channel geometry versus flow, and generalised habitat versus flow (Booker 2016), methods to ungauged streams/rivers using NIWA's recently developed eFlows Explorer webtool (https://shiny.niwa.co.nz/eflowsexplorer/) mentioned above. The app can predict relationships between hydraulic geometry variables such as wetted width and flow, and between generalised habitat and flow for chosen species.

Setting minimum flow limits based on generalised habitat is more complex than default limits based on percentage of MALF owing to the challenge of deciding which species to model and which to base minimum flow limits on. Moreover, habitat–flow relationships are not used for setting the allocation limit, although the effect of the allocation rate on duration of habitat below habitat thresholds can be examined. There is no guidance available that would allow setting of a default allocation limit based on habitat. Nevertheless, the eFlows Explorer's prediction of MALF could be used to set the allocation limit as a percentage of MALF and set the minimum flow as a percentage of wetted width, depth or instream habitat for specific species.

APPENDIX 2. METHODS USED IN THE ASSESSMENT OF ECOLOGICAL FLOW REQUIREMENTS FOR DEGREES OF HYDROLOGICAL ALTERATION AND SIGNIFICANCE OF INSTREAM VALUES.

Table reproduced from MfE (2008).

Degree of hydrological alteration	Significance of instream values		
	Low	Medium	High
Low	Historical flow method Expert panel	Historical flow method Expert panel	Generalised habitat models 1D hydraulic habitat model Connectivity/fish passage Flow duration analysis
Medium	Historical flow method Expert panel Generalised habitat models	Generalised habitat models 1D hydraulic habitat model Connectivity/fish passage	1D hydraulic habitat model 2D hydraulic habitat model Dissolved oxygen model Temperature models Suspended sediment Fish bioenergetics model Groundwater model Seston flux Connectivity/fish passage Flow variability analysis
High	Generalised habitat models 1D hydraulic habitat model Connectivity/fish passage Periphyton biomass model	Entrainment model 1D hydraulic habitat model 2D hydraulic habitat model Bank stability Dissolved oxygen model Temperature models Suspended sediment Fish bioenergetics model Inundation modelling Groundwater model Seston flux Connectivity/fish passage Periphyton biomass model	Entrainment model 1D hydraulic habitat model 2D hydraulic habitat model Bank stability Dissolved oxygen model Temperature models Suspended sediment Fish bioenergetics model Inundation modelling Groundwater model Seston flux Connectivity/fish passage Periphyton biomass model Flow variability analysis