Management Flows for Aquatic Ecosystems in the Kākaunui River

October 2024

Otago Regional Council
Private Bag 1954, Dunedin 9054
70 Stafford Street, Dunedin 9016
Phone 03 474 0827
Fax 03 479 0015
Freephone 0800 474 082
www.orc.govt.nz

© Copyright for this publication is held by the Otago Regional Council. This publication may be reproduced in whole or in part, provided the source is fully and clearly acknowledged.

Report writer: Dean Olsen, Freshwater Scientist, Otago Regional Council
External reviewer: Dr Duncan Gray (Senior Scientist – Water Quality and Ecology, Environment Canterbury)
Jen Dodson (Senior Scientist – hydrology, Environment Canterbury).

Published October 2024

Acknowledgements
The author would like to thank the ORC Environmental Monitoring team for the collection and verification of the hydrological data used in this report. Sean Leslie (Systems and Information Analyst , ORC) provided the consenting information used in this report.

Otago Regional Council

Executive summary

The Kākaunui catchment has a long history of water abstraction. It is one of the first catchments in Otago to have a minimum flow, with a 200 l/s minimum flow at the Mill Dam hydrological monitoring site in effect since the late 1970s. Currently, a minimum flow of 250 l/s (1 October to 30 April) at Mill Dam and McCones flow sites applies to primary permits in the Kākaunui catchment, while a minimum flow of 300 l/s at these sites applies to secondary permits. The primary/secondary allocation limit for the Kākaunui catchment in Schedule 2A is 750 l/s, while consented primary/secondary allocation is 930.3 l/s.

Flow statistics for three sites on the mainstem of the Kākaunui River and sites on the Kauru, Island Stream and Waiareka Creek were calculated by Lu (2023). The naturalised 7-d MALF at the McCones hydrological site was estimated to be 712 l/s, while the observed 7-d MALF is 462 l/s. The Schedule 2A primary allocation is 750 l/s. The current primary allocation in the Kākaunui catchment is 914.6 l/s, or 128% of the natural 7-d MALF. The estimated 7-d MALF for Island Stream at the confluence with the Kākaunui was estimated to be 24 l/s, while the total primary allocation in the Island Stream catchment is 124 l/s, or 516% of the 7-d MALF. The estimated 7-d MALF for Waiareka Creek at Taipo Road was estimated to be 126 l/s, while the observed 7-d MALF is 114 l/s. The total primary allocation in the Waiareka Creek catchment is 116.3 l/s, or 92% of the 7-d MALF.

Medium and thick light brown mats (including Didymo) were the most common periphyton cover at the McCones monitoring site, while benthic cyanobacteria mats were also frequently abundant. Blooms of benthic cyanobacteria are known to occur throughout the Kākaunui catchment and signs have been installed at major access points warning of the potential presence of toxin-producing cyanobacteria. Filamentous algae have also been abundant at the McCones monitoring site at times and can be associated with the high chlorophyll *a* concentrations observed at this site.

Macroinvertebrate communities in the Kākaunui River at McCones were dominated by the mudsnail *Potamopyrgus* and chironomid midges, while oligochaete worms and various caddis flies have been abundant at times. In comparison the macroinvertebrate community at Clifton Falls in the upper catchment has been dominated by the mudsnail *Potamopyrgus* and the common mayfly *Deleatidium*. The macroinvertebrate community in the Kauru at Kauru Hill Rd 700m Upstream has been dominated by the mudsnail *Potamopyrgus*, the common mayfly *Deleatidium*, chironomid midges and oligochaete worms. Macroinvertebrate indices for McCones put this site in the 'poor to 'fair' water/habitat quality classes, while scores for the Clifton Falls site are consistent with 'poor to 'fair' water/habitat quality. Macroinvertebrate indices for the Kauru at Kauru Hill Rd 700m Upstream are consistent with 'poor' to 'good' water/habitat quality, while scores for the Waiareka Creek at Taipo Road is consistent with 'poor' water/habitat quality.

The Kākaunui catchment supports a highly diverse community of indigenous fish with 14 species recorded including several that are at risk or threatened – longfin eel (at risk – declining), torrentfish (at risk – declining), bluegill bully (at risk – declining), kōaro (at risk – declining), inanga (at risk – declining), Canterbury galaxias (at risk – declining), kanakana/lamprey (threatened – nationally vulnerable), and lowland longjaw galaxias (threatened – nationally critical) (Dunn *et al*. 2018). Brown trout are the only introduced fish species present in the Kākaunui River itself, although perch and tench have been recorded from the Island Stream and Waiareka Creek sub-catchments.

An instream habitat model developed for the mainstem of the Kākaunui River between Mill Dam and Gemmels Crossing was applied to consider the effects of different flows on the physical characteristics of the Kākaunui River and habitat for periphyton, macroinvertebrates and fish. The current minimum flow in the Kākaunui catchment (250 l/s) is predicted to maintain between 21% (food-producing habitat) and 72% (the common mayfly *Deleatidium*) of habitat for macroinvertebrates available at the naturalised 7-d MALF. It is predicted to maintain 14% of habitat for torrentfish, 17% of bluegill bully habitat, and 67-77% of habitat for lowland longjaw galaxias compared to the naturalised 7-d MALF. The current minimum flow is predicted to achieve >56% habitat retention for other indigenous species considered and between 55-70% habitat retention for the various brown trout life-stages considered.

Flows of 351-463 l/s are predicted to retain 80% of the habitat for tuna/longfin eel available at the naturalised 7-d MALF. Torrentfish are among the most flow-demanding indigenous fish species in the Kākaunui catchment, and a flow of 624 l/s is predicted to provide 80% habitat retention in the Kākaunui River. Flows of 600 l/s, 340 l/s and 244 l/s are expected to provide 80% habitat retention for bluegill, common and upland bullies, respectively. Flows of 344 l/s, 276 l/s, and 391-449 l/s would provide 80% habitat retention for inanga, Canterbury galaxias and lowland longjaw galaxias, respectively. Habitat for kanakana/lamprey was predicted to be highest at low flows.

The existing minimum flow and allocation limits are predicted to result in flows that are unimpacted or have a low risk of impact relative to naturalised flows (based on the DHRAM score). However, periphyton biomass in the Kākaunui River at McCones exceeds the LWRP objectives for the North Otago FMU and the national bottom line (based on Table 2 of the NOF; NPSFM 2022). Water abstraction and use can affect periphyton accrual and may contribute to high periphyton biomass and exceedance of these objectives. However, the natural characteristics of the Kākaunui (high summer temperatures, long daylight hours, high water clarity and long periods of low flows) along with other factors (such as high nitrogen concentrations observed in the river will also contribute to the high biomasses observed in the Kākaunui catchment. The effects of climate change may exacerbate the current high biomass of periphyton observed in the Kākaunui River.

Minimum flows in both the Kākaunui River and Waiareka Creek have the potential to interact with water quality in the Kākaunui Estuary – higher flows in the river may increase dilution of nitrogen-enriched groundwater and potentially influencing nitrogen concentrations and therefore blooms of macroalgae in the estuary. However, minimum flows typically apply for a relatively short period of time over the irrigation season and so will have a limited impact on nitrogen concentrations entering the Kākaunui Estuary. In comparison, reducing the allocation from the upper Kākaunui catchment will increase flows in the lower catchment and should reduce nitrogen concentrations whenever significant abstraction is occurring.

Minimum flows currently apply at two minimum flow sites on the lower Kākaunui River – Mill Dam and McCones – in addition to the Clifton Falls minimum flow site (1 May – 30 September). The McCones site has been in place since 2003 making the Mill Dam minimum flow site unnecessary. It is recommended that the Mill Dam site is removed as a minimum flow site and that the McCones site is the minimum site on the lower Kākaunui River along with the Clifton Falls site in the upper catchment that applies to winter takes (1 May-30 September).

Setting a minimum flow on the Kauru at Kauru Hill Rd 700m Upstream that is equivalent to the 7-d MALF at this site (120 l/s) would ensure that the extent of drying would not get any larger than would be expected to occur naturally each year, on average. However, whilst introducing a minimum flow on the Kauru would limit the spatial extent of drying, it would not address the duration of drying in the lower reaches of the Kauru River. However, reducing allocation would reduce the effect of water abstraction on the duration of drying in the lower Kauru River.

Contents

List of figures

List of tables

Glossary

Catchment	The area of land drained by a river or body of water.
Existing flows	The flows observed in a river under current water usage and with current water storage and transport.
Habitat suitability curves (HSC)	Representations of the suitability of different water depths, velocities and substrate types for a particular species or life-stage of a species. Values vary from 0 (not suitable) to ideal (1). HSC are used in instream habitat modelling to predict the amount of suitable habitat for a species/life-stage.
Hydrological year	The twelve-month period from 1 July to the 30 June in the subsequent year.
Instream habitat modelling	An instream habitat model used to assess the relationship between flow and available physical habitat for fish and invertebrates.
Irrigation	The artificial application of water to the soil, usually for assisting the growing of crops and pasture.
7-day low flow	The lowest seven-day low flow in any hydrological year is determined by calculating the average flow over seven consecutive days for every seven consecutive day period in the year and then choosing the lowest value.
7-d Mean Annual Low Flow (7-d MALF)	The average of the lowest seven-day low flow for each hydrological year of record.
Mean flow	The average flow of a watercourse (i.e. the total volume of water measured divided by the number of sampling intervals).
Primary allocation	Primary allocation refers to water takes with the highest priority that can be taken when flows are higher than the primary minimum flow. Primary allocation water takes have high reliability for water users and can be used for run-of-the-river irrigation
Minimum flow	The flow below which the holder of any resource consent to take water must cease taking water from that river.
Natural flows	The flows that occur in a river in the absence of any water takes or any other flow modification.
Naturalised flows	Synthetic (calculated) flows created to simulate the natural flows of a river by removing the effect of water takes or other flow modifications.

NOIC	North Otago Irrigation Company
Reach	A specific section of a stream or river.
River	A continually or intermittently flowing body of fresh water that includes a stream and modified watercourse but does not include any artificial watercourse (such as an irrigation canal, water-supply race or canal for the supply of water for electricity power generation and farm drainage canal).
Secondary allocation	Secondary allocation refers to water takes with the second highest priority that can be taken when flows are higher than the secondary minimum flow. Secondary allocation water takes have high reliability for water users and can be used for run-of-the-river irrigation.
Supplementary allocation	Policy 6.4.9 of the RPW provides for the abstraction of flows in additional blocks above the primary and secondary allocation blocks, with such abstraction subject to supplementary minimum flows that are equivalent to a 1:1 flow-sharing ratio.
Taking	The taking of water is the process of abstracting water for any purpose and for any period of time.

1. Introduction

The Kākaunui[1]/Kakanui River (hereafter referred to as Kākaunui) is a medium-sized river that rises in the Pokohiwitahi[1]/Kakanui Range, before flowing eastward and entering the Pacific Ocean 10 km south of Oamaru in North Otago.

The upper reaches of the Kākaunui and Kauru Rivers arise within high-altitude tussock grasslands and extensively grazed grasslands. There are areas of exotic forestry within the Island Stream and Fuchsia Creek/ Te Horoku Kōtukutuku sub-catchments. The remainder of the catchment is dominated by high-producing grasslands with areas of cropping. Sheep and beef farming, sheep farming, dairy farming, beef farming and deer farming are the dominant land-uses within the Kākaunui catchment, with irrigation supporting a shift in land use from sheep farming towards dairy and beef farming (Ozanne & Wilson, 2013). In recent years, some properties that have previously been extensively grazed as sheep and beef farms have been converted to carbon forestry[2]. This has led to concerns from residents, including the potential for reduced water yields from areas of forestry, leading to lower flows in the Kākaunui catchment.

The Kākaunui catchment includes sites recognised as kāinga mahinga kai (food-gathering place) where a range of foods were gathered including tuna (eels), inaka (whitebait), mata (juvenile whitebait), aua (yelloweye mullet), and maunu (moulting ducks), weka, tutu, and kōareare (the edible root or rhizome of raupō/bulrush[1]).

The Kākaunui catchment is within the North Otago Freshwater Management Unit (FMU). Irrigators taking water from the Kākaunui River have been subject to a minimum flow since the late 1970s, with a 200 l/s minimum flow at the Mill Dam hydrological monitoring site applying to water permits in the catchment[3]. Since 2004, the current minimum flow for the Kākaunui River has been in place, with a summer minimum flow of 250 l/s for primary permits, or 300 l/s for secondary permits at Mill Dam and McCones flow sites (**Error! Reference source not found.**). A winter (1 May to 30 September) m inimum flow of 400 l/s applies to the Clifton Falls, Mill Dam and McCones flow sites. The primary allocation limit specified for the Kākaunui catchment (excluding Waiareka Creek and Island Stream catchments) in Schedule 2A is 750 l/s.

The North Otago Irrigation Company (NOIC; formerly the North Otago Downlands Water Company) brings water from the Waitaki River into the Kākaunui catchment to irrigate up to 26,000 ha. Stage 1 was completed in 2006 and irrigated up to 10,000 ha with up to 4 m^3/s of water from the Waitaki River. Stage 2 was started in 2016 and completed in 2017, allowing delivery of the full design capacity of 8 m^3/s. The NOIC scheme discharges water into Waiareka Creek, with this augmented water abstracted at various points along the creek. A residual flow of 100 l/s must be maintained in the lower Waiareka Creek while the scheme is operating.

There are several water quality issues recognised within the Kākaunui catchment. Land-use intensification within the Waiareka Creek catchment resulting from irrigation has been associated with

[1] https://www.kahurumanu.co.nz/atlas
[2] Forestry planted and managed for carbon sequestration and registered for inclusion within the New Zealand Emissions Trading Scheme.
[3] Environment Court decision C79/2002, paragraph 12

an increase in nitrogen and phosphorus concentrations in Waiareka Creek (Ozanne & Wilson, 2013). Nitrogen-enriched groundwater enters the lower reaches of the Kākaunui River, leading to prolific growths of periphyton (Ozanne & Wilson, 2013). The combined nutrients of the Kākaunui and Waiareka Creek have led to prolific algal growth in Kakanui Estuary at times (Ozanne & Wilson, 2013).

1.1. Purpose of the report

This report presents information to inform water management decision-making in the Kākaunui catchment including hydrological information (flow naturalisation and flow statistics), data on aquatic values (including the distribution of indigenous fish), application of instream habitat modelling to guide flow-setting processes, and consideration of the current state of the Kākaunui River compared to the proposed objectives for the North Otago FMU set out in the proposed Otago Land and Water Regional Plan.

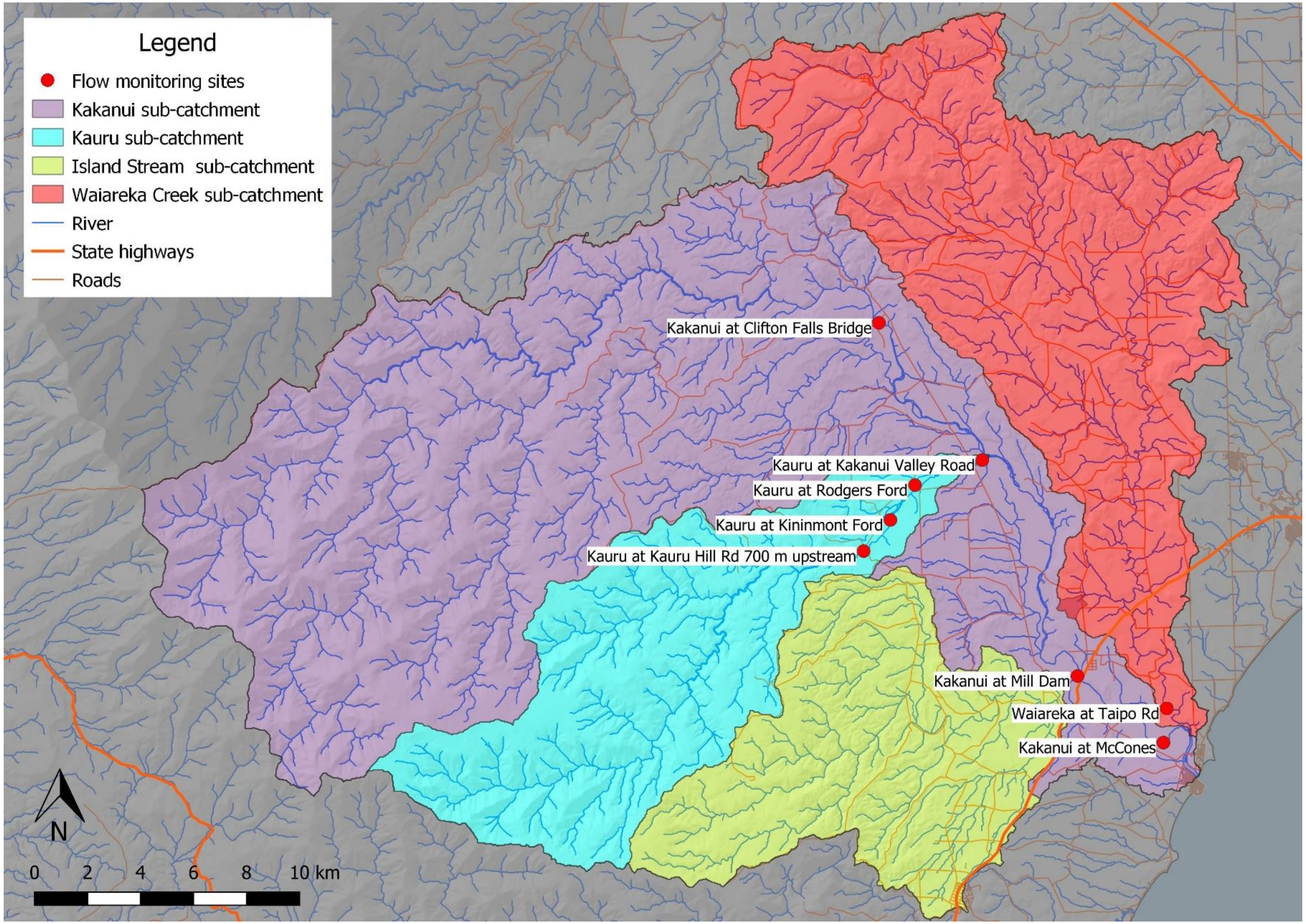

Figure 1 Map of the Kākaunui catchment showing the sub-catchments and flow recorder sites.

2. Background information

2.1. Catchment description

The Kākaunui River (total catchment area of 894 km^2) has three major tributaries – the Kauru River (143 km^2), Island Stream (122 km^2), and Waiareka Creek (213 km^2). From its source in the Pokohiwitahi/Kakanui Range, the Kākaunui River flows north-east for about 40 km, through gorges incised in rolling or downland country, before emerging onto plains at Clifton. It then flows south-eastwards at a gentler gradient through highly developed pastures to be joined further down the widening valley by the Kauru River. The headwaters of the Kauru River also arise at high elevations in the Pokohiwitahi/Kakanui Range, flowing through a steep, incised valley before emerging out onto a broad gravel bed for 6 km between the Kauru Hill Road bridge and its confluence with the Kākaunui River (**Error! Reference source not found.**). Island Stream flows from its headwaters in the foothills of t he Pokohiwitahi/Kakanui Range (maximum elevation 850 m a.s.l.) to meet the Kākaunui River at Maheno, just upstream of the State Highway 1 (SH1) (**Error! Reference source not found.**). In contrast, W aiareka Creek catchment is characterised by distinctive lowland topography, formed mainly on limestone to the north and east of the Kākaunui River catchment. The high porosity of the limestone means that the Waiareka has few tributaries. The Waiareka joins the Kākaunui River in the estuary (**Error! Reference source not found.**).

The Kākaunui River can be divided into three sections of different character. The upper 32 km of river is generally contained by steep hillsides. The gradient decreases in the middle reaches, and the lower river is low gradient (Ozanne & Wilson, 2013). It flows into Kākaunui Estuary before flowing into the Pacific Ocean 10 km south of Oamaru (see Section 2.1.4).

2.1.1. Climate

The climate within the Kākaunui catchment is classified as either 'cool-dry' (mean annual temperature <12°C, mean annual effective precipitation ≤500 mm) or 'cool-wet' (mean annual temperature <12°C, mean annual effective precipitation 500-1500 mm) (River Environment Classification, Ministry for the Environment & NIWA, 2004). There is a strong gradient in rainfall within the catchment, with more than a metre of rain falling in the higher elevation areas in the upper catchment, while near the coast mean annual rainfall is as low as 600 mm (Figure 2).

Annual sunshine hours at Oamaru exceed 1,800 h, with common summer temperatures of around 20°C. The North Otago downland region is well known for its low rainfall. The mean monthly precipitation at three rainfall stations is shown in Table 1. Drought seasons had a severe impact on agricultural activity until the North Otago Irrigation Company (NOIC) was granted consent to take water from the Waitaki River to use as irrigation water in the Kākaunui catchment. Table 2.1 shows a marked seasonal variation in rainfall, with highest rainfall occurring in summer (December-January),m although the effectiveness of the summer rainfall is reduced due to high evapotranspiration. Drought seasons had a severe impact on agricultural activity until the North Otago Irrigation Company (NOIC) was granted consent to take water from the Waitaki River to use as irrigation water in the Kākaunui catchment.

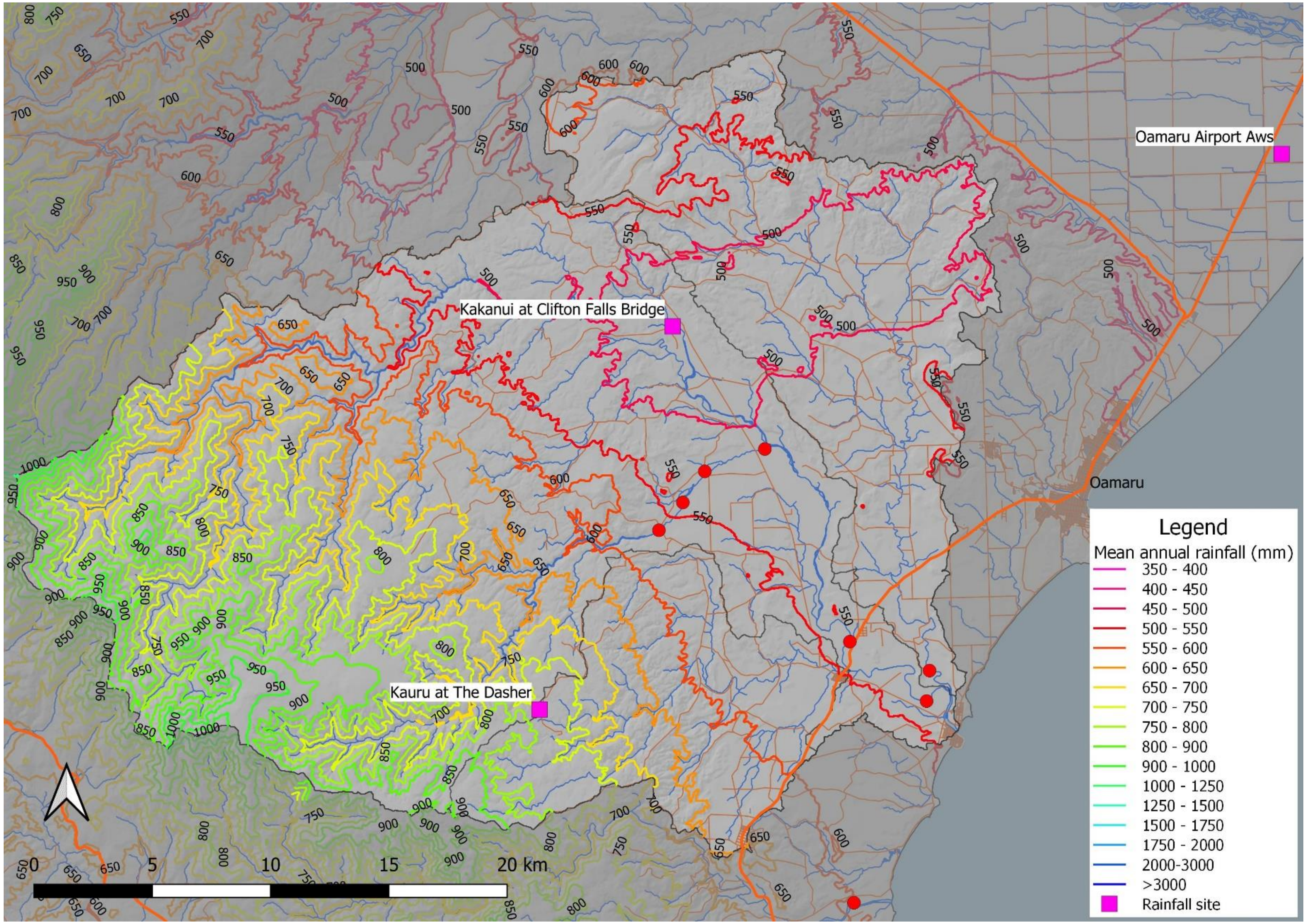

Figure 2 Distribution of rainfall (annual median rainfall) in the Kākaunui catchment. From GrowOtago (Otago Regional Council (2004).

Table 1 Mean monthly precipitation (mm) at sites in or near the Kākaunui catchment based on rainfall data (1996-2022). Data for Oamaru Airport AWS was downloaded from Cliflo (4 December 2023).

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Clifton Falls Bridge	52.2	48.9	32.7	42.0	37.4	29.6	39.7	32.5	24.5	36.6	50.0	57.5	479.5
Kauru at The Dasher	89.6	73.6	51.0	64.0	65.0	47.8	68.9	64.8	45.7	62.4	70.5	75.8	779.1
Oamaru Airport Aws	51.5	47.1	34.3	52.5	46.4	39.5	45.0	48.7	29.9	41.7	49.1	51.2	536.9

2.1.2. Geology and geomorphology

The geology of the upper Kākaunui catchment consists mainly of semischist (Rakaia Terrane, TZIIA semischist, with some areas of basalt (Dunedin Volcanic Group; Forsyth 2001). The Waiareka Creek catchment is dominated by sandstone, mudstone (Onekakara Group) and quartz conglomerate, sandstone, siltstone, mudstone (Taratu Formation), overlain by limestone (Kekenodon Group) (Forsyth 2001).

The upper reaches of the Kākaunui River catchment are single-threaded and meandering while the lower reaches exhibit localised braiding, lateral migration of river channels and the active transport and deposition of sediment (Williams & Goldsmith, 2013). Between Five Forks and the coast, the main channel of the Kākaunui River and the lower reaches of the Kauru River follow a meandering path through old river terraces (Williams & Goldsmith, 2013). The channel gradient of the Kākaunui is about 1:400 upstream of Maheno and 1:800 downstream (Williams & Goldsmith, 2013).

Gravel deposition is common in the lower reaches of the Kauru River and between its confluence and Gemmells Crossing on the Kākaunui River, particularly during flood events. Between the Kauru River confluence and Maheno, the river has a history of breaking out of the main channel and crossing farmland (Williams & Goldsmith, 2013). River breakout during flood events has also occurred in the lower reaches of the Kauru River (Williams & Goldsmith, 2013).

2.1.3. Vegetation and land use

Vegetation cover in the upper catchment is mainly low-producing grassland, tussock and sub-alpine scrub, while much of the lower catchment is dominated by high-producing exotic grassland with areas of cropping particularly common in the Waiareka Creek catchment (Figure 3). Indigenous forest is found in the upper reaches of the Kauru River, while substantial areas of exotic forest are found in the upper Island Stream and Fuchsia Creek catchments (Figure 3). Gorse and broom are commonly found on the margins of waterways throughout the catchment (Figure 3).

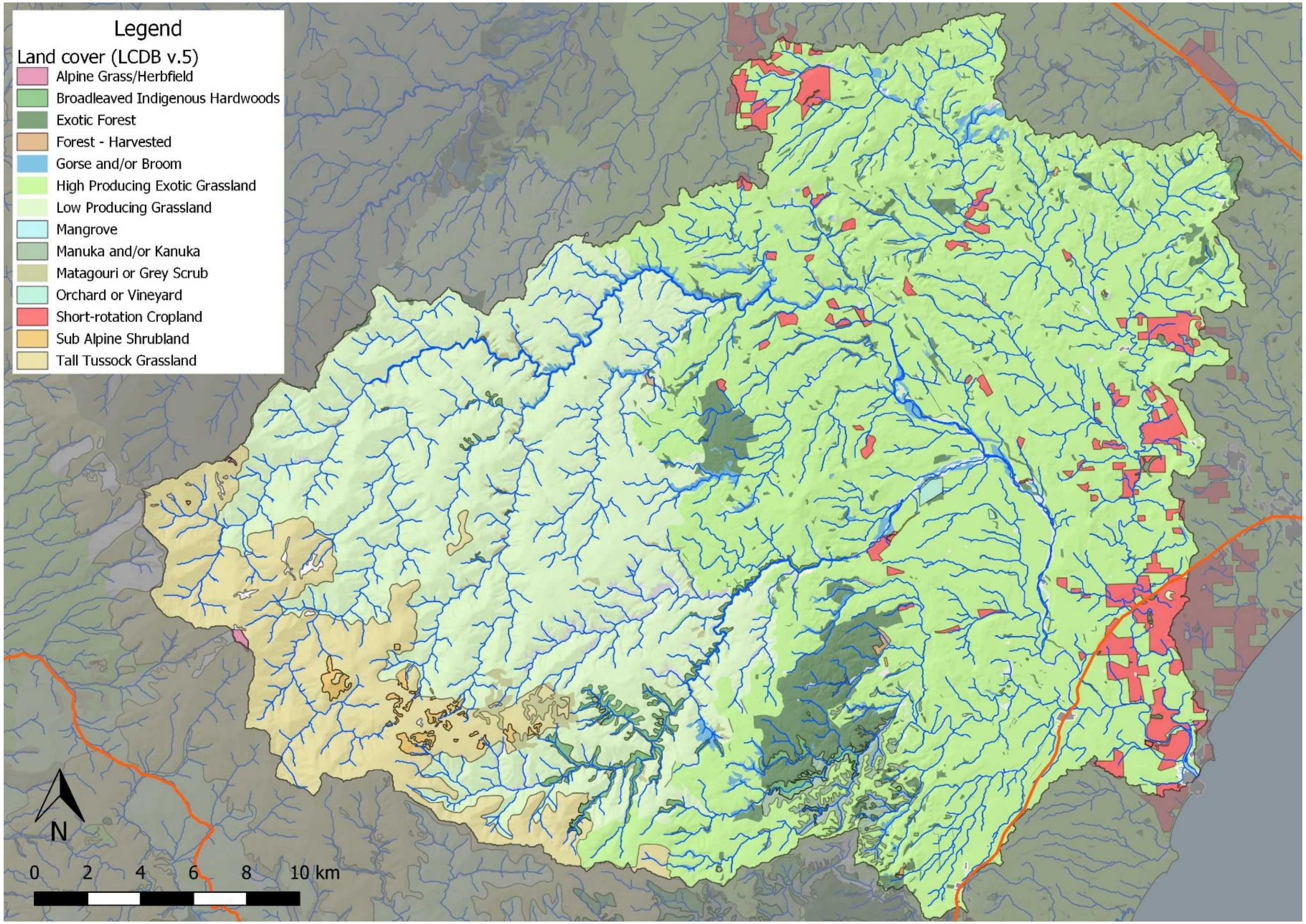

Figure 3 Land cover in the Kākaunui catchment.

2.1.4. Kakanui Estuary

The Kākaunui Estuary receives inflows (and nutrients) from the Kākaunui River and Waiareka Creek. At times of low inflows, the mouth of the estuary can be closed, a combination of factors that can result in high algae growth in summer months. Large mats of the green alga *Ulva*, predominantly *U. intestinalis*, can be observed over much of the estuary bed, and, at times, suspended algae concentrations are also high (Plew & Barr, 2015).

Minimum flows and water allocation in both the Kākaunui River and Waiareka Creek have the potential to interact with water quality in the Kākaunui Estuary. Plew (2016) predicted that higher residual flows in Waiareka Creek were predicted to result in higher DIN concentrations in the estuary, while Plew & Duncan (2017) predicted that a higher minimum flow in the Kākaunui River would result in lower nutrient concentrations in the river, particularly if more of the cleaner water originating from higher in the Kākaunui catchment is retained, rather than being extracted for irrigation.

2.2. North Otago Irrigation Company (NOIC)

The North Otago Downlands Water Company was formed in 1990 to investigate the use of water abstracted from the Waitaki River to irrigate the drought-prone areas of North Otago. These consents were granted in 2003, including Water Permit 2001.658 to discharge water from the Waitaki River into Waiareka Creek. Under this consent, up to 300 l/s may be discharged at Queen's Flat and up to 1,000 l/s downstream of the Weston-Ngapara Road Bridge at Elderslie. The augmented water flows in the creek to below Cormacks-Kia Ora Road, where it is piped to the farms that have purchased it for irrigation. A condition of Consent 2001.658 was that the irrigation company maintains a minimum flow of at least 100 l/s in Waiareka Creek at its confluence with the Kākaunui River. The irrigation company was also required to install a flow-gauging site in the lower reaches of the Waiareka Creek at Taipo Road to help manage the creek flow.

Stage 1 to irrigate up to 10,000 ha with up to 4 m^3/s of water from the Waitaki River was started in 2004 and completed in 2006. Subsequent to this first stage of development, a number of extensions have been undertaken. Started in 2016, the Stage 2 expansion project was completed in 2017, allowing delivery of the full design capacity of 8 m^3/s. The completed scheme can irrigate up to 26,000 ha.

3. Regulatory setting

3.1. Regional Plan: Water (RPW)

The minimum flow for the Kākaunui River was included in the RPW, which was notified on 28 February 1998 and became operative on 1 January 2004. Schedule 2A of the RPW specifies summer (1 October to 30 April) minimum flows of 250 l/s for primary permits, or 300 l/s for secondary permits at Mill Dam and McCones flow sites. If flows drop below 250 l/s, then the flow must return to 400 l/s before taking can recommence. A winter (1 May to 30 September) minimum flow of 400 l/s applies at Clifton Falls, Mill Dam and McCones flow sites. The primary allocation limit specified for the Kākaunui catchment (excluding Waiareka Creek and Island Stream catchments) in Schedule 2A is 750 l/s. Primary/secondary allocation at the time of writing is 914.6 l/s in the Kākaunui catchment, 124 l/s from the Island Stream catchment, and 133.8 l/s from the Waiareka Creek catchment (see Section 4.2.3).

In addition, Schedule 2B of the RPW specifies a summer minimum flow for the first supplementary allocation block of 1,050 l/s (1 October-30 April), with a supplementary allocation block of 300 l/s. The winter minimum flow for the first supplementary allocation block of 1,500 l/s (1 May-30 September), with a supplementary allocation block size of 500 l/s. At the time of writing, 217.8 l/s has been allocated from the first supplementary allocation block (see Section 4.2.3). The summer supplementary minimum flow for each subsequent supplementary block increases by 300 l/s and the winter supplementary block by 500 l/s, meaning that the second supplementary allocation block has a summer minimum flow of 1,350 l/s and a winter minimum flow of 2,500 l/s.

3.2. Proposed Land and Water Plan

The ORC has undertaken a full review of the RPW, and the results of this review will be incorporated into a new Land and Water Regional Plan (LWRP). As part of consultation for the LWRP, objectives have been developed for the North Otago Freshwater Management Unit (FMU), which includes the Kākaunui catchment. The proposed objectives, valid at the time of writing, are presented in Table 2.

Table 2 Possible environmental outcomes for the values identified in the North Otago FMU and their attributes and target attribute states (A, B, C, from corresponding tables in the National Objectives Framework of the National Policy Statement for Freshwater Management 2022).

Value	Narrative outcome statement	Attribute	Target attribute state
Ecosystem health – (all biophysical components)	Freshwater bodies within the North Otago FMU support healthy ecosystems with thriving habitats for a range of indigenous species, and the life stages of those species, that would be expected to occur naturally. This is achieved where the target attribute state for each biophysical component (as set in table) are reached.		
EH - Aquatic life:		Phytoplankton mg chl-a/ m3 (milligrams chlorophyll-a per cubic metre	B
		Periphyton - mg chl-a/m2 (milligrams chlorophyll-a per square metre)	B
		Submerged plants (natives) - Lake Submerged Plant (Native Condition Index)	B
		Submerged plants (invasive species Lake Submerged Plant (Invasive Impact Index)	B
		Fish - Fish index of biotic integrity (F-IBI)	A
		Macroinvertebrates - Macroinvertebrate Community Index (MCI) score; Quantitative Macroinvertebrate Community Index (QMCI) score	C
		Macroinvertebrates - Macroinvertebrate Average Score Per Metric (ASPM)	C
EH – Water quality		Total nitrogen (mg/m3 (milligrams per cubic metre)	B
		Total phosphorus -mg/m3 (milligrams per cubic metre)	B
		Ammonia (toxicity) mg NH4-N/L (milligrams ammoniacal-nitrogen per litre)	A
		Nitrate (toxicity) - mg NO3 – N/L (milligrams nitrate-nitrogen per litre)	A
		Dissolved oxygen - mg/L (milligrams per litre	B
		Suspended fine sediment - Visual clarity (metres)	A
		Dissolved oxygen - mg/L (milligrams per litre)	A
		Lake-bottom dissolved oxygen mg/L (milligrams per litre	Not applicable
		Dissolved reactive phosphorus - DRP mg/L (milligrams per litre)	B
		Mid-hypolimnetic dissolved oxygen - mg/L (milligrams per litre)	Not applicable
EH - Habitat		Deposited fine sediment - % fine sediment cover	A
EH – Ecological processes		Ecosystem metabolism (both gross primary production and ecosystem respiration) - g O2 m-2 d-1 (grams of dissolved oxygen per square metre per day)	C
EH – Water quantity		Under development – awaiting national guidance	Not applicable

Table 2 Possible environmental outcomes for the values identified in the North Otago FMU and their attributes and target attribute

Value	Narrative outcome statement	Attribute	Target attribute state
Human contact	Water bodies within the North Otago FMU are clean and safe for human contact activities.	Escherichia coli (E. coli) - E. coli/100 mL (number of E. coli per hundred millilitres)	A
		Cyanobacteria (planktonic) - Biovolume mm3/L (cubic millimetres per litre)	A
		Escherichia coli (E. coli) (primary contact sites) - 95th percentile of E. coli/100 mL (number of E. coli per hundred millilitres)	A
		Phytoplankton mg chl-a/ m3 (milligrams chlorophyll-a per cubic metre)	B
		Suspended fine sediment - Visual clarity (metres)	A
Fishing	For parts of the North Otago FMU valued for fishing, the numbers of fish are sufficient and safe to eat.	Key attributes include those identified for Ecosystem Health (all biophysical components) and Human Contact	See target attribute states for ecosystem health and human contact above
Animal drinking water	Water from water bodies within the North Otago FMU is safe for the reasonable drinking water needs of stock and domestic animals.	Key attributes include those identified for Ecosystem Health (all biophysical components) and Human Contact	See target attribute states for ecosystem health and human contact above
Cultivation and production of food and beverages and fibre	After the health and wellbeing of water bodies and freshwater ecosystems and human health needs are provided for, water bodies within the North Otago FMU can provide a suitable supply of water for the cultivation and production of food, beverages and fibre.		
Commercial and industrial use	After the health and wellbeing of water bodies and freshwater ecosystems and human health needs are provided for, water bodies within the North Otago FMU can provide a suitable supply of water for commercial and industrial activities.		
Drinking water supply	Source water from waterbodies within the North Otago FMU is safe and reliable for the drinking water supply needs of the community.	Key attributes include those identified for Ecosystem Health (all biophysical components) and Human Contact	See target attribute states for ecosystem health and human contact above
		Source water (after treatment) capable of meeting NZ Drinking water standards	

Table 2 Possible environmental outcomes for the values identified in the North Otago FMU and their attributes and target attribute

Value	Narrative outcome statement	Attribute	Target attribute state
Natural form and character	Water bodies and riparian margins, and connected estuaries and hāpua within the North Otago FMU can behave in a way that is consistent with their natural form and character.	Key attributes include those identified for Ecosystem Health (all biophysical components) and Human Contact	See target attribute states for ecosystem health and human contact above
		Other attributes under development	Not applicable
Threatened species	The North Otago FMU supports self-sustaining populations of threatened species.	Under development (Possible attributes based on presence, abundance, survival, recovery, habitat conditions)	Not applicable
Wetlands	Wetlands within the North Otago FMU are resilient and support a diversity of habitats.	Under development	Not applicable
Hydro-electric power generation	After the health and wellbeing of water bodies and freshwater ecosystems and human health needs are provided for, water bodies within the North Otago FMU can support low impact hydro-electric generation.		

4. Hydrology

4.1. Surface water-groundwater interactions

The Kākaunui-Kauru alluvium has been a recognised riverine ribbon aquifer since the Otago Catchment Board investigation of the North Otago groundwater resource in the 1980s. The alluvial sands and sandy gravels making up the floodplains of the Kākaunui and Kauru rivers are thin (6-6.5 m thick, 5.5-5.8 m saturated thickness; from Table 3.1 of Ozanne & Wilson, 2013) and couched within less permeable sedimentary rocks (Ozanne & Wilson, 2013).

Five sub-basins are recognised along the Kākaunui River: the **Five Forks sub-basin** extends from Clifton Falls (flow loss) to upstream of the Kākaunui-Kauru confluence (flow gain), the **Kauru sub-basin** extends from the Kauru at Kauru Hill Rd 700m Upstream to the confluence with the Kākaunui and the **Gemmells sub-basin**, which extends down to immediately below Gemmell's Crossing. These losses and gains represent 10-15% of river base flow (ORC, 1993). The lower reach of the Kauru River ceases to flow in dry weather, as the alluvium drains river flow and conducts it underground to the Kākaunui River. Figure 4 depicts the relevant features of the Kākaunui-Kauru alluvium aquifer from Ozanne & Wilson (2013). The remaining section of the Kākaunui River below the Gemmells sub-basin is split into two sections – upstream and downstream of State Highway 1 or approximately the Mill Dam site.

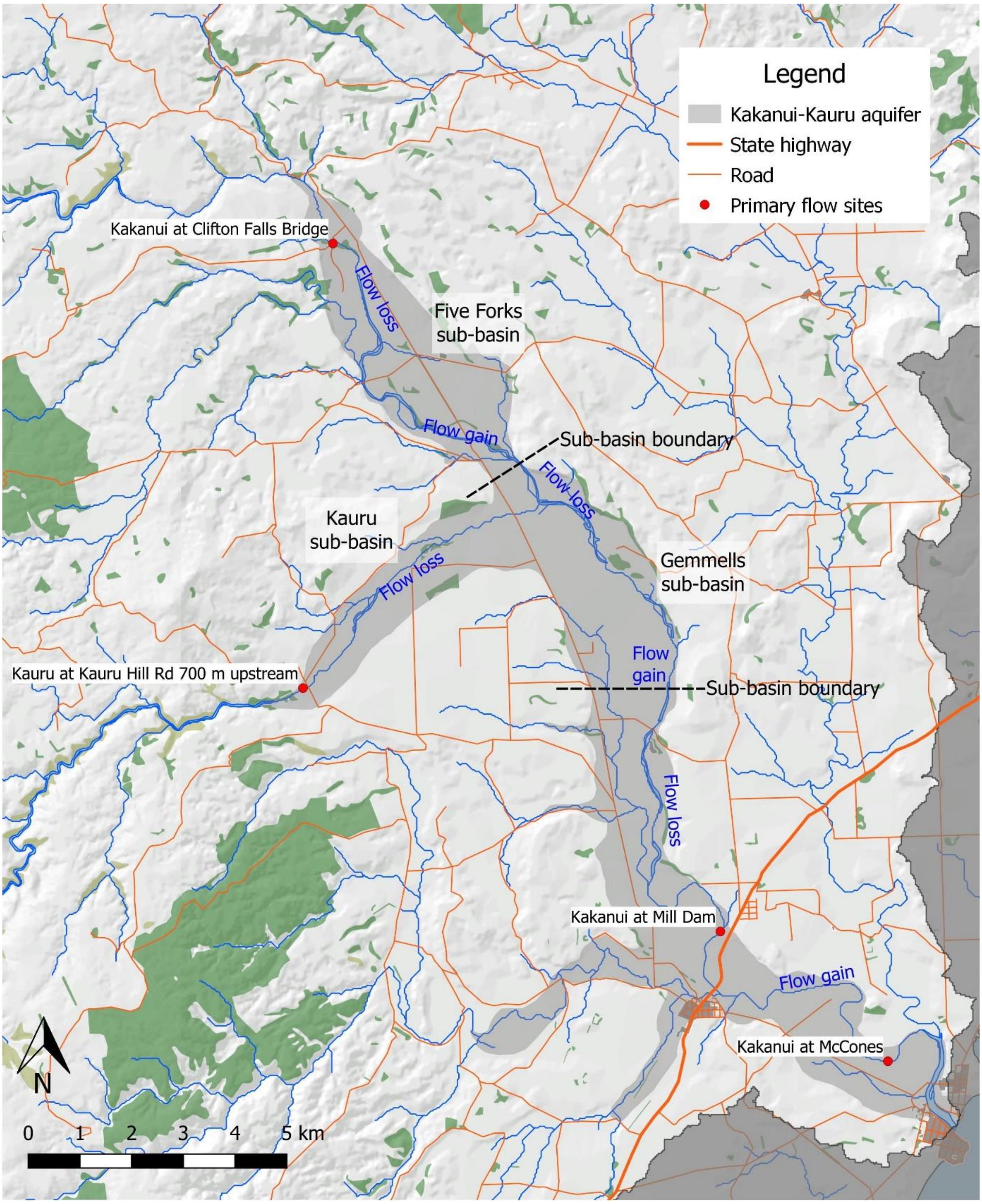

Figure 4 Map of groundwater sub-basins and areas of river flow gain and loss. Redrawn based on Ozanne & Wilson (2013)

4.2. Flow statistics

Continuous flow recorders have been installed in the Kākaunui River at Clifton Falls since 9 April 1981, Mill Dam since 18 December 1989, and McCones since 22 January 2003. The Kākaunui at Clifton Falls bridge flow site is located 31 km from where the Kākaunui River enters the Pacific Ocean, Mill Dam 11 km, and McCones 3.4 km, while the Kauru at Kauru Hill Rd 700m Upstream (since 13 November 1991) flow monitoring site is located approximately 30 km from the sea.

Lu (2023) used available flow data for hydrological sites in the Kākaunui catchment and corresponding water use data to produce naturalised flow time-series for the period 1 July 2011 to 28 February 2023. The flow statistics based on the analysis of Lu (2023) are summarised in Table 3.

Table 3 Flow statistics for hydrological monitoring sites in the Kākaunui catchment from Lu (2023). The period used in this analysis was 7 July 2010 – 24 April 2023 for sites in the Kākaunui River, while statistics for the Kauru River at Kauru Hill Rd 700m Upstream are based on the period 24 September 2016 – 24 April 2023.

Site		Flow statistics (l/s)		
		Mean	Median	7d MALF (Jul-Jun)
Kakanui River at Clifton Falls	Naturalised flows	3,528	1,714	551
	Observed flows	3,507	1,698	523
Kakanui River at Mill Dam	Naturalised flows	5,293	2,394	685
	Observed flows	5,170	2,284	501
Kakanui River at McCones	Naturalised flows	5,650	2,645	712
	Observed flows	5,497	2,512	462
Kauru River at Kauru Hill Rd 700m Upstream	Naturalised flows	1,425	575	122
	Observed flows	1,421	572	119
Island Stream	Naturalised flows	323	227	24
Waiareka Creek	Naturalised flows	503	-	126
	Observed flows	493	-	114

4.2.1. Flow variability

The average number of events per year that exceed three times the median flow (FRE3) at hydrological monitoring sites in the Kākaunui catchment is summarised in Table 4.

Table 4 Average number of events per year that exceed three times the median flow (FRE3) for hydrological monitoring sites in the Kākaunui catchment from Lu (2023)

Site		FRE3
Kakanui River at Clifton Falls	Naturalised flows	8.0
	Observed flows	8.1
Kakanui River at Mill Dam	Naturalised flows	7.7
	Observed flows	7.9
Kakanui River at McCones	Naturalised flows	7.0
	Observed flows	7.3
Kauru River at Kauru Hill Rd 700m Upstream	Naturalised flows	7.6
	Observed flows	7.6

4.2.2. Flow intermittence in the Kauru River

Comparisons of flows in the Kauru at Kauru Hill Rd 700m Upstream with those measured at Rodgers Road Crossing suggest that Rodgers Ford are dry when flows in the Kauru at Kauru Hill Road 700 m upstream are 106-220 l/s (Figure 5a). Similarly, zero or near-zero flows at Kakanui Valley Road 400 m downstream were recorded when flows in the Kauru at Kauru Hill Road 700 m upstream were 100-337 l/s (Figure 5b). This indicates that the lower reaches of the Kauru River are naturally intermittent since the average rate of loss exceeds the estimated naturalised 7-d MALF at the Kauru Hill Rd 700m Upstream hydrological monitoring site (122 l/s), which is in a perennial reach upstream of the drying reach of the Kauru.

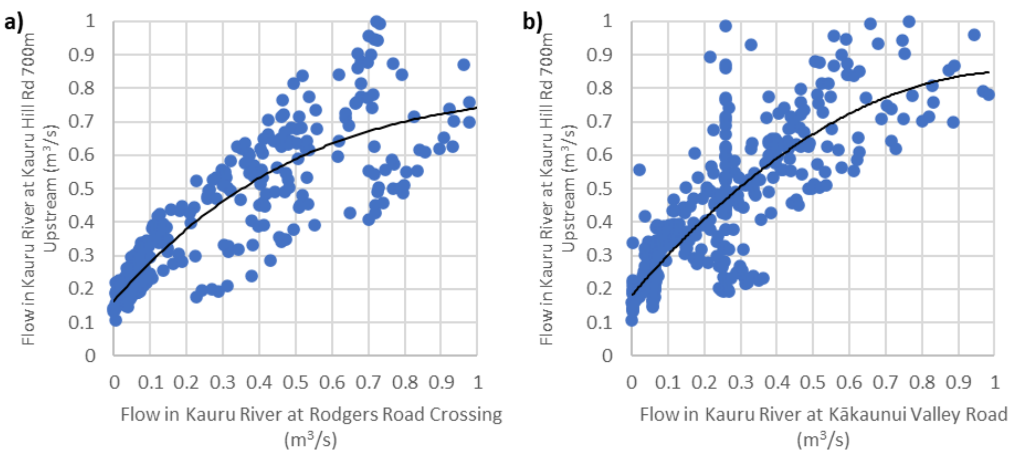

Figure 5 Comparison of flows at sites in the Kauru River a) Rodgers Road Crossing with flows in the Kauru River at Kauru Hill Rd 700m Upstream. b) Kākaunui Valley Road with flows in the Kauru River at Kauru Hill Rd 700m Upstream. Fitted lines are polynomial (a) 3rd order, b) 2nd order).

Using a flow loss of 230 l/s, the Kauru was predicted to disconnect from the Kākaunui naturally on an average of 16% of the time (range: 0-28%)[4]. In comparison, the Kauru with water take[5] was predicted to disconnect from the Kākaunui on an average of 19% of the time (range: 1-38%). The greatest effect of water abstraction would have been in the 2014/15 hydrological year, when the Kauru was predicted to be dry at the Kakanui Valley Road naturally for 94 days but was predicted to have dried for 137 days (43 day increase, 12% increase). A minimum flow equivalent to the 7-d MALF at the Kauru at Kauru Hill Rd 700m Upstream hydrological monitoring site (120 l/s) would not affect the duration of time that the Kauru was dry at Kakanui Valley Road, since this flow at the Kauru Hill Rd 700m Upstream flow site is not sufficient to maintain wetted habitat all the way to the Kakanui Valley Road bridge. However, it would maintain the extent of wetted habitat to no less than that which would occur at the 7-d MALF (keeping in mind uncertainty regarding the relationship between the extent of drying and groundwater levels). This is an important matter when considering the long-term maintenance of the critically endangered lowland longjaw galaxias found in the drying reach of the Kauru, as the presence of upstream and/or downstream refugia may contribute to the long-term resilience of the remaining population(s) of this species.

The duration of drying in the lower reaches of the Kauru will be affected by the magnitude of water allocation in the catchment. At present, there is only one substantial consumptive primary take (38 l/s) in the Kauru sub-catchment (RM19.357.01), although consent 2007.666.V1 is major supplementary take from the Kauru River (maximum rate of take = 500 l/s) that may contribute to the duration of drying in the lower Kauru River.

[4] Flows at Kauru at Kauru Hill Rd 700m Upstream were naturalised by adding back actual use data for RM16.370.V1 and RM15.240.01.

[5] Flows with take were synthesised by subtracting actual use for water meters in the Kauru sub-catchment downstream of the Kauru Hill Rd 700m Upstream flow site from the measured flow at Kauru at Kauru Hill Rd 700m Upstream.

4.2.3. Water allocation & use

The consenting and allocation data presented in this section were correct at the time of writing (22 March 2023). Information such as consent numbers, maximum rates of take and seasonal volumes may have changed, and some consents may no longer be active. Refer to Otago Maps[6] for up-to-date information.

Primary and secondary allocation

There are 33 resource consents for primary and secondary water takes from the Kākaunui River catchment, four of which are from upstream of Clifton Falls (total primary allocation = 92.5 l/s), nine consents for primary water from the Kākaunui River between Clifton Falls and Mill Dam, (total primary and secondary allocation = 341.5 l/s) and nine takes for primary/secondary allocation from below Mill Dam (total primary and secondary allocation = 223 l/s) (Table 1). A further five takes from the Kauru sub-catchment have a primary/secondary allocation of 70.6 l/s (Table 6) and there are six takes from other waterbodies within the Kākaunui catchment with a combined primary/secondary take of 187 l/s (Table 7). Thus, the total primary allocation in the Kākaunui catchment is 914.6 l/s.

There are three resource consents for primary takes from the Island Stream catchment with a total primary allocation is 124 l/s (Table 9) while there are eight resource consents for primary water takes from the Waiareka Creek catchment with a total primary allocation is 133.8 l/s (Table 10).

Supplementary Allocation

There are ten resource consents for supplementary water takes from the Kākaunui and Kauru Rivers. The combined maximum take in Supplementary Block 1 is 217.8 l/s, in addition to 500 l/s of further supplementary allocation (Table 8).

[6] https://maps.orc.govt.nz/OtagoMaps/

Table 5 Current resource consents for primary and secondary takes in the Kākaunui catchment. Yellow = primary allocation, orange – secondary allocation, green = public water supply. The data presented in this table were correct at the time of download (22 March 2023).

Consent number	Min flow block	Instant. Max (l/s)	Monthly volume (m^3)	Annual Volume (m^3)	Summer min flow (l/s)	Winter min flow (l/s)
Below Mill Dam Min flow site						
2001.114.V1	Primary	15	20,000	240,000	250	400
2001.115	Secondary	28	11,500	120,000	300	400
2001.168	Primary	32	33,000	623,000	250	400
	Secondary	32	25,000		300	400
2003.131.V1	Primary	9	18,000	216,000	250	400
2001.167	Primary	28	30,000	624,000	250	400
	Secondary	28	22,000	-	300	400
2001.145	Primary	38	87,000	900,000	250	400
2001.110.v1	Primary	40	36,000	267,500	250	400
RM14.104.V1	Secondary	40	90,000	936,000	300	400
2001.132	Primary	33	72,000	535,000	250	400
Subtotal	**Primary**	195	296,000	3,405,500		
	Secondary	128	148,500	1,056,000		
Clifton Falls to Mill Dam						
2001.159	Primary	28	10,000	120,000	250	400
	Secondary	28	33,000	396,000	300	400
2001.158	Primary	31	22,000	528,000	250	400
	Secondary	31	25,000		300	400
2001.140	Primary	45	90,000	554,000	250	400
RM14.360.01	Primary	32	65,450	687,427	250	400
2001.141	Primary	22	33,000	330,000	250	400
2008.267	Primary	23	20,000	121,500	250	400
2010.061	Primary	57.5	78,000	862,510	250	400
2001.100	Primary	29	50,000	600,000	250	400
2000.622	Primary	32	36,000	627,000	250	400
	Secondary	32	19,000		300	400
2003.752	Primary	33	60,000	720,000	250	400
RM13.051.01	Primary	9	23,357	168,285	250	400
Subtotal	**Primary**	341.5	487,807	5,318,722		
	Secondary	91	77,000	396,000		
Upstream Clifton Falls						
RM15.240.02	Primary	6.6		569,850	250	
2000.469.V1†	Water supply	2.9	7,767	91	250	
2003.05	Primary	38	70,000	778,800	250	400
2001.123*	Primary	45	74,000*	880,000*	250	400
Subtotal	**Primary**	92.5	151,767	2,228,741		
	Secondary					

* Monthly and annual volumes are split between primary and supplementary takes

† Water supply scheme, restricted to domestic water and stock water when flows are below 250 l/s

‡ Non-consumptive

Table 6 Current resource consents for primary and secondary takes in the Kauru catchments. Yellow = primary allocation, orange – secondary allocation, green = public water supply, blue = non-consumptive. The data presented in this table were correct at the time of download (22 March 2023).

Consent number	Min flow block	Instant. Max (l/s)	Monthly volume (m^3)	Annual Volume (m^3)	Summer min flow (l/s)	Winter min flow (l/s)
Kauru sub-catchment						
RM16.370.01.V1	Primary	0.5	1,339.2	15,768	250	400
RM15.240.01†	Water supply	7.1	611,150	223,069	250	400
RM19.357.01	Primary	38	36,000	207,443	250	400
	Secondary	38	3,000	36,000	300	400
RM18.305.01‡		5	7.2	403.2	-	-
RM16.103.01‡	Primary	20	17,280	45,000	250	
Subtotal	**Primary**	45.6	648,489	446,280		
	Secondary	38	3,000	36,000		
	Non-consumptive	25	17,287	45,403		

* Monthly and annual volumes are split between primary and supplementary takes

† Water supply scheme, restricted to domestic water and stock water when flows are below 250 l/s

‡ Non-consumptive

Table 7 Current resource consents for primary takes in minor tributaries in the Kākaunui catchment. Yellow = primary allocation. The data presented in this table were correct at the time of download (22 March 2023).

Consent number	Min flow block	Instant. Max (l/s)	Monthly volume (m^3)	Annual Volume (m^3)	Summer min flow	Winter Min flow	Source
2001.157	Primary	28	72000	429000	250	400	Patons Stream
2006.400	Primary	60	127500	1269973	250	400	Unnamed Tributary
2006.400	Primary	25	64800	259.2			Unnamed Tributary
2001.12	Primary	11	19500	234000	250	400	Unnamed Tributary
2006.407	Primary	18	39500	474000	250	400	Unnamed Tributary
2001.147	Primary	45	75000	900000	250	400	Unnamed Tributary

Table 8 **Current resource consents for supplementary takes in the Kākaunui and Kauru catchments. Yellow = first supplementary allocation block, orange – second supplementary allocation block. The data presented in this table were correct at the time of download (22 March 2023).**

Consent number	Min flow block	Instant. Max (l/s)	Monthly volume (m^3)	Annual Volume (m^3)	Summer min flow	Winter Min flow
Kākaunui River						
RM19.295.02	First supplementary	5	9,136	44,012		
RM19.351.01	First supplementary	32	68,000	261,870	1050	1500
RM14.357.01	First supplementary	37.8		276,022	1050	1500
RM14.339.01	First supplementary	50	43,150	116,570	1050	1500
2010.062	First supplementary	500		4,857,840	As per consent	
RM18.172.01	First supplementary	45		871,200	1050	
2001.123	First supplementary	15	74,000	880,000	1000	
2009.213	Second supplementary	60	262,620	1,600,535	2550	3000
Kauru River						
2007.666.V1	Supplementary (various)	750	5,869,150		1350-2500	1500-2500
2008.129_V1	First supplementary	38	101,779	1,198,368	1050	

Table 9 **Current resource consents for primary, secondary and supplementary takes in the Island Stream catchment. The data presented in this table were correct at the time of download (22 March 2023).**

Consent number	Min flow block	Instant. Max (l/s)	Monthly volume (m^3)	Annual Volume (m^3)
RM21.078.01	Primary	25	32,900	123,390
RM21.100.01	Primary	36	66,000	563,500
2010.060	Primary	63	97,000	1,164,000
2010.248	Supplementary	500		954,800
2010.122	Augmentation water	-	-	-
Subtotals	**Primary**	**124**	**195,900**	**1,850,890**
	Supplementary	**500**		**954,800**

Table 10 Current resource consents for primary, secondary and supplementary takes in the Waiareka Creek catchment. The data presented in this table were correct at the time of download (22 March 2023).

Consent number	Min flow block	Instant. Max (l/s)	Monthly volume (m^3)	Annual Volume (m^3)
2006.228.V2	Retake of augmented water			
RM10.471.01.V1		20.8		657,000
2002.007.V1	Primary	11.5	30,000	243,960
2001.644.V1	Primary	7.5		114.688
2002.511.V1	Primary	7.5	80,00	64,000
2005.021.V1	Primary	19	18,000	346,680
2001.266.V1	Primary	25		256,800
2004.367.V1	Primary	14	15,000	256,800
2002.705.V5	Primary	11	13,664	89,880
RM19.048.01	Supplementary	30	14,558	52,488
RM17.327.02	Supplementary	30	21,480	85,360
RM20.225.03	Supplementary	30	22,480	86,680
RM17.326.02	Further supplementary*	77	43392	143500
Subtotals	**Primary**	**116.3**		**2,029,808**
	Supplementary	**90**		**224.528**
	Further supplementary	**77**	**43,392**	**143,500**

* Further supplementary allocation is available when flows exceed mean flow.

5. Water temperature

Water temperature is a fundamental factor affecting all aspects of stream ecosystems. It can directly affect fish populations by influencing survival, growth, spawning, egg development and migration. It can also affect fish populations indirectly, through effects on physicochemical conditions and food supplies (Olsen *et al*., 2012). Of all the fish in the Kākaunui catchment, brown trout (*Salmo trutta*) are likely to be the most sensitive to high water temperatures. Their thermal requirements are relatively well understood, and Todd *et al*. (2008) calculated acute and chronic thermal criteria for both of these species. The objective of acute criteria is to protect species from the lethal effects of short-lived high temperatures. In this case, acute criteria are applied as the highest two-hour average water temperature measured within any 24-hour period (Todd et al., 2008). In contrast, the intent of chronic criteria is to protect species from sub-lethal effects of prolonged periods of elevated temperatures. In this study, chronic criteria are expressed as the maximum weekly average temperature (Todd et al., 2008).

The thermal tolerance of an organism is affected by preceding temperatures (referred to as the acclimation temperature[7]). Thus, different thermal criteria apply depending on the summer mean temperatures (Todd et al., 2008). When developing thermal criteria for indigenous species, Olsen et al. (2012) considered acclimation temperatures of 15°C (upland waters) or 20°C (lowland waters). Mean summer (December-February) temperature at Clifton Falls was 17.0°C (14.3-20.0°C) and 17.4°C (16.4-19.1°C) at McCones.

Water temperatures in the Kākaunui River at Clifton Falls between October 1992 and April 2023 are presented in Figure 6 and Figure 7, while temperatures in the Kākaunui River at McCones between October 2003 and April 2023 are presented in Figure 8 and Figure 9.

Water temperatures in the Kākaunui River at Clifton Falls exceeded acute (39% of years) and chronic thermal criteria (65% of years) for brown trout and at the McCones monitoring site exceeded acute criteria for brown trout in 10% of years and chronic thermal criteria for brown trout in 80% of years (Table 12). Of the indigenous species present in the Kākaunui catchment, temperatures at Clifton Falls frequently exceeded acute criteria for the common mayfly *Deleatidium*, net-spinning caddis flies and longfin eels (Table 12). Similarly, temperatures in the Kākaunui at McCones frequently exceeded acute criteria for the common mayfly *Deleatidium*, net-spinning caddis flies, common bully, longfin and shortfin eels (Figure 6; Table 12).

These data suggest that at times the thermal environment of the Kākaunui is not suitable for many of the indigenous and introduced fish species found in the catchment.

[7] The acclimation temperature is the temperature that an organism is exposed to prior to experimentation, usually in a laboratory setting. Acclimatisation is the physiological response to multiple environmental variables in a natural setting.

Table 11 Thermal criteria for species present in the Kākaunui catchment. Criteria for brown trout are from Todd *et al*. (2008), while criteria for indigenous species are from Olsen *et al*. (2012).

Common name	Species	Upland (Summer mean water temperature ≈ 15°C)		Lowland (Summer mean water temperature ≈ 20°C)	
		Acute criteria (°C)	Chronic criteria (°C)	Acute criteria (°C)	Chronic criteria (°C)
Brown trout	*Salmo trutta*			24.6	19.6
Shortfin eel	*Anguilla australis*	26	30	-	31
Longfin eel	*Anguilla dieffenbachii*	23	28	-	
Common bully	*Gobiomorphus cotidianus*	22	24	-	30
Torrentfish	*Cheimarrichthys fosteri*	-	25	-	
Inanga	*Galaxias maculatus*	-	22	-	29
Common mayfly	*Deleatidium*	21	-	-	-
Net-spinning caddis fly	*Aoteapsyche*	24	-	-	-
Stony-cased caddis fly	*Pycnocentrodes*	30	-	-	-
Sand-cased caddis fly	*Pycnocentria*	23	-	-	-
Riffle beetle	*Hydora*	31	-	-	-
Mudsnail	*Potamopyrgus*	30	-	-	-
Fingernail clam	*Sphaerium*	29	-	-	-
Shrimp	*Paratya curvirostris*	24	-	-	-
Amphipod	*Paracalliope fluviatillis*	22	-	-	-
Blackworm	*Lumbriculus variegatus*	25	-	-	-

Water temperatures in the Kauru River at Kauru Hill Rd 700m Upstream between July 2004 and April 2023 are presented in Figure 10 and Figure 11, while temperatures in the Kauru River at Kinnimont between November 2015 and April 2023 are presented in Figure 12.

Water temperatures in the Kauru River at Kauru Hill Rd 700m Upstream exceeded acute (79% of years) and chronic thermal criteria (89% of years) for brown trout, while the Kinnimont Ford monitoring site did not exceed acute criteria for brown trout but exceeded chronic thermal criteria for brown trout in 13% of years (Table 12). Of the indigenous species present in the Kākaunui catchment, temperatures in the Kauru at Kauru Hill Rd 700m Upstream frequently exceeded acute criteria for the common mayfly *Deleatidium*, the net-spinning caddis fly *Hydropsyche*, the sand-cased caddis fly *Pycnocentrodes* and longfin eels (Table 12). Similarly, temperatures in the Kauru at Kinnimont Ford exceeded the acute criteria for the common mayfly *Deleatidium* in 38% of years but were within the acute criteria for the net-spinning caddis fly *Hydropsyche*, the sand-cased caddis fly *Pycnocentrodes* and longfin eels (Table 12).

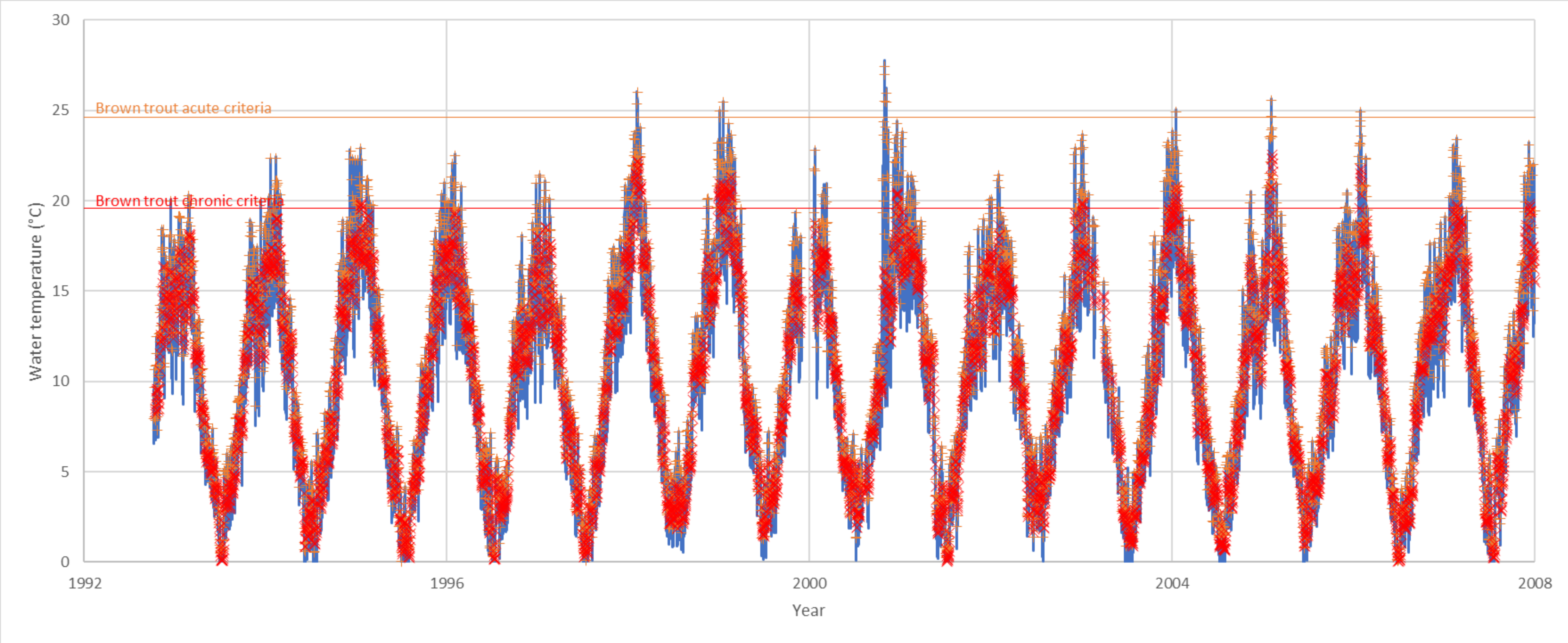

Figure 6 **Water temperature in the Kākaunui River at Clifton Falls between 1992 and December 2007. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red Xs are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.**

Otago Regional Council

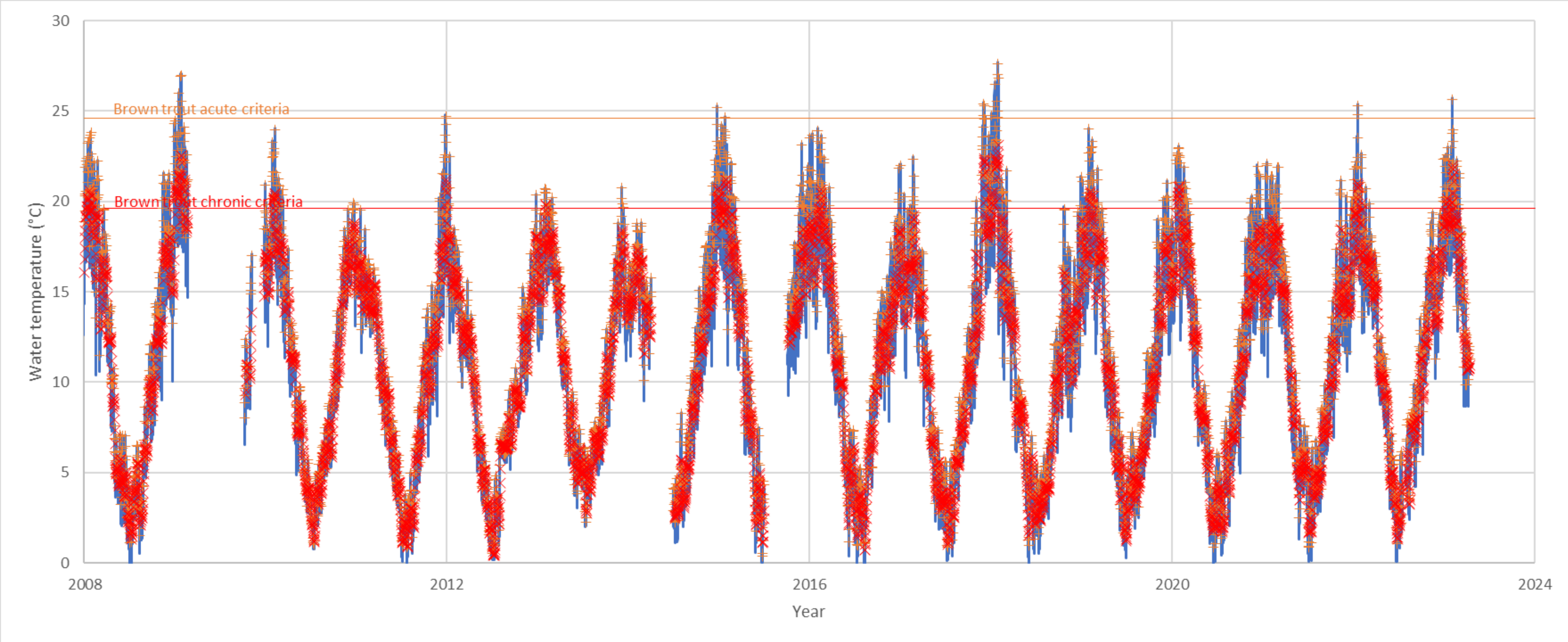

Figure 7 Water temperature in the Kākaunui River at Clifton Falls between January 2008 and April 2023. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red Xs are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.

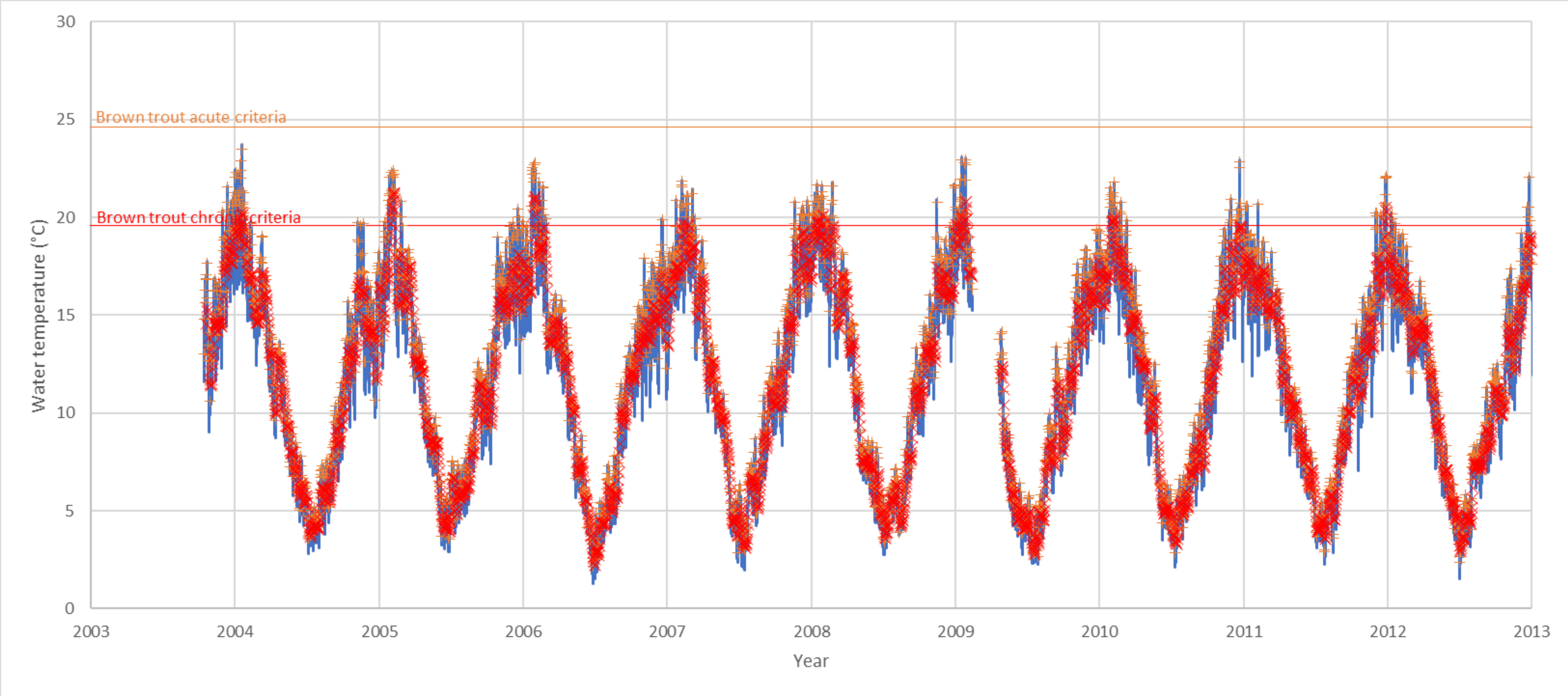

Figure 8 **Water temperature in the Kākaunui River at McCones between October 2003 and December 2013. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red Xs are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.**

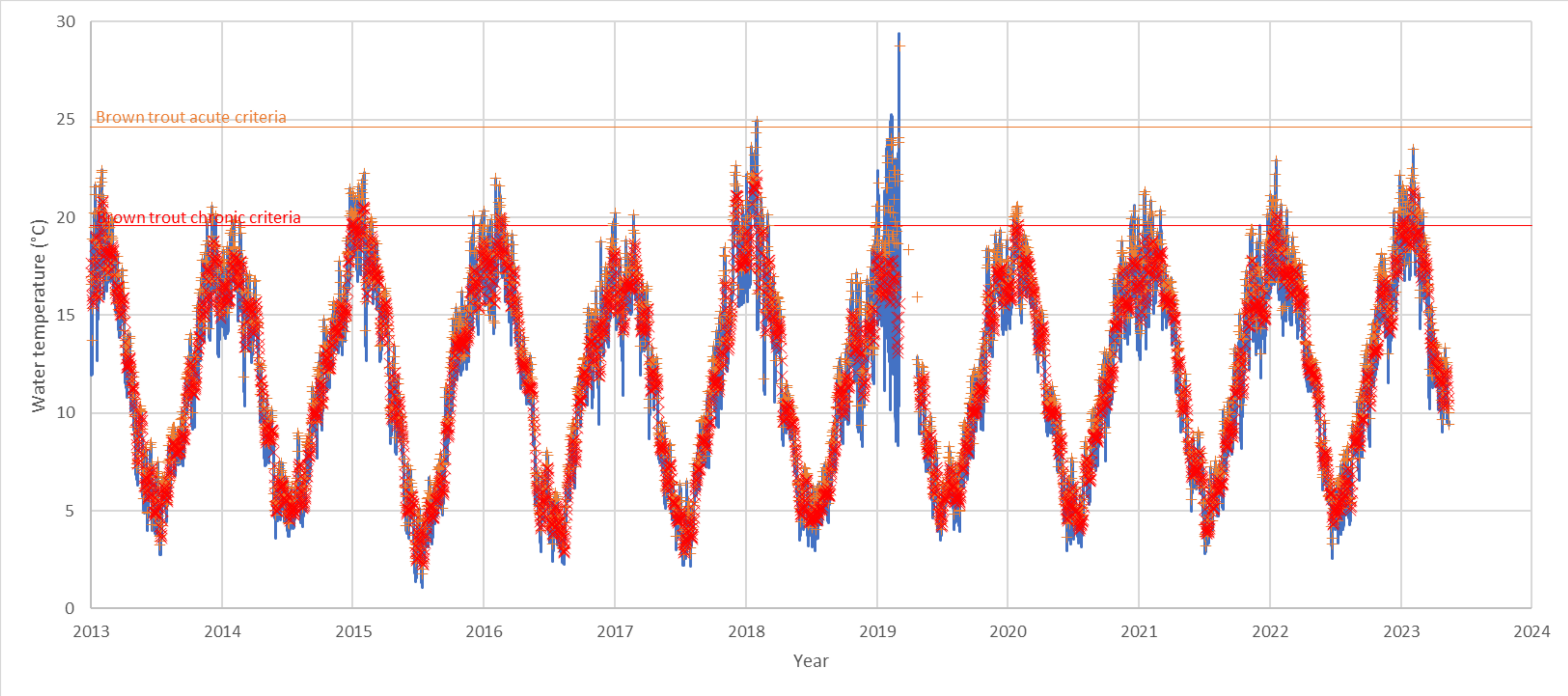

Figure 9 Water temperature in the Kākaunui River at McCones between January 2013 and April 2023. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red Xs are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.

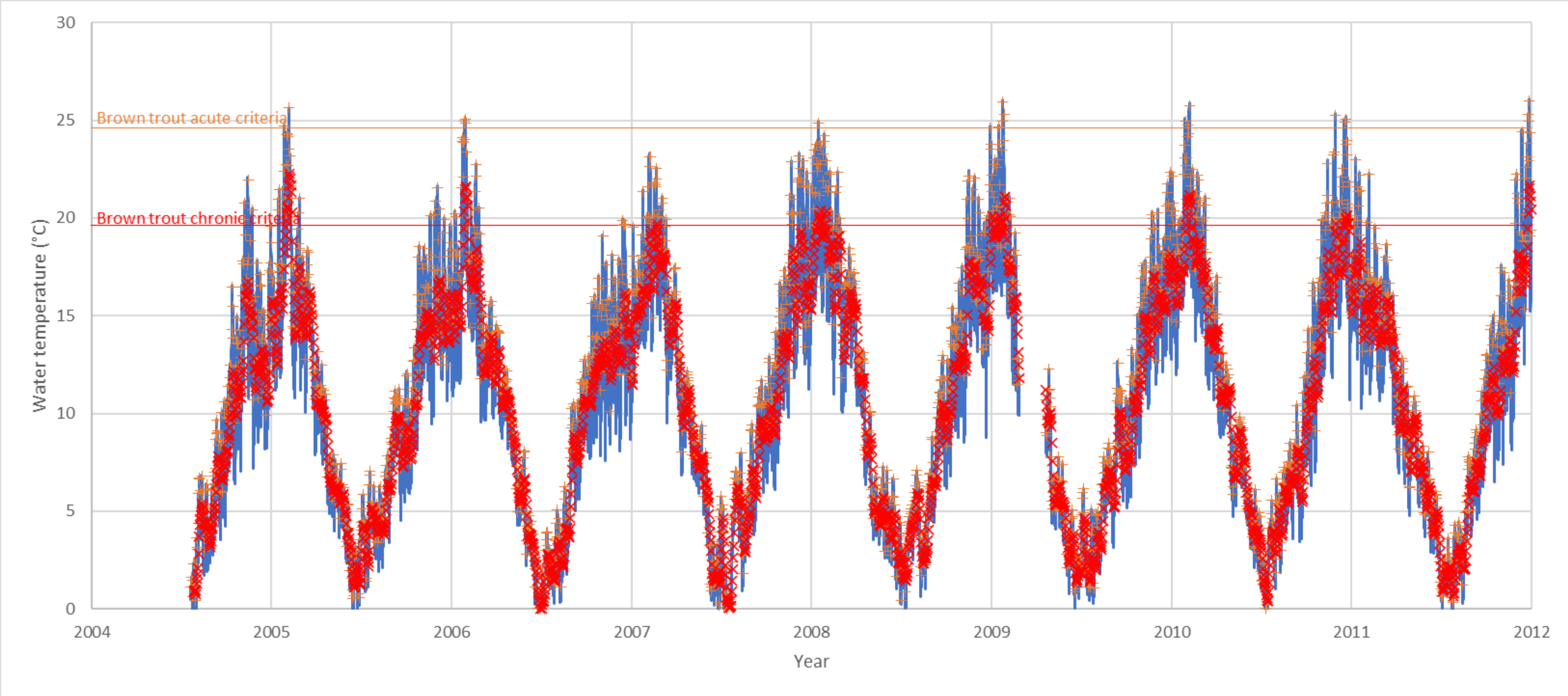

Figure 10 Water temperature in the Kauru River at Kauru Hill Rd 700m Upstream between July 2004 and December 2011. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red Xs are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.

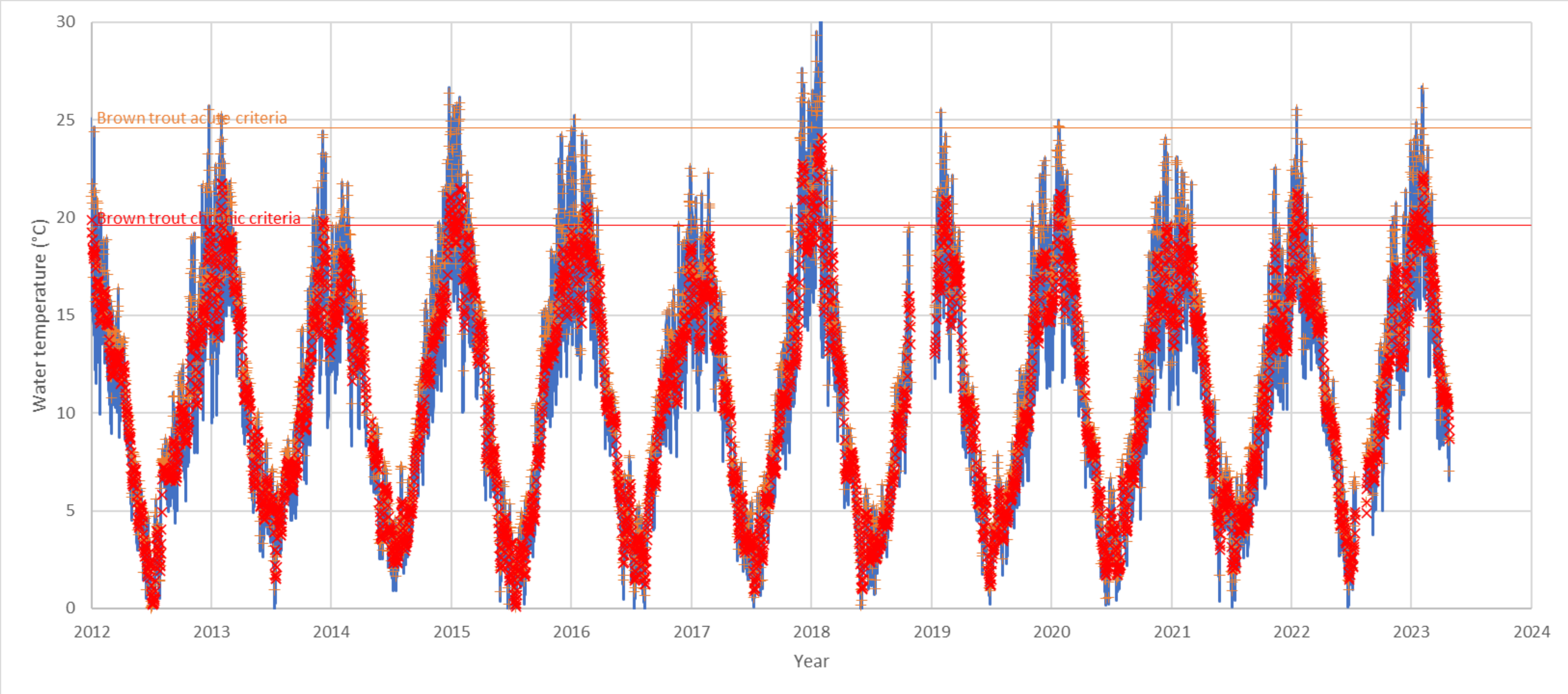

Figure 11 Water temperature in the Kauru River at Kauru Hill Rd 700m Upstream between January 2012 and April 2023. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red Xs are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.

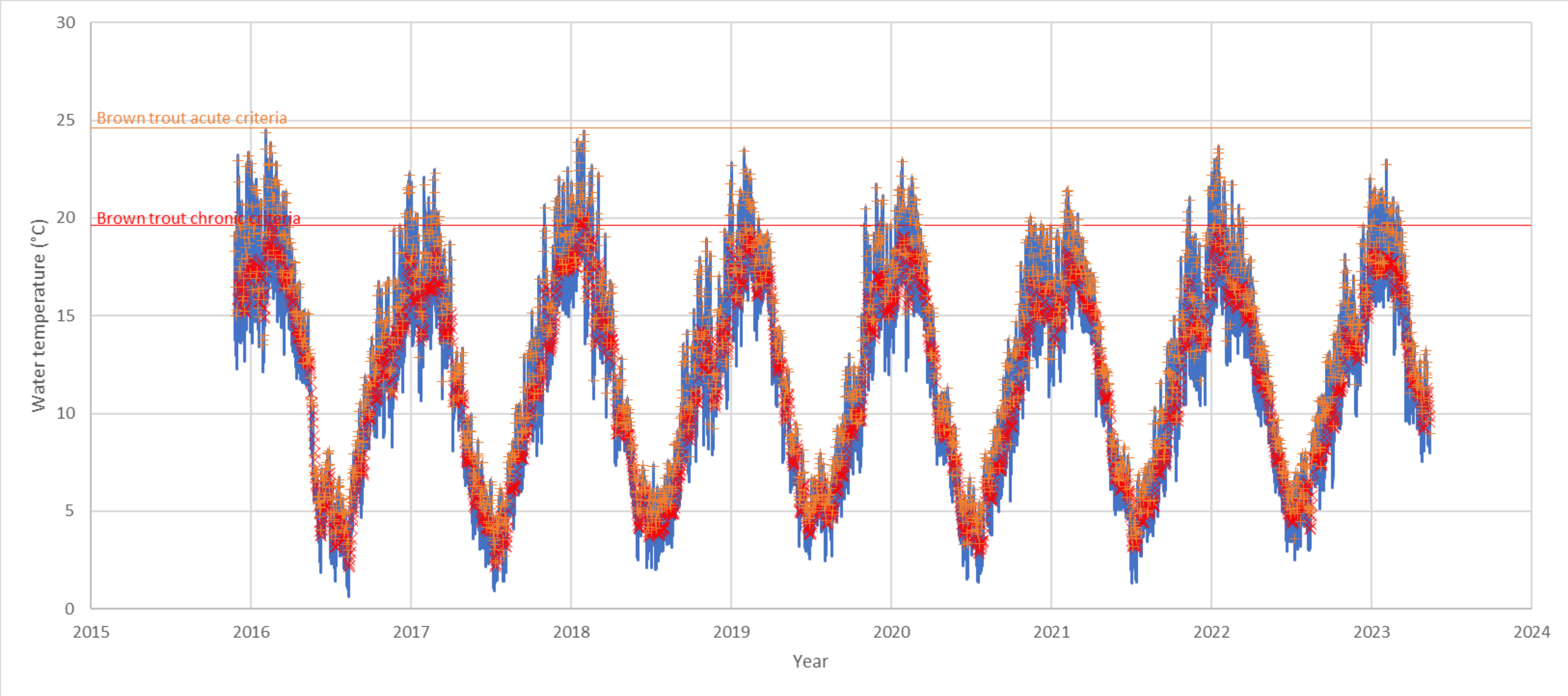

Figure 12 Water temperature in the Kauru River at Kininmont Ford between November 2015 and April 2023. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red Xs are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.

Table 12 Number of exceedances of thermal criteria in the Kakanui River at Clifton Falls and McCones and the Kauru River at Kauru Hill Rd 700m Upstream and Kinnimont Ford.

Site	Thermal criteria	Number of days where criteria were exceeded per year		Years with no exceedances	Total number of years
		Mean	Max		
Kakanui at Clifton Falls	Brown trout acute (>24.6°C)	1.3	12	19	31
	Deleatidium acute (21°C)	16.3	51	5	31
	Longfin eel, *Pycnocentria* acute (23°C)	4.8	28	14	31
	Aoteapsyche acute (24°C)	2.0	18	18	31
	Brown trout chronic (>19.6°C)	10.3	49	11	31
Kakanui at McCones	Brown trout acute (>24.6°C)	0.1	1	18	20
	Deleatidium acute (21°C)	8.2	25	3	20
	Common bully, *Paracalliope* acute (22°C)	3.3	14	8	20
	Longfin eel, *Pycnocentria* acute (23°C)	0.8	8	16	20
	Aoteapsyche acute (24°C)	0.3	3	18	20
	Shortfin eel acute (26°C)	0.1	1	19	20
	Brown trout chronic (>19.6°C)	7.2	27	4	20
Kauru at Kauru Hill Rd 700m Upstream	Brown trout acute (>24.6°C)	3.6	25	4	19
	Deleatidium acute (21°C)	23.9	58	0	19
	Longfin eel, *Pycnocentria* acute (23°C)	9.2	36	1	19
	Aoteapsyche acute (24°C)	5.3	29	2	19
	Brown trout chronic (>19.6°C)	11.3	44	2	19
Kauru at Kinnimont	Brown trout acute (>24.6°C)	0	0	8	8
	Deleatidium acute (21°C)	0.6	3	5	8
	Longfin eel, *Pycnocentria* acute (23°C)	0	0	8	8
	Aoteapsyche acute (24°C)	0	0	8	8
	Brown trout chronic (>19.6°C)	1.6	13	7	8

6. The aquatic ecosystem of the Kākaunui catchment

6.1. Periphyton

The periphyton community forms the slimy coating on the surface of stones and other substrates in freshwaters and can include a range of different types and forms. Periphyton is an integral part of the food web of many rivers; it captures energy from the sun and converts it, via photosynthesis, to energy sources available to macroinvertebrates, which feed on it. These, in turn, are fed on by other invertebrates and fish.

However, periphyton can form nuisance blooms that can detrimentally affect other instream values, such as aesthetics, biodiversity, recreation (swimming and angling), water-takes (irrigation, stock/drinking water and industrial) and water quality. Some types of cyanobacteria may produce toxins that pose a health risk to humans and animals. These include toxins that affect the nervous system (neurotoxins), liver (hepatotoxins), and dermatotoxins that can cause severe irritation of the skin.

The presence of potentially toxic cyanobacteria is undesirable as it can affect the suitability of a waterway for drinking, recreation (swimming), dogs, stock drinking water and food-gathering (by affecting palatability or through accumulation of toxins in organs such as the liver). Cyanobacteria-produced neurotoxins have been implicated in the deaths of numerous dogs in New Zealand (Hamill, 2001; Wood et al., 2007). Filamentous algae, and in particular long filamentous algae, can form nuisance blooms during periods of stable flows and under enriched nutrient conditions. Such blooms can affect a range of instream values, including aesthetics, biodiversity, recreation (swimming and angling), water-takes (irrigation, stock/drinking water and industrial) and water quality.

The invasive stalked diatom *Didymosphenia geminata* (known as Didymo) was first identified in the Kākaunui River in 2007 (Otago Regional Council 2007) and has been recorded from the Kākaunui and Kauru Rivers.

Medium and thick light brown mats was the most abundant periphyton cover on more than half of occasions, while benthic cyanobacteria mats were also frequently abundant at the McCones monitoring site. Blooms of benthic cyanobacteria (predominantly *Phormidium/Oscillatoria*) are known to occur throughout the Kākaunui catchment and signs have been installed at major access points warning of the potential presence of toxin-producing cyanobacteria. The benthic cyanobacteria Filamentous algae have also been abundant at the McCones monitoring site and are associated with high chlorophyll *a* concentrations.

Chlorophyll *a* concentrations in the Kākaunui at Clifton Falls exceeded 200 mg/m^2 on one of the seven sampling occasions over the January 2016-January 2018 period. The sampling period at this site is limited and sampling was only undertaken during the warmer months (December – April) and the high value was in January 2016, during a period of particularly low flows, therefore, it is not appropriate to compare the data for this site with Table 2 of the National Objectives Framework (NOF). In comparison, the chlorophyll *a* concentrations at the McCones exceeded 200 mg/m^2 on 15 occasions (54%) of sampling occasions over the June 2019 – 2022 period, placing this site in Band D of the NOF, which exceeds the national bottom line for periphyton (trophic state).

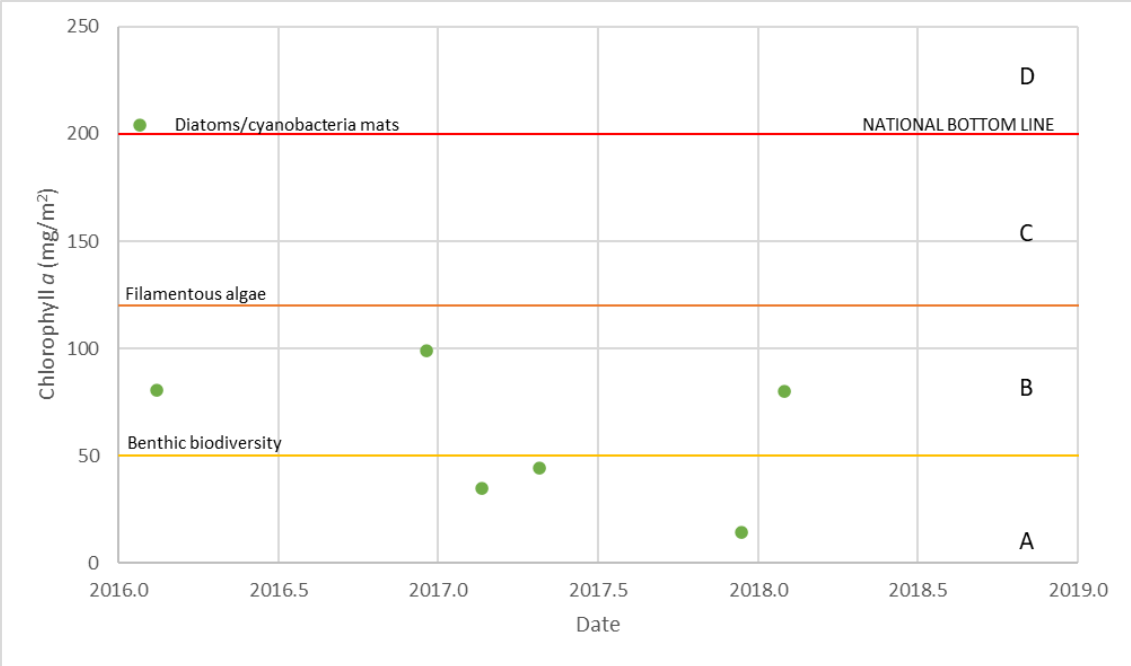

Figure 13 Chlorophyll *a* concentrations in the Kākaunui River at Clifton Falls over the period 2016-2018. Periphyton biomass attribute states (from Table 2 of the NOF) are shown, but the data available for this site falls well short of the requirements for comparison with the attribute table (monthly sampling, 3 years).

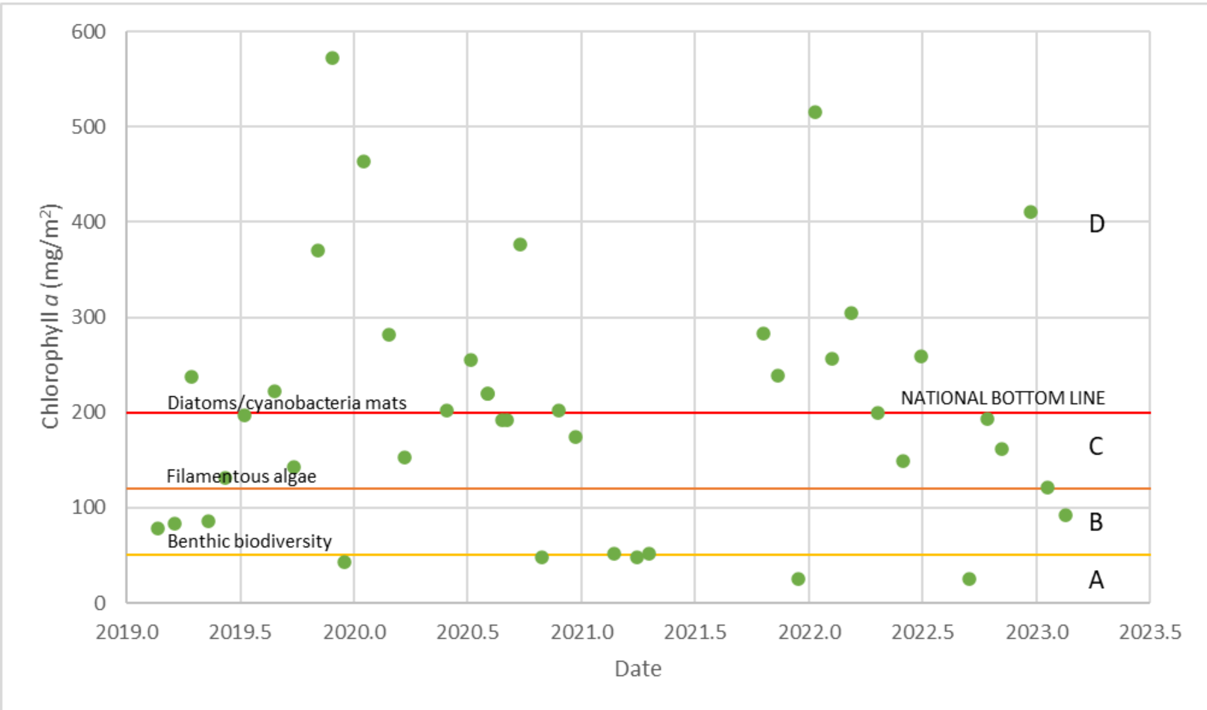

Figure 14 Chlorophyll *a* concentrations in the Kākaunui River at McCones over the period 2019-2022. The periphyton biomass attribute is applied such that no more than three values can exceed the numeric attribute state in any three-year period (8% exceedence, based on monthly sampling over a 3-year period).

6.2. Macroinvertebrates

Macroinvertebrates are an important part of stream food webs, linking primary producers (periphyton and terrestrial leaf litter) to higher trophic levels (fish and birds). Macroinvertebrates have long been used as indicators of ecosystem health and, conversely, the impacts of pollutants (e.g. Hilsenhoff 1977, 1987; Stark 1985). The Macroinvertebrate Community Index and its variants have been widely used in New Zealand to assess the effects of nutrients and sediment (Wagenhoff et al. 2016).

In a survey in 2012, the macroinvertebrate community in the Kākaunui River at Clifton Falls common mayfly *Deleatidium* was the most abundant macroinvertebrate taxa collected at sites in the upper Kākaunui River and in the Kauru River, while the macroinvertebrate communities in the Kākaunui River at McCones were dominated by the mudsnail *Potamopyrgus* (Ozanne & Wilson 2013).

In State of the Environment (SoE) sampling since 2007 , macroinvertebrate communities in the Kākaunui River at McCones were dominated by the mudsnail *Potamopyrgus*, chironomid midges (Orthocladiinae and Tanytarsini) and the stony-cased caddis *Pycnocentrodes*, while oligochaete worms, the common mayfly *Deleatidium*, the net-spinning caddis *Hydropsyche*, the purse-cased caddises (Hydroptilidae), the sand-cased caddis *Pycnocentria* have been abundant at this site at times (Table 13).

The Kākaunui River at Clifton Falls has been sampled as part of the SoE monitoring in 2007-2018 and 2022, the macroinvertebrate community at this site was dominated by the mudsnail *Potamopyrgus*, and the common mayfly *Deleatidium*, while the stony-cased caddis *Pycnocentrodes* and the net-spinning caddis *Hydropsyche* were also abundant at this site (Table 13).

The Kauru at Kauru Hill Rd 700m Upstream monitoring site has been sampled in 2006-2018 and 2022, the macroinvertebrate community was dominated by the common mayfly *Deleatidium*, with the mudsnail *Potamopyrgus*, the stony-cased caddis *Pycnocentrodes*, and the net-spinning caddis *Hydropsyche*, chironomid midges (Orthocladiinae and Tanytarsini) were also abundant at this site (Table 13).

MCI scores for McCones (Range: 78-95, mean = 88, N=15), which would put this site in the 'poor to 'fair' water/habitat quality classes, while scores for the Clifton Falls site put this site in the 'fair' to 'good' (Range: 94-116, mean = 108, N=12) (Figure 15a; Table 13). SQMCI scores for McCones (Range: 2.23-4.82, mean = 3.80, N=15), which would put this site in the 'poor to 'fair' water/habitat quality classes, while scores for the Clifton Falls site put this site in the 'fair' to 'good' (Range: 4.49-6.63, mean = 5.54, N=12) (Figure 15b; Table 13). ASPM scores for McCones (Range: 0.26-0.48, mean = 0.36, N=15), which would put this site in the 'poor to 'good' water/habitat quality classes, while scores for the Clifton Falls site put this site in the 'fair' to 'excellent' (Range: 0.33-0.61, mean = 0.50, N=12) (Figure 15c; Table 13).

No statistically significant trends in macroinvertebrate metrics were detected for the McCones monitoring site (Table 14).

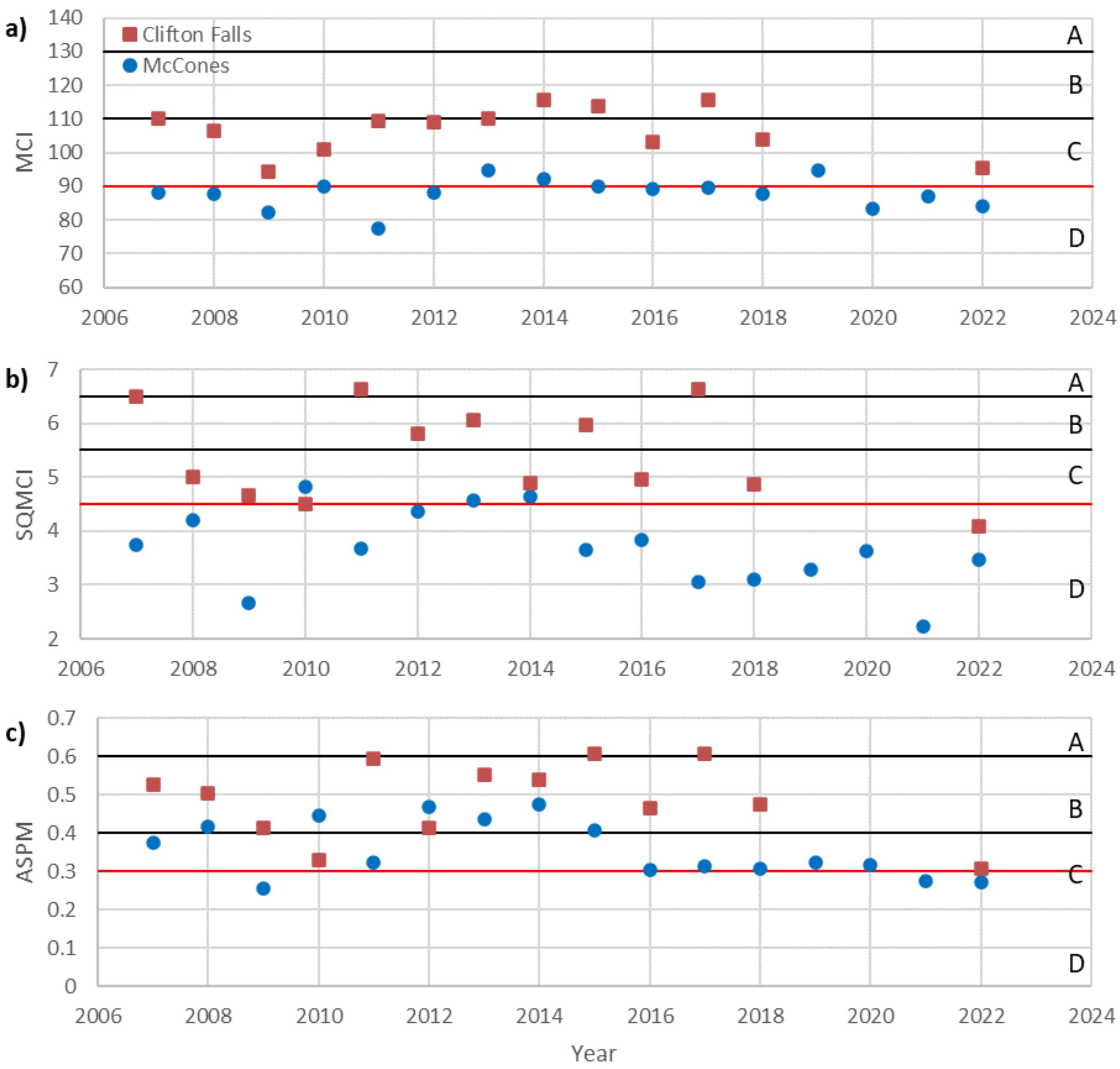

Figure 15 Macroinvertebrate indices for Kākaunui River at McCones (blue circles) and Clifton Falls (red squares) between 2007 and 2021. a) Macroinvertebrate community index (MCI), b) semi-quantitative MCI (SQMCI) and c) average score per metric (ASPM). Each plot includes thresholds for attribute states based on Tables 14 and 15 of the National Objectives Framework.

Table 13 Macroinvertebrate state of the environment data from the Kākaunui River at McCones and Clifton Falls and Kauru River at Kauru Hill Rd 700m Upstream between 2018 and 2022. Coded-abundance scores: R = 1-4, C = 5-19, A = 20-99, VA = 100-499, VVA = >500.

TAXON		MCI score	Kākaunui at Clifton Falls		Kākaunui at McCones					Kauru at Kauru Hill Rd 700m	
			2018	2022	2018	2019	2020	2021	2022	2018	2022
ACARINA		5		3			R		60		
CNIDARIA	*Hydra* species	3				R			20		10
HIRUDINEA		3				R					
NEMATOMORPHA		3						R			
NEMERTEA		3		3	R	C	R		100		10
OLIGOCHAETA		1	R	37	VA	VA	VA	VVA	1200		550
PLATYHELMINTHES		3		3	R	A	A	C	100		
MOLLUSCA	*Ferrissia = Gundlachia*	3					R				
	Gyraulus species	3			A	C	A	C	160		
	Physa / Physella species	3		10	VVA	VA	A	A	720		
	Potamopyrgus antipodarum	4	VA	727	A	VVA	VVA	VA	4680	VA	380
	Sphaeriidae	3		3							
CRUSTACEA	Cladocera	5							20		
	Copepoda	5					R		20		
	Ostracoda	3			C	C	C	C	60	R	
	Paracalliope fluviatilis	5			C	R	VA	C	60		
COLEOPTERA	*Berosus* species	5	C		R					R	10
	Elmidae	6	C	20	R			C	1	R	30
	Scirtidae	8				R					
	Staphylinidae	5	R								
COLLEMBOLA		6									
DIPTERA	*Aphrophila* species	5	R	1		C	R	R		R	10
	Austrosimulium species	3								C	
	Chironomus species	1							20		
	Empididae	3	R	3	R			R	20		50
	Ephydridae	4			R						1
	Eriopterini	9								R	1
	Maoridiamesa species	3		3							
	Muscidae	3	R		R	R		R			1
	Orthocladiinae	2	VA	23	VVA	VVA	VVA	VVA	340	A	520
	Polypedilum species	3	R								
	Tanypodinae	5	C			C		R			90
	Tanytarsini	3	A	3	VA	VVA	VA	VA	100	A	100
EPHEMEROPTERA	*Atalophlebioides cromwelli*	9	A								
	Austroclima species	9		17		C		R		C	
	Coloburiscus humeralis	9								C	
	Deleatidium species	8	VA	83	C	VA	A	A	120	VA	390
	Nesameletus species	9	C	1						R	1
HEMIPTERA	*Sigara* species	5								R	
MEGALOPTERA	*Archichauliodes diversus*	7	C	1	R		R		1	C	
PLECOPTERA	*Zelandoperla* species	10								R	

Table 13 Macroinvertebrate state of the environment data from the Kākaunui River at McCones and Clifton Falls and Kauru River at Kauru Hill Rd 700m Upstream between 2018 and 2022. Coded-abundance scores: R = 1-4, C = 5-19, A = 20-99, VA = 100-499, VVA = >500.

TAXON		MCI score	Kākaunui at Clifton Falls		Kākaunui at McCones					Kauru at Kauru Hill Rd 700m	
			2018	2022	2018	2019	2020	2021	2022	2018	2022
TRICHOPTERA	*Hydropsyche (Aoteapsyche)*	4	VA	17	VA	VA	A	A	120	A	50
	Hudsonema amabile	6	A	13	A	C	A	C	120	C	10
	Hydrobiosidae early instar	5							1		40
	Hydrobiosis species	5	R			A	R	A		R	40
	Neurochorema species	6	R		R		R	C	1	R	40
	Olinga species	9	A	1		R				A	150
	Oxyethira albiceps	2	A	23	C	VA	VA	C	220		350
	Paroxyethira hendersoni	2			R		VA		40		
	Plectrocnemia maclachlani	8				R					
	Polyplectropus species	8			C				60		
	Psilochorema species	8	C		R	R		C		C	1
	Pycnocentria species	7	C	13	VA	C	VA	A	60	R	
	Pycnocentrodes species	5	A	27	VA	VA	VVA	A	560	C	170
Number of taxa			**25**	**23**	**26**	**27**	**24**	**26**	**28**	**24**	**25**
Number of EPT taxa			**11**	**8**	**9**	**10**	**8**	**9**	**9**	**13**	**10**
% EPT taxa			**44**	**35**	**35**	**37**	**33**	**35**	**32**	**54**	**40**
% EPT abundance				**17**					**12**		**30**
MCI score			**104**	**96**	**88**	**95**	**83**	**87**	**84**	**123**	**98**
QMCI score				**4.32**					**3.52**		**3.76**
SQMCI score			**4.88**	**4.08**	**3.10**	**3.30**	**3.62**	**2.23**	**3.48**	**5.72**	**3.06**
ASPM			**0.48**	**0.31**	**0.31**	**0.32**	**0.32**	**0.28**	**0.27**	**0.53**	**0.38**

Table 14 Trends in macroinvertebrate metrics in Kākaunui at the McCones state of the environment monitoring site between 2014 and 2023. From Ozanne et al (2023). The Z-statistic indicates the direction of any trend detected. Trends with a *P*-value of 0.05 or less (highlighted red) are considered to be statistically significant.

Site	Metric	Z	P	Trend
Kākaunui at McCones	MCI	-2.504	0.0123	Decreasing trend exceptionally unlikely
	SQMCI	-1.981	0.0476	Extremely unlikely
	ASPM	-1.581	0.1138	Very unlikely

6.3. Fish

6.3.1. Indigenous fish

Fourteen species of indigenous freshwater fish have been recorded from the Kākaunui catchment, with twelve of these species recorded from the Kākaunui River (Table 16). This represents a very high level of indigenous biodiversity. The species present include several species that are at risk or threatened – longfin eel, torrentfish, bluegill bully, kōaro, inanga and Canterbury galaxias are classified as at risk – declining, while lamprey are classified as threatened – nationally vulnerable and lowland longjaw galaxias are classified as threatened – nationally critical (Dunn *et al*. 2017).

The diversity of indigenous fish species decreases with distance from the coast, as species with weaker swimming and/or climbing abilities drop out of the community. Giant bully (naturally uncommon) and inanga (declining) have been recorded from the mainstem downstream of Gemmells Crossing, while bluegill and redfin bullies have been recorded as far upstream as the Kauru confluence, and shortfin eel, torrentfish and kōaro have been recorded from as far upstream as the Clifton Falls bridge. Seven indigenous fish species have been recorded from Island Stream (shortfin and longfin eel, upland bully, common bully inanga, Canterbury galaxias, and lamprey) and eight species of indigenous fish species have been recorded from the Waiareka Creek Stream (shortfin and longfin eel, upland bully, common bully, giant bully, redfin bully, inanga and lamprey) (Table 16).

6.3.2. Introduced fish

Brown trout, perch and tench have been collected from the Kākaunui catchment. Of these, only brown trout have been recorded from the Kākaunui River itself, although there is a single record of chinook salmon from the Kākaunui River from 1992. Brown trout, perch and tench have been recorded from the Island Stream catchment, and perch and tench have been recorded from the Waiareka Creek catchment (Table 16).

The Kākaunui River supports a locally significant sport fishery (Central South Island Fish & Game Council 2022). Table 15 presents angler effort in the Kākaunui River recorded during National Angler Surveys conducted in 1994/95, 2007/08 and 2014/15. In the 2014/15 season, angling effort occurred in the early part of the fishing season (October to January; Unwin, 2016). Whilst no angler effort has been recorded from Island Stream and Waiareka Creek, they are among the very few waterways to provide the opportunity to fish for tench in New Zealand (Central South Island Fish & Game Council 2022).

Table 15 Angler effort on the Kākaunui River based on the National Angler Survey (Unwin, 2016)

	National Angler Survey			
Catchment	**1994/95**	**2001/02**	**2007/08**	**2014/15**
Kākaunui	2040 ± 650	220 ± 100	890 ± 380	530 ± 250
			180 ± 180	110 ± 110

Table 16 Fish species recorded from the Kākaunui River catchment. * = single record.

Common name	Species	Threat classification	Subcatchment				
			Kākaunui		Kauru	Island Stm	Waiareka Ck
			Upstream Clifton Falls	Downstream of Clifton Falls			
Anguillidae							
Shortfin eel	*Anguilla australis*	Not threatened		P	P	P	P
Longfin eel	*Anguilla dieffenbachii*	Declining	P	P	P	P	P
Cheimarrichthyidae							
Torrentfish	*Cheimarrichthys fosteri*	Declining		P			
Eleotridae							
Upland bully	*Gobiomorphus breviceps*	Not threatened	P	P	P	P	P
Common bully	*Gobiomorphus cotidianus*	Not threatened		P	P	P	P
Giant bully	*Gobiomorphus gobioides*	Naturally uncommon		P			P
Bluegill bully	*Gobiomorphus hubbsi*	Declining		P	P		
Redfin bully	*Gobiomorphus huttoni*	Not threatened		P	P		P
Galaxidae							
Kōaro	*Galaxias brevipinnis*	Declining			P		
Lowland longjaw galaxias	*Galaxias cobitinis*	Nationally critical		P	P		
Banded kokopu	*Galaxias fasciatus*	Not threatened		P			
Inanga	*Galaxias maculatus*	Declining		P	P	P	P
Canterbury galaxias	*Galaxias vulgaris*	Declining	P	P	P	P	
Geotriidae							
Lamprey	*Geotria australis*	Nationally vulnerable		P	P	P	P
Percidae							
	Perca fluviatilis	Introduced and naturalised				P	P
Salmonidae							
Brown trout	*Salmo trutta*	Introduced and naturalised	P	P	P	P	
Chinook salmon*	*Oncorhynchus tshawytscha*	Introduced and naturalised		P			
Cyprinidae							
Tench	*Tinca tinca*	Introduced and naturalised				P	P

6.4. Current ecological state

The current minimum flow and allocation in the Kākaunui catchment was included in the RPW which became operative on 1 January 2004. Thus, the current minimum flow and allocation limit have been in effect for many years and is reflected in the current state of the Kākaunui River. Therefore, comparison of the current state of the Kākaunui River with objectives for the North Otago FMU provide insight into whether the current minimum flow and allocation regime are consistent with the objectives proposed in the Land & Water Regional Plan.

At the time of writing, the proposed objectives for the North Otago FMU include the following narrative objectives: *"Freshwater bodies within the North Otago FMU support healthy ecosystems with thriving habitats for a range of indigenous species, and the life stages of those species, that would be expected to occur naturally"* and *"This is achieved where the target attribute state for each biophysical component (as set in table) are reached."*. The table referred to is presented in Table 17 below.

6.4.1. Ecosystem health

In addition to the ecosystem health and human contact values identified in (Table 17), the proposed objectives for fishing, animal drinking water, cultivation and production of food and beverages and fibre, commercial and industrial use, drinking water supply are measured by the target attribute states for ecosystem health and human contact presented in (Table 17). Attributes for natural form and character and threatened species within the North Otago FMU are under development, so it is not possible to consider the current state of the Kākaunui catchment relative to these attributes.

Table 17 presents the current attribute state for the Kākaunui River at McCones and Clifton Falls, Kauru at Kauru Hill Rd 700m Upstream (limited attributes) and Waiareka Creek at Taipo Road compared to the proposed target attribute state for the North Otago FMU. Attributes for Ecosystem Health – Aquatic life meet the target states for macroinvertebrates and fish, but not for periphyton (Table 17).

6.4.1.1. Kākaunui River

Periphyton biomass (as measured by benthic chlorophyll *a* concentrations) at Clifton Falls was in B-band, while chlorophyll *a* concentrations at McCones exceed the national bottom line (>8% of values exceeding 200 mg/m^2) (Table 8). MCI and ASPM indices for the Kākaunui at Clifton Falls were both in C-band, while the QMCI score for this site was in D-band, below the national bottom line, whereas the at Kākaunui at McCones, the ASPM was in C-band, while the MCI and QMCI scores for this site were in D-band, below the national bottom line (Table 8).

Periphyton biomass at a point in time reflects the balance of two opposing processes – biomass accrual and biomass loss. The rate of biomass accrual is driven by the rate of cell division which is, in turn, affected by factors such as the supply of resources (nutrients and light) and water temperature, while biomass loss is driven by two main mechanisms: disturbance caused by high flows (resulting in high water velocities, substrate instability and/or abrasion caused by suspended or saltating sediments) and physical removal by grazing my macroinvertebrates (Biggs, 2000). The Kākaunui River flows through a dry catchment characterised by high summer temperatures and long daylight hours and naturally experiences long periods of low flows, thereby favouring periphyton accrual processes at times. There is limited water storage within the Kākaunui catchment, so most of the abstraction will be run-of-the-river and is not expected to affect the magnitude and duration of high-flow events. Given the water in the Kākaunui is very clear at low flows, light availability is not likely to be affected appreciably by flow at low flows. The main effect of water allocation on periphyton biomass is expected to be via enhanced accrual resulting from nitrogen concentrations (via reduced dilution of nitrogen-enriched groundwater in the lower reaches; Ozanne & Wilson, 2013).

The macroinvertebrate attributes are likely to be a response to long periods between high-flow events and moderate to high periphyton biomass observed in the Kākaunui catchment. Landuse intensity upstream of Clifton Falls is generally extensive, and water quality is generally good (Table 17), thus macroinvertebrate communities at this site provide some indication of community structure and scores under lightly impacted conditions. The MCI score at this site was 100, while the QMCI score at this site is 4.18, scores that are consistent with *"moderate organic pollution or nutrient enrichment*" (narrative description in Table 14 of the NPS-FM). This provides some doubt regarding the appropriateness of the QMCI attribute bands in the NPSFM to the Kākaunui catchment – particularly given that the QMCI score for the Kauru site is also below the national bottom line (see Section 6.4.1.2).

6.4.1.2. Kauru River

Periphyton cover and biomass in the Kauru River are not routinely measured. However, MCI and ASPM indices for the Kauru at Kauru Hill Rd 700m Upstream were both in B-band, while the QMCI score for this site was in D-band, below the national bottom line (4.50; Table 18). A QMCI score in D-band is below the bottom line and is consistent with *"severe organic pollution or nutrient enrichment*" (narrative description in Table 14 of the NPS-FM). This provides some doubt regarding the appropriateness of the QMCI attribute bands in the NPSFM in the Kākaunui catchment given the lack of intensive land use activities or point-source discharges upstream of the Kauru at Kauru Hill Rd 700m Upstream monitoring site.

6.4.1.3. Waiareka Creek

Periphyton cover and biomass are not routinely measured in Waiareka Creek. However, macroinvertebrate communities have been monitored at Taipo Road. Macroinvertebrate indices for Waiareka Creek at Taipo Road were all below the national bottom line (Table 18). Macroinvertebrate indices in the D-band is below the bottom line and is consistent with *"severe organic pollution or nutrient enrichment*" (narrative description in Table 14 of the NPS-FM).

Table 17 Comparison of the current attribute state at sites on the Kākaunui River based on Ozanne, Borges & Levy (2023).

Value	Attribute	Clifton Falls			McCones		
		Baseline state	Target 2050	Current state	Baseline state	Target 2050	Current state
EH - Aquatic life:	Periphyton (trophic state) (chlorophyll *a*)		C	B 80 mg/m^2	D	C	D 464 mg/m^3
	Fish index of biotic integrity	A (B-A)	A (B-A)	A Mean (5-y): 57.6	A	A	A Mean (5-y): 53.2
	Macroinvertebrate Community Index (MCI) score	B (C-B)	C	C (100)	D	C	D (87)
	Quantitative Macroinvertebrate Community Index (QMCI) score			D (4.18)			D (3.30)
	Macroinvertebrate Average Score Per Metric (ASPM)	B (C-B)	C	C (0.38)	B (C-B)	C	C (0.31)
EH – Water quality	Ammonia (toxicity)	A	A	A Median: 0.002 Max: 0.019	A	A	A Median: 0.003 Max: 0.010
	Nitrate (toxicity)	A	A	A Median: 0.024 95th %: 0.108	A	A	A Median: 0.380 95th %: 0.845
	Dissolved oxygen			Not able to be determined			Not able to be determined
	Suspended fine sediment - Visual clarity	A	A	A 7.14 m		A	A 5.52 m
	Dissolved reactive phosphorus	A	A	A Median: 0.001 Max: 0.009	A	A	A Median: 0.003 Max: 0.013
EH - Habitat	Deposited fine sediment (% cover)			-			A Median: 0
EH – Ecological processes	Ecosystem metabolism (both gross primary production and ecosystem respiration)			Not able to be determined			Not able to be determined
Human contact	*Escherichia coli*			D			D
		A (A - D)	C	Median: 214		B	Median: 107
		B (B - C)	B	95th %: 1,115		B	95th %: 1,255
		B (B - D)	B	% >260: 36		B	% >260: 22
		B (B - E)	B	% >540: 29		B	% >540: 13
	Escherichia coli (E. coli) (primary contact sites) - 95th percentile			C 95th %: 1,115			D 95th %: 1,255
	Suspended fine sediment - Visual clarity (metres)	A	A	A 7.14 m		A	A 5.52 m

Table 18 Comparison of the current attribute state at two sites on tributaries of the Kākaunui River based on Ozanne, Borges & Levy (2023).

Value	Attribute	Kauru at Kauru Hill Rd 700m u/s			Waiareka Ck at Taipo Rd		
		Baseline state	Target 2050	Current state	Baseline state	Target 2050	Current state
EH - Aquatic life:	Periphyton (trophic state) (chlorophyll *a*)		C	-		C	-
	Fish index of biotic integrity			-			-
	Macroinvertebrate Community Index (MCI) score	B (C-B)	C	B (110)	D	C	D (73)
	Quantitative Macroinvertebrate Community Index (QMCI) score			D (4.39)			D (4.29)
	Macroinvertebrate Average Score Per Metric (ASPM)	B (C-B)	C	B (0.45)	D	C	D (0.15)
EH – Water quality	Ammonia (toxicity)	A	A	A Median: 0.002 Max: 0.007	A-B	A	B Median: 0.008 Max: 0.320
	Nitrate (toxicity)	A	A	A Median: 0.014 95th %: 0.059	A-B	A	B Median: 0.48 95th %: 1.99
	Dissolved oxygen			Not able to be determined			Not able to be determined
	Suspended fine sediment - Visual clarity		A	A 7.62 m	A	A	A 2.21 m
	Dissolved reactive phosphorus	A	A	A Median: 0.002 Max: 0.006	D	C	D Median: 0.187 Max: 0.369
EH - Habitat	Deposited fine sediment (% cover)			-			-
EH – Ecological processes	Ecosystem metabolism (both gross primary production and ecosystem respiration)			Not able to be determined			Not able to be determined
Human contact	*Escherichia coli*		 B B B B	D Median: 119 95th %: 3,512 % >260: 25 % >540: 15	 D D (B-D) D D	 C C C C	D Median: 212 95th %: 856 % >260: 44 % >540: 20
	Escherichia coli (E. coli) (primary contact sites) - 95th percentile			D 95th %: 3,512			B 95th %: 856
	Suspended fine sediment - Visual clarity (metres)		A	A 7.62 m	A	A	A 2.21 m

6.4.2. Water quality

6.4.2.1. Kākaunui River

Most water quality parameters considered were in A-band (Table 17), which is consistent with the findings of a previous catchment water quality study (Ozanne & Wilson 2013). The exception to this was the faecal indicator bacterium *Escherichia coli* (*E. coli*), which exceeded the target attribute state for 95th percentile and percentage of values exceeding 540 cfu/100 mL at Clifton Falls and the 95th percentile at McCones (Table 17).

Water allocation is not expected to directly affect the concentrations of *E. coli* in the Kākaunui, other than in its potential to support irrigated land uses that may support higher stocking rates.

It should be kept in mind that the NPS-FM attribute tables for ammoniacal nitrogen and nitrate-nitrogen (Tables 5 & 6 of the NOF) relate to the toxic effects of these compounds, not for their effect on the growth of periphyton. The concentrations required to manage eutrophication risk would be considerably lower than those in the NPS-FM tables. Development of objectives to manage eutrophication risk in the Kākaunui will require full consideration of the nutrient requirements of the catchment, including the estuary.

6.4.2.2. Kauru River

Most water quality parameters considered were in A-band in the Kauru River at Kauru Hill Rd 700m Upstream (Table 18), which is consistent with the findings of a previous catchment water quality study (Ozanne & Wilson, 2013). However, E. coli exceeded the target attribute state for 95th percentile concentrations (Table 18).

6.4.2.3. Waiareka Creek

Ammoniacal nitrogen and nitrate-nitrogen concentrations in Waiareka Creek at Taipo Road were in B-band (for toxicity), while concentrations of dissolved reactive phosphorus at this site placed it in D band, and concentrations of faecal indicator bacterium Escherichia coli (E. coli), exceeded the target attribute state for 95th percentile, percentage of values exceeding 260 cfu/100 mL and percentage of values exceeding 540 cfu/100 mL placed this site in D-band, which is below the national bottom line (Table 18). Similarly, water clarity in Waiareka Creek at Taipo Road placed this site in D-band, below the bottom line (Table 18Table 17).

7. Instream Habitat Assessment

7.1. Instream habitat modelling in Kākaunui River

Instream habitat modelling is a method that can be used to consider the effects of changes in flow on instream values, such as physical habitat, water temperature, water quality and sediment processes. The strength of instream habitat modelling lies in its ability to quantify the loss of habitat caused by changes in the flow regime, which helps to evaluate alternative flow proposals. However, it is essential to consider all factors that may affect the organism(s) of interest, such as food, shelter and living space, and to select appropriate habitat-suitability curves, for an assessment to be credible. Habitat modelling does not take other factors into consideration, including the disturbance and mortality caused by flooding as well as biological interactions (such as predation), which can have a significant influence on the distribution and abundance of aquatic species.

Instream habitat modelling requires detailed hydraulic data, as well as knowledge of the ecosystem and the physical requirements of stream biota. The basic premise of habitat methods is that if there is no suitable physical habitat for a given species, then they cannot exist (Jowett & Wilding, 2003). However, if physical habitat is available for that species, then it may or may not be present in a survey reach, depending on other factors not directly related to flow, or to flow-related factors, which have operated in the past (e.g. floods). In other words, habitat methods can be used to set the outer envelope of suitable living conditions for the target biota (Jowett, 2005).

Instream habitat is expressed as Reach Area Weighted Suitability (RAWS), a measure of the total area of suitable habitat per metre of stream length. It is expressed as square metres per metre (m^2/m). Another metric, the reach-averaged Combined Suitability Index (CSI) is a measure of the average habitat quality provided at a particular flow. CSI is useful when considering the effects of changes in flow regime on periphyton where it is not the overall population response that is of interest (such as for fish), but rather the percentage cover across the riverbed (such as periphyton).

These assessments are based on an instream habitat model developed by Water Ways Consulting Ltd for the mainstem of the Kākaunui River between Robs Crossing and Gemmells Crossing during the summer of 2022-2023 (Water Ways Consulting, 2023).

7.1.1. Habitat preferences and suitability curves

Habitat suitability curves (HSC) for a range of organisms present in the Kākaunui catchment were modelled (Table 19) to understand the full range of potential effects of flow regime changes in the Kākaunui River – from changes in the cover and type of periphyton, to changes in the availability of macroinvertebrate prey, to changes in the habitat for fish and birds.

Table 19 Habitat suitability curves used in instream habitat modelling in the Kākaunui River.

Group	HSC name	HSC source
Periphyton	Cyanobacteria	Ex Heath et al. (2013)
	Didymo	Jowett unpublished data
	Diatoms	Unpublished NIWA data
	Long filamentous	Unpublished NIWA data
	Short filamentous	Unpublished NIWA data
Macroinvertebrates	Food producing	Waters (1976)
	Mayfly nymph (*Deleatidium*)	Jowett et al. (1991)
	Net-spinning caddis fly (*Aoteapsyche*)	Jowett et al. (1991)
	Sand-cased caddis fly (*Pycnocentrodes*)	Jowett et al. (1991)
Indigenous fish	Tuna/longfin eel (>300 mm)	Jowett & Richardson (2008)
	Tuna/longfin eel (<300 mm)	Jowett & Richardson (2008)
	Torrentfish	Jowett & Richardson (2008)
	Upland bully	Jowett & Richardson (2008)
	Common bully	Jowett & Richardson (2008)
	Bluegill bully	Jowett & Richardson (2008)
	Redfin bully	Jowett & Richardson (2008)
	Inanga	Jowett & Richardson (2008)
	Canterbury galaxias	Jowett & Richardson (2008)
	Juvenile lowland longjaw galaxias	Jowett & Richardson (2008)
	Adult lowland longjaw galaxias	Jowett & Richardson (2008)
	Kanakana/Lamprey	Jowett & Richardson (2008)
Sports fish	Brown trout adult	Hayes & Jowett (1994)
	Brown trout yearling	Raleigh *et al.* (1986)
	Brown trout spawning	Shirvell & Dungey (1983)

7.1.2. Physical characteristics

The hydraulic component of instream habitat modelling can be used to make predictions over how water depth, channel width and water velocity will change with changes in flow. The relationships between flow and water depth, channel width and water velocity in the Kākaunui River are shown in Figure 16.

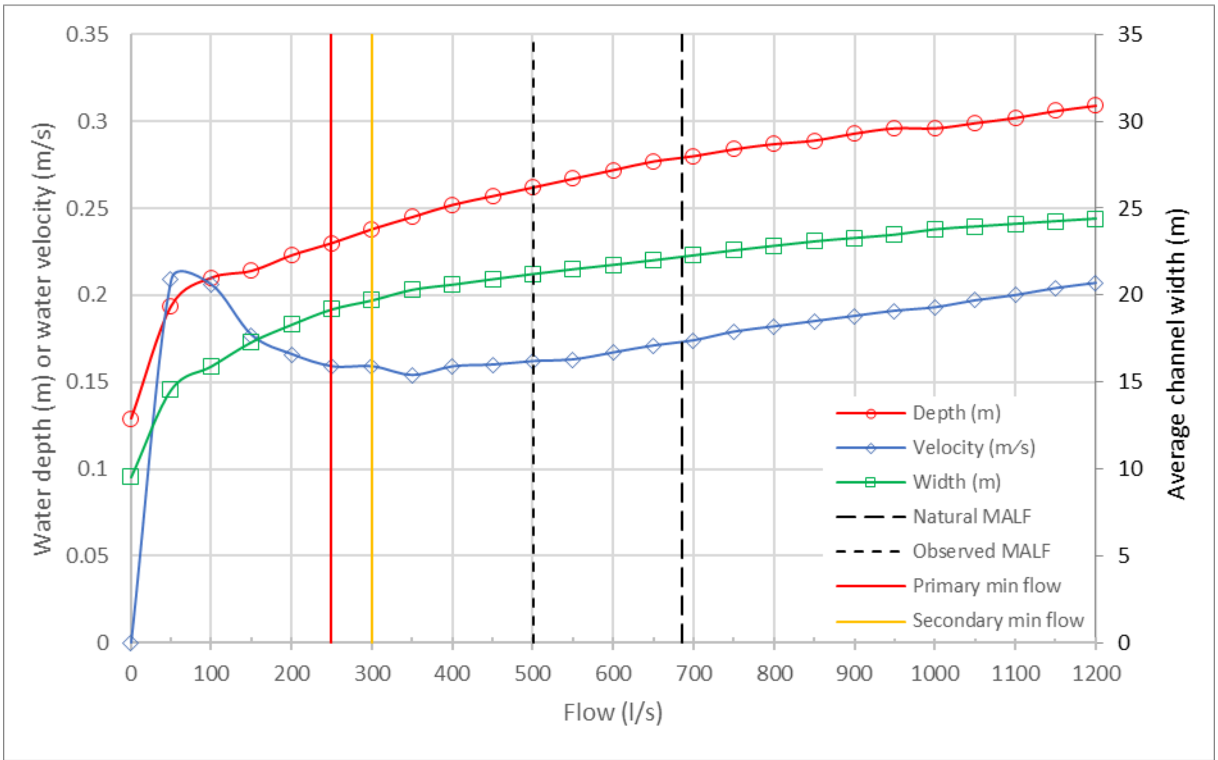

Figure 16 Changes in mean channel width, mean water depth and mean water velocity with changes in flow in the survey reach of the Kākaunui River between Gemmells Crossing and Rob's Crossing.

7.2. Periphyton

The main purpose of considering periphyton is to understand how changes in flow are likely to affect how much of the riverbed is covered by periphyton and the relative contribution of the different types of periphyton to the overall community. Given this, it is the percentage of the wetted channel covered by periphyton, not the total area of suitable habitat that is of interest. For this reason, the habitat suitability index (reach-averaged CSI) was used instead of weighted usable area (RAWS) in instream habitat analyses for periphyton.

Flow was predicted to have little effect on habitat quality for cyanobacteria (*Phormidium*) with habitat quality predicted to increase very gradually across the modelled flow range (Figure 17). Habitat quality for native diatoms was predicted to be low across the modelled flow range (Figure 17). Habitat quality for short filamentous algae was predicted to increase with increasing flows across the modelled flow, while habitat quality for long filamentous algae was predicted to be highest in the absence of flow and to decline with increasing flows across the modelled flow range (Figure 17). The results of these analyses are summarised in Table 20.

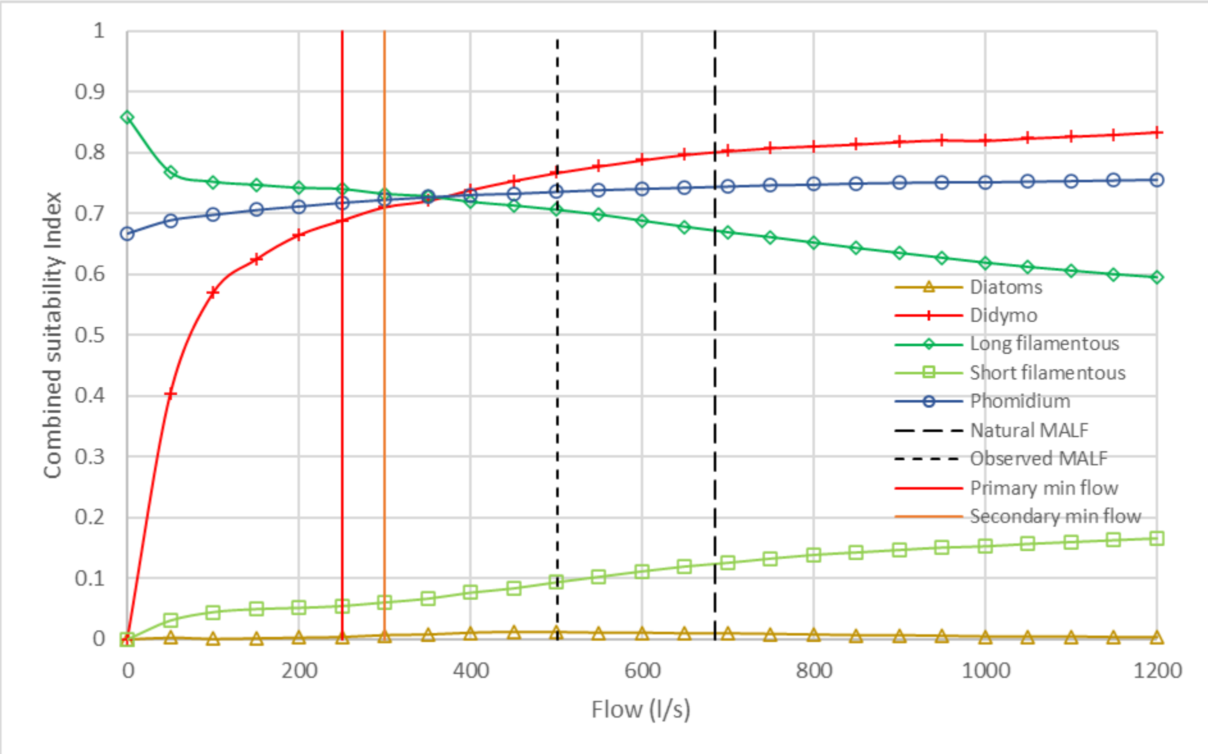

Figure 17 Variation in instream habitat quality for periphyton relative to flow in the survey reach of the Kākaunui River between Gemmells Crossing and Rob's Crossing.

Table 20 Flow requirements for periphyton habitat in the Kākaunui River. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction).

Species	Maximum flow (l/s)	Flow at which % habitat retention occurs (l/s)				Habitat retention at 250 l/s (%)	Habitat retention at 300 l/s (%)
		120%	150%	200%	300%		
Cyanobacteria (*Phormidium*)	-	-	-	-	-	96	97
Diatoms	>1,200	-	-	-	-	40	70
Didymo	>1,200	-	-	-	-	86	89
Short filamentous	>1,200	-	-	-	-	44	49
Long filamentous	-	-	-	-	-	110	109

7.3. Macroinvertebrates

Food producing habitat is an overseas HSC that describes the most productive habitat conditions for macroinvertebrates. The mayfly *Deleatidium* is arguably the most abundant and widespread aquatic macroinvertebrate in New Zealand and is abundant at sites in the upper Kākaunui River (Ozanne & Wilson, 2013), and habitat for *Deleatidium* was modelled for this reason. The net-spinning caddisfly *Aoteapsyche* is also widespread and can be particularly abundant in stable and productive systems (e.g. lake outlets). Habitat for *Aoteapsyche* is included here because the habitat preferences of this species means that it is the most flow-demanding common macroinvertebrates in New Zealand and can be abundant in the Kākaunui River (Section 6.2). The stony-cased caddis *Pycnocentrodes* can be amongst the most common macroinvertebrate taxa in moderate to slow-moving streams and is abundant in the Kākaunui River at times (Section 6.2). It is included in habitat modelling to represent taxa that prefer slower-flowing habitats.

Food producing habitat and habitat for all macroinvertebrate taxa increased with flow across the modelled flow range (Figure 18). Flows required to achieve different levels of habitat retention for each of the macroinvertebrate taxa are presented in Table 21.

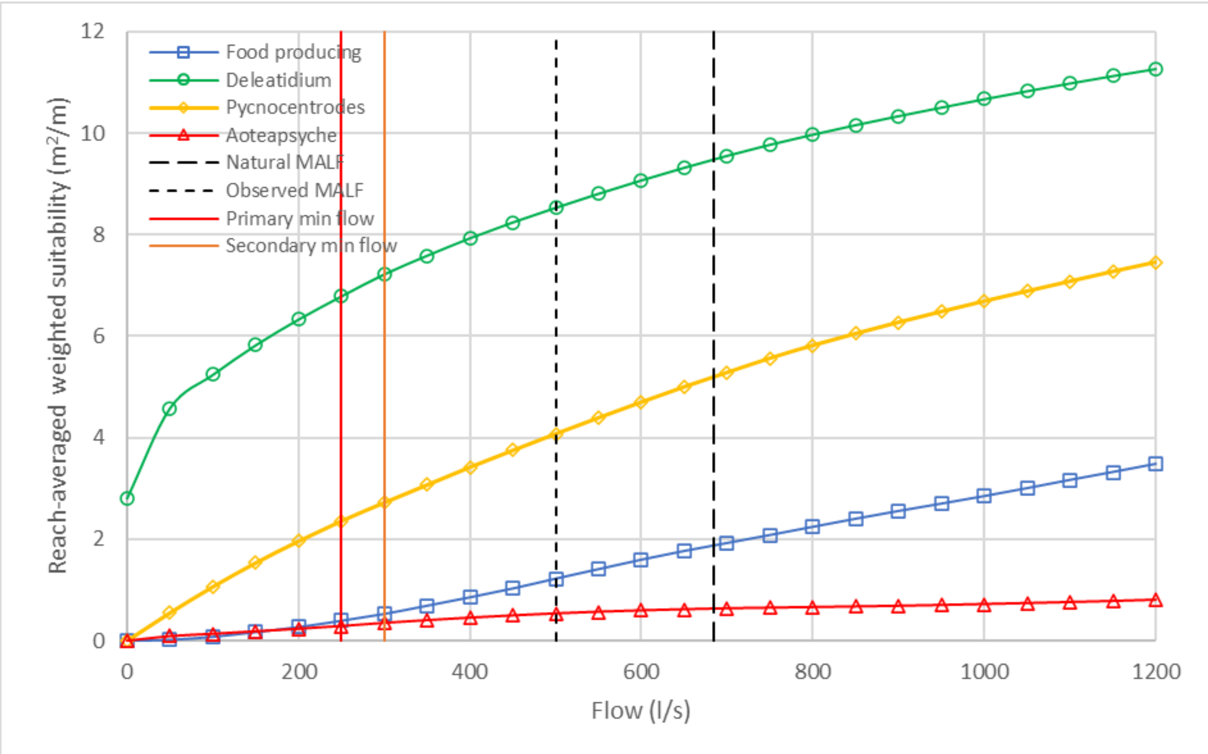

Figure 18 Variation in instream habitat for common macroinvertebrates relative to flow in the survey reach of the Kākaunui River between Gemmells Crossing and Rob's Crossing.

Table 21 Flow requirements for macroinvertebrate habitat in the Kākaunui River. Flows required for the various habitat retention values are given relative to the naturalised 7-d MALF (i.e., flows predicted in the absence of any abstraction).

Species	Maximum flow (l/s)	Flow at which % habitat retention occurs (l/s)				Habitat retention at 200 l/s (%)	Habitat retention at 300 l/s (%)
		60%	70%	80%	90%		
Food producing habitat	>1,200	475	524	574	627	21	28
Common mayfly *Deleatidium*	>1,200	139	234	350	501	72	76
Net-spinning caddis fly (*Aoteapsyche*)	>1,200	326	388	459	547	46	56
Cased caddis fly (*Pycnocentrodes*)	>1,200	357	433	513	596	45	52

7.4. Indigenous fish

Habitat for tuna/longfin eel (<300 mm and >300 mm), torrentfish, bluegill and common bullies and Canterbury galaxias is predicted to increase across the modelled flow range (Figure 18). Habitat for upland bully is predicted to increase with increasing flow to 1,000 l/s, before gradually declining (Figure 18). Habitat for inanga is predicted to increase with increasing flow to 300 l/s and decline gradually at higher flows (Figure 18). Habitat for kanakana/lamprey is predicted to decline with increasing flows, with no flow providing maximum habitat for juvenile lamprey, while adult habitat was highest at 50 l/s (Figure 18).

Habitat for juvenile lowland longjaw galaxias is predicted to be highest at 50 l/s, dropping at higher flows, while habitat for adult lowland longjaw galaxias increased rapidly to 400 l/s, and increased gradually above 400 l/s to a maximum at approximately 1,000 l/s before gradually declining (Figure 18).

Flows required to achieve different levels of habitat retention for indigenous fish species are presented in Table 22.

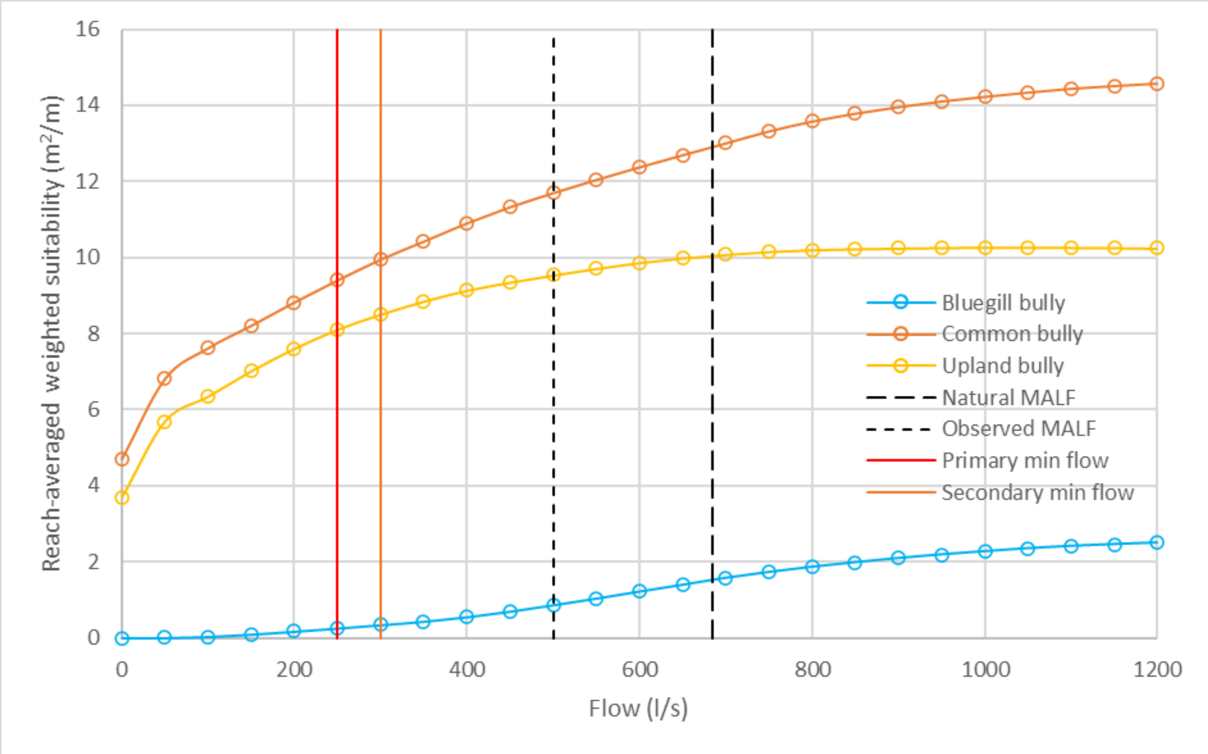

Figure 19 Variation in instream habitat for bully species relative to flow in the survey reach of the Kākaunui River between Gemmells Crossing and Rob's Crossing.

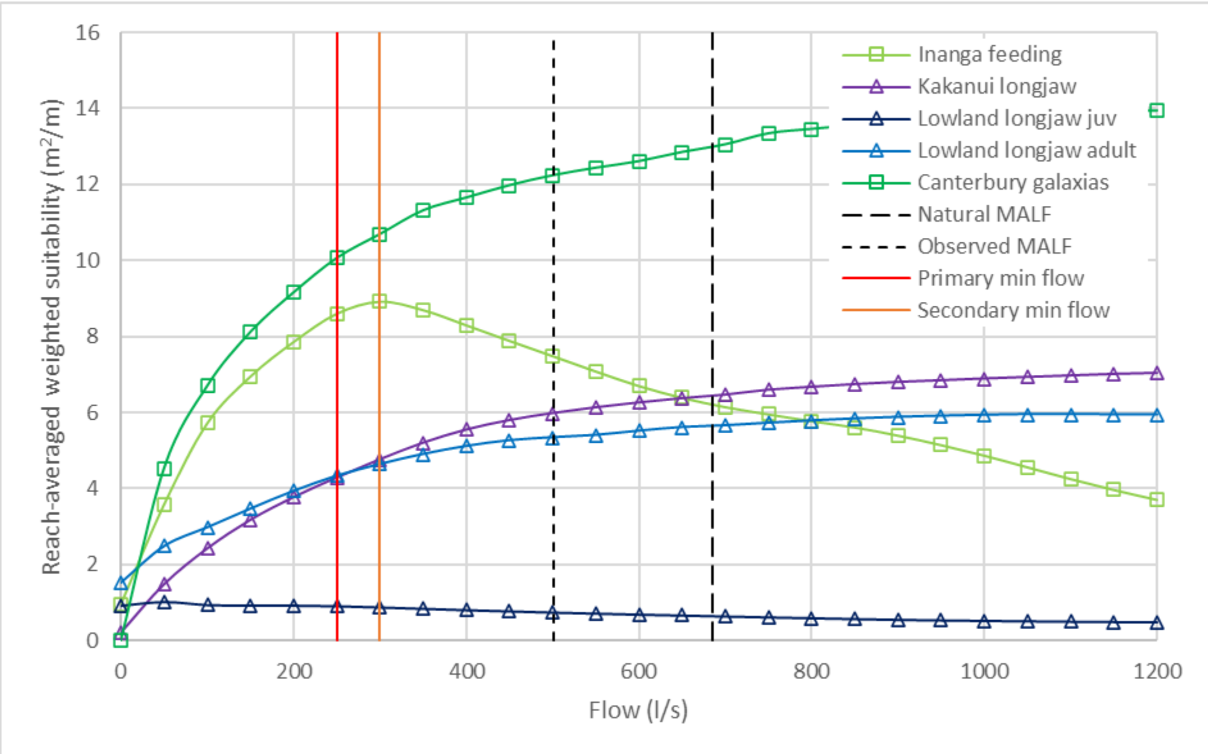

Figure 20 Variation in instream habitat for galaxias species relative to flow in the survey reach of the Kākaunui River between Gemmells Crossing and Rob's Crossing.

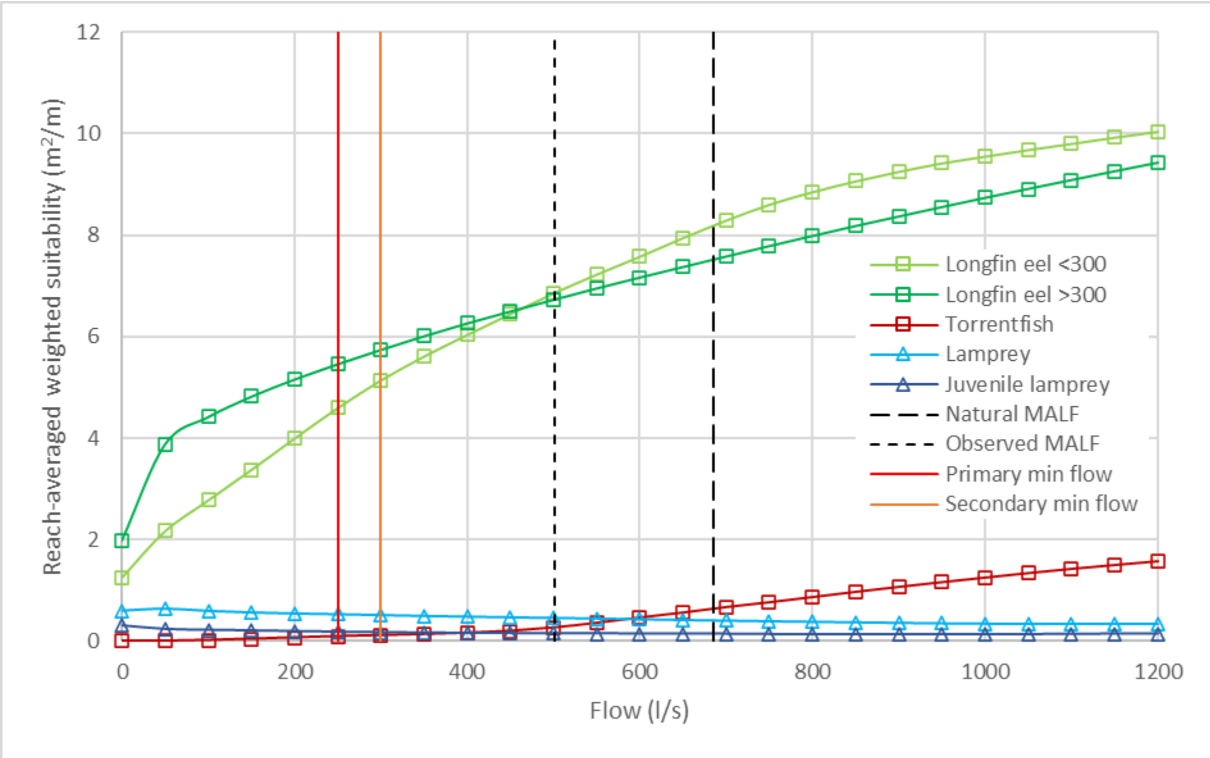

Figure 21 Variation in instream habitat for eel, torrentfish and lamprey relative to flow in the survey reach of the Kākaunui River between Gemmells Crossing and Rob's Crossing.

Table 22 Flow requirements for indigenous fish habitat in the Kākaunui River. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction).

Species	Maximum flow (l/s)	Flow at which % habitat retention occurs (l/s)				Habitat retention at 250 l/s	Habitat retention at 300 l/s
		60%	70%	80%	90%		
Tuna/longfin eel <300 mm	>1,200	279	364	463	570	56	63
Tuna/longfin eel >300 mm	>1,200	111	217	351	509	73	76
Torrentfish	>1,200	562	592	624	655	14	18
Bluegill bully	>1,200	516	559	600	643	17	23
Common bully	>1,200	110	218	340	490	73	77
Upland bully	1,000	76	152	244	385	81	85
Canterbury galaxias	>1,200	139	197	276	406	77	82
Inanga	300	53	68	83	97	138	143
Kakanui lowland longjaw galaxias	>1,200	209	273	344	449	67	74
Lowland longjaw galaxias juvenile	50					141	136
Lowland longjaw galaxias adult	1,000	141	201	279	391	77	82
Kanakana/lamprey juvenile	0					129	122
Kanakana/lamprey	50					129	125

7.5. Sports fish

Habitat for brown trout adult, juveniles and spawning is predicted to increase with flow across the modelled range (Table 23). Flows required to achieve different levels of habitat retention for each of these species/life-stages are presented in Table 23.

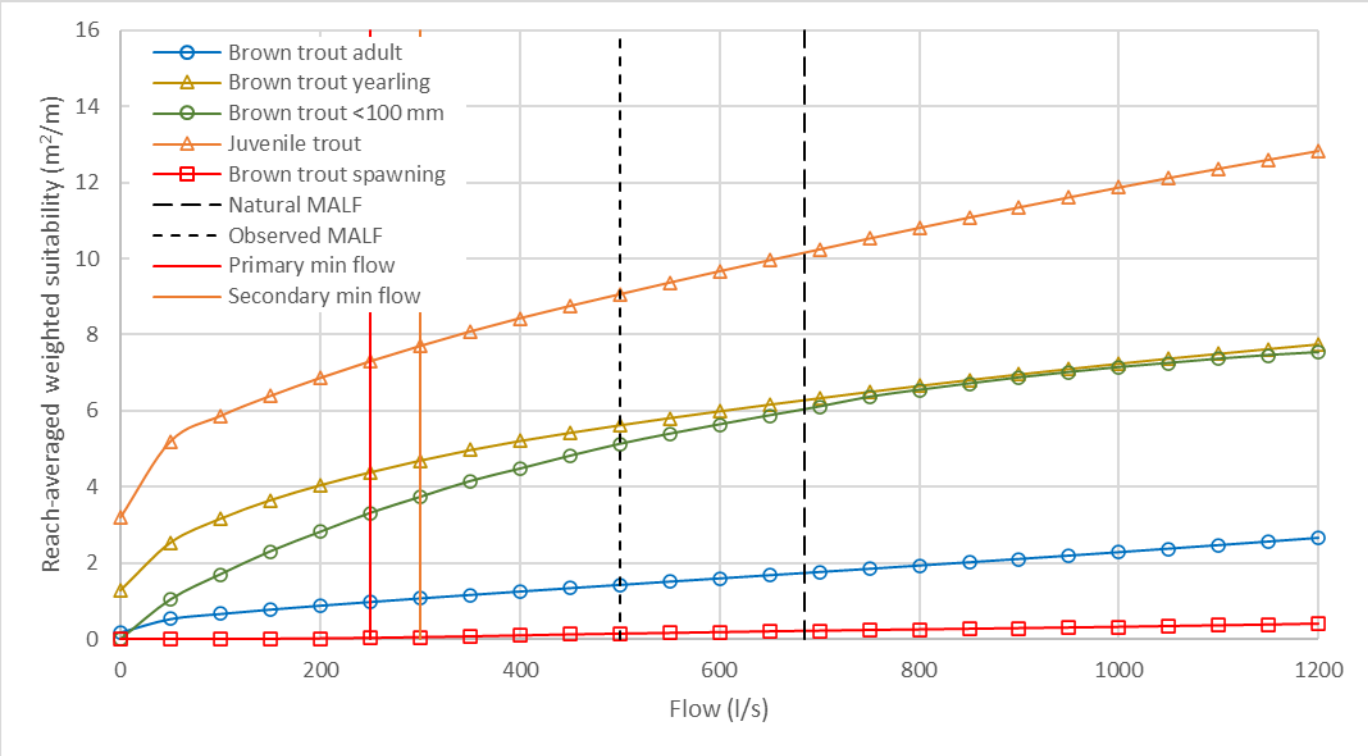

Figure 22 Variation in instream habitat for sportsfish relative to flow in the survey reach of the Kākaunui River between Gemmells Crossing and Rob's Crossing.

Table 23 Flow requirements for sportsfish habitat in the Kākaunui Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction).

Species	Maximum flow (l/s)	Flow at which % habitat retention occurs (l/s)				Habitat retention at 200 l/s	Habitat retention at 300 l/s
		60%	70%	80%	90%		
Brown trout adult	>1,200	285	381	480	581	56	62
Brown trout yearling	>1,200	165	252	362	509	70	75
Brown trout (<100 mm)	>1,200	287	362	453	558	55	62
Juvenile trout	>1,200	122	228	356	513	72	76
Brown trout spawning	>1,200	470	524	576	628	15	22

7.6. Summary of instream habitat assessments

The objective of imposing a minimum flow is to protect instream values from the adverse effects of water abstraction. In doing this, consideration must be given to the National Policy Statement for Freshwater Management (NPSFM) and LWRP objectives for the North Otago FMU outlined in Table 2. In the Kākaunui catchment, these considerations intersect with water quality issues, particularly when it comes to issues associated with the degradation of Kākaunui Estuary.

The approach taken in this report is to assess the flow required to achieve various levels of habitat retention compared to the natural 7-d MALF predicted. Choosing an appropriate level of habitat retention is based on the species present and the fishery and/or conservation value for each species/life stage is based on the approach of Jowett & Hayes (2004) (Table 24).

Table 24 Suggested signficance ranking (from highest (1) to lowest (5)) of critical values and levels of habitat retention. Based on Table 4.1 of Jowett & Hayes (2004).

Species/life-stage	Fishery/ conservation value	Significance ranking	Recommended % of habitat retention	Example
Longfin eel	High	1	90	Identified mahika kai site
	Moderate	2	80	
Diadromous galaxiid	High	1	90	Nationally significant fishery, threatened species
	Moderate	3	80	Regionally significant fishery, at risk species
	Low	3	70	Locally significant fishery, not threatened
Indigenous fish	High	1	90	Threatened species (i.e. nationally critical, nationally endangered, nationally vulnerable)
	Moderate	2	80	At risk species (i.e. declining, naturally uncommon)
	Low	3	70	Not threatened
Large adult trout - perennial fishery	High	1	90	Nationally significant trout fishery
	Moderate	2	80	Regionally significant trout fishery
	Low	3	70	Locally significant trout fishery
Trout spawning/ juvenile rearing	High	2	80	Significant spawning/rearing for nationally significant fishery
	Moderate	3	70	Significant spawning/rearing for regionally significant fishery
	Low	5	60	Significant spawning/rearing for locally significant fishery

Based on the assessment presented in Table 24, the flows required to achieve 80% habitat retention was applied to most indigenous species in Table 25, with flows required to achieve 90% habitat retention also presented for longfin eels and lowland longjaw galaxias (Table 25). Flows of 351-463 l/s are predicted to retain 80% of the habitat for tuna/longfin eel available at the naturalised MALF (Table 25). Torrentfish is among the most flow-demanding indigenous fish species in the Kākaunui catchment and a flow of 624 l/s would provide 80% habitat retention in the Kākaunui River. In contrast, the current minimum flow is predicted to retain 14% of the habitat for torrentfish at the naturalised MALF (Table 25). Flows of 600 l/s, 340 l/s and 244 l/s would provide 80% habitat retention for bluegill, common and upland bullies, respectively; the current minimum flow retains 17%, 73% and 81% of the habitat for these species at the naturalised MALF, respectively (Table 25).

Flows of 83 l/s and 276 l/s would provide 80% habitat retention for inanga and Canterbury galaxias, respectively; the current minimum flow retains 138% and 73% of the habitat for these species at the naturalised MALF, respectively (Table 25). Flows of 391-449 l/s would provide 90% habitat retention for adult lowland longjaw galaxias, while habitat for juvenile lowland longjaw was highest at very low flows (>100 l/s) and the current minimum flow retains 141% of the habitat available at the naturalised MALF (Table 25). Habitat for kanakana/lamprey was predicted to be highest at very low flows (>100 l/s), and the current minimum flow retains almost 130% of the habitat available at the naturalised MALF (Table 15).

Flows of 350, 547 and 596 l/s would provide 80% habitat retention (relative to naturalised flows) for the common mayfly *Deleatidium*, net-spinning caddis fly *Aoteapsyche*, and *Pycnocentrodes*, respectively (Table 15). The current minimum flow retains 72% of habitat for *Deleatidium*, 46% of habitat for *Aoteapsyche* and 45% of the habitat for *Pycnocentrodes*, relative to habitat available at the naturalised MALF (Table 15).

The current minimum flow (250 l/s) retains 55-70% of the habitat for the various life-stages of trout relative to naturalised flows (Table 15). The Kākaunui River supports a locally significant fishery (Central South Island Fish & Game Council, 2022). Based on the assessment presented in Table 24, Table 25 presents the flows to retain 70% and 80% of the habitat for various life stages of brown trout predicted at the naturalised 7-d MALF. A minimum flow of 381 l/s would retain 70% of habitat for adult brown trout relative to the naturalised MALF (Table 15).

Table 25 Flow requirements for habitat objectives in the Kākaunui River. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction).

Value	Season	Significance	Level of habitat retention	Flow to maintain suggested level of habitat retention (l/s)	Habitat retention at 250 l/s	Habitat retention at 300 l/s
Food producing habitat	All year	Life-supporting capacity	80% relative to naturalised	574	21%	28%
Common mayfly *Deleatidium*	All year	Life-supporting capacity	80% relative to naturalised	350	72%	76%
Net-spinning caddisfly *Aoteapsyche*	All year	Life-supporting capacity	80% relative to naturalised	459	46%	56%
Stony-cased caddisfly *Pycnocentrodes*	All year	Life-supporting capacity	80% relative to naturalised	513	45%	52%
Tuna/longfin eel	All year	Life-supporting capacity, indigenous biodiversity, mahika kai, at risk (declining)	80% relative to naturalised	351-463	56-73%	63-76%
			90% relative to naturalised	509-570		
Torrent fish	All year	Life-supporting capacity, indigenous biodiversity, at risk (declining)	80% relative to naturalised	624	14%	18%
Bluegill bully	All year	Life-supporting capacity, indigenous biodiversity, at risk (declining)	80% relative to naturalised	600	17%	19%
Common bully	All year	Life-supporting capacity, indigenous biodiversity	80% relative to naturalised	340	73%	77%
Upland bully	All year	Life-supporting capacity, indigenous biodiversity	80% relative to naturalised	244	81%	85%
Canterbury galaxias	All year	Life-supporting capacity, indigenous biodiversity	80% relative to naturalised	276	77%	82%
Inanga	All year	Life-supporting capacity, indigenous biodiversity, at risk (declining), mahika kai	80% relative to naturalised	344	67%	74%

Table 25 Flow requirements for habitat objectives in the Kākaunui River. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction).

Value	Season	Significance	Level of habitat retention	Flow to maintain suggested level of habitat retention (l/s)	Habitat retention at 250 l/s	Habitat retention at 300 l/s
Lowland longjaw galaxias	All year	Threatened (nationally critical), life-supporting capacity, indigenous biodiversity	90% relative to naturalised	391-449	67-77%	74-82%
Kanakana/lamprey	All year	Threatened (nationally vulnerable), life-supporting capacity, indigenous biodiversity, mahika kai	80% relative to naturalised	Juvenile: <250 Adult: <250	129%	122%
			90% relative to naturalised	Juvenile: <250 Adult: <250		
Brown trout adult	All year	Locally significant fishery	70% relative to naturalised	381	56%	62%
			80% relative to naturalised	480		
			Maintain existing	250		
Juvenile trout	All year	Locally significant fishery	70% relative to naturalised	252-362	55-70%	62%
			80% relative to naturalised	362-453		
			Maintain existing	250		
Brown trout spawning	Winter	Locally significant fishery	Current winter minimum	400	74% at 400 l/s	

7.7. Kauru River

Water takes from the Kauru River are currently subject to minimum flows in the mainstem of the Kākaunui River, but there is not a minimum flow in the Kauru River itself. The lower reaches of the Kauru River are naturally intermittent (see Section 4.2.2), and so it is expected that water abstraction from the Kauru will enhance the duration and extent of drying. This, along with the presence of lowland longjaw galaxias (nationally critical) in the lower reaches of the Kauru River, is sufficient justification for a flow management approach that is specific to the Kauru River and provides for its character and values.

Setting a minimum flow on the Kauru at Kauru Hill Rd 700m Upstream that is equivalent to the 7-d MALF at this site (120 l/s) would ensure that the extent of drying would not get any larger than would be expected to occur naturally each year, on average. However, whilst introducing a minimum flow on the Kauru would limit the spatial extent of drying, it would not address the duration of drying in the lower reaches of the Kauru River. Reducing allocation would reduce the effect of water abstraction on the duration of drying in the lower Kauru River.

7.8. Island Stream

Island Stream is excluded from the Kākaunui catchment for the purposes of water allocation. Thus, water permits in the Island Stream catchment are not subject to minimum flows set for the Kākaunui River. Given the very low flows in this catchment (with an estimated naturalised 7-d MALF of 24 l/s), inflows from the Island Stream catchment are not expected to meaningfully contribute to flows in the lower Kākaunui River. Given this, and the lack of instream habitat modelling that is applicable to Island Stream, continuation of the current management approach (residual flows and flow limits set out in consents) is suggested.

If the current management approach is to be revised in the future, this will require collection of hydrological data and data collected to inform habitat assessments (such as instream habitat modelling or habitat surveys). Data on water use is also likely to be needed, and this may require water metering data to be audited to ensure its accuracy.

7.9. Waiareka Creek

Waiareka Creek is also excluded from the Kākaunui catchment for the purposes of water allocation. Thus, water permits in the Waiareka Creek catchment are not subject to minimum flows set for the Kākaunui River. Waiareka Creek flows into the Kākaunui Estuary, and so does not affect flows in the lower Kākaunui River. Flows in Waiareka Creek are augmented with water from the Waitaki River by NOIC, although the augmented flows are abstracted upstream of the Taipo Road hydrological site, resulting in flows that are very similar (observed 7-d MALF of 114 l/s versus estimated naturalised 7-d MALF of 126 l/s). Given this, and the lack of instream habitat modelling that is applicable to Island

Stream, continuation of the current management approach (residual flows and flow limits set out in consents held by NOIC) is suggested.

If the current management approach is to be revised in the future, this will require collection of additional hydrological data (to estimate naturalised flows) and data collected to inform habitat assessments (such as instream habitat modelling or habitat surveys). Data on water use is also likely to be needed, and this may require water metering data to be audited. In addition, investigations of the consequences of flow management on water quality in Waiareka Creek are essential to consider the effects on the Kakanui Estuary (see Section 7.10).

7.10. Consideration of the Kākaunui Estuary

Minimum flows in both the Kākaunui River and Waiareka Creek have the potential to interact with water quality in the Kākaunui Estuary. Using a hydrodynamic model developed for the Kākaunui Estuary (Plew & Barr, 2015), Plew (2016) predicted that higher residual flows in Waiareka Creek were likely to result in higher dissolved inorganic nitrogen (DIN) concentrations in the estuary, while Plew (2017) predicted that a higher minimum flow in the Kākaunui River would result in lower nutrient concentrations in the river, particularly if more of the cleaner water originating from higher in the Kākaunui catchment is retained, rather than being extracted for irrigation. Using observed concentrations of DIN in Waiareka Creek and the Kākaunui River, Plew (2016) concluded that at all flows, the Kākaunui River was the largest source of DIN in the Kākaunui Estuary.

On the basis of these studies, an increase in the minimum flow and/or reduction in abstraction from the Kākaunui River may be beneficial for water quality outcomes in the Kākaunui Estuary. However, increases in the minimum flow would be unlikely to meet the estuary DIN target (0.070 mg/L, from Plew & Barr 2015) if there are further increases in catchment load relative to 2016/17 summer loading (34 kg/day for flows below 2,000 l/s). Thus, addressing water quality issues in the Kākaunui Estuary will require an integrated approach targeting nutrient loads in addition to the alteration of minimum flow/allocation in the Kākaunui catchment.

The hydrological analysis summarised in Table 3 estimated the naturalised 7-d MALF at McCones is 712 l/s, while the observed 7-d MALF is 462 l/s. The reduction in flows from naturalised to those observed may have increased DIN concentrations in the Kākaunui River by 25%[8]. Thus, the maximum potential reduction in DIN achievable by increasing the minimum flow in the Kākaunui River is expected to fall within this range.

However, minimum flows typically apply for a relatively short period of time over the irrigation season. Observed flows in the Kākaunui at McCones have dropped to the minimum flow on about 0.4% of occasions. Raising the minimum flow would increase the length of time that the river was at the minimum flow: minimum flows of 350 l/s, 450 l/s and 500 l/s would be reached approximately 5%, 10% and 12% of occasions[9]. This illustrates the limited impact a minimum flow will have on nitrate-

[8] Extrapolated from Figure 3-17 of Plew (2017). Estimated DIN concentration at 462 l/s = 0.243 mg/L, estimated DIN concentration at 712 l/s = 0.180 mg/L.

[9] Based on observed flows in the Kākaunui at McCones between 18 January 2003-12 June 2023.

nitrite nitrogen concentrations entering the Kākaunui Estuary. In comparison, reducing the allocation from the upper Kākaunui catchment will increase flows in the lower catchment and should reduce nitrogen concentrations whenever significant abstraction is occurring, both by diluting nitrogen (and possibly by reducing groundwater residence time) in connected groundwater, and also by increasing dilution of groundwater inputs entering the river.

8. Assessment of alternative minimum flows and allocation limits

Four alternative minimum flows were considered representing different proportions of the 7-day MALF along with four allocation limits (Table 26). The alternative minimum flows considered ranged from the current minimum flows (250 l/s for primary allocation, 300 l/s for secondary allocation), to a primary minimum flow equivalent to 77% of the 7-day MALF (which is close to the default guidelines of Hayes et al. 2020 of 80% of the naturalised 7-d MALF), with two other minimum flow options between these values considered (Table 26). The seven allocation scenarios considered ranged from the current allocation (136% of the naturalised 7-d MALF) to the equivalent to 20% of the 7-day MALF (Table 26).

To consider the hydrological effects of the various combinations of minimum flow/allocation, simulations were run for the period 1 July 2011 – 20 March 2023 using a naturalised flow time-series estimated by Lu (2023). Water takes were simulated to be restricted by pro-rata partial restrictions to maintain the simulated minimum flow and seasonal water usage was based on historical patterns of seasonal water usage. For each simulation, supplementary allocation blocks of 300 l/s were included, with minimum flows increasing proportionally with the increase in the primary minimum flow relative to the existing primary minimum flow (i.e., if the minimum flow is 350 l/s (which is 100 l/s higher than the current minimum flow)

The degree of hydrological alteration resulting from each minimum flow/allocation scenario was assessed using the Dundee Hydrological Regime Assessment Method (DHRAM) (Black *et al*., 2005). This method involves the calculation of 32 parameters relating to the seasonality of flows, magnitude and duration of annual extremes (high and low flow events), timing of annual extremes, frequency and duration of high and low pulses and the rate and frequency of change in flow (Black *et al*., 2005). For each parameter, the mean and co-efficient of variation[10] are calculated. These indices are used to calculate an overall score, which is categorised based on the risk of ecological impact (Table 27). The results of these simulations are presented in Table 28.

The intent of using a hydrological method such as DHRAM as part of these assessments is to complement the habitat modelling approach, which is focussed on protecting habitat for aquatic ecosystems during periods of low flow, while DHRAM considers the broader effects of water abstraction on the hydrology of the Kākaunui River.

All scenarios considered, including the existing minimum flow and allocation limit, are predicted to result in a hydrograph that is either unimpacted or presents a low risk of adverse impacts relative to naturalised flows (Table 28; Figure 23, Figure 24, Figure 25, Figure 26 and Figure 27).

[10] Coefficient of variation is a measure of the variability around the mean (average) value. At its simplest, the coefficient of variation is calculated as the standard deviation divided by the mean.

Table 26 Minimum flow and allocation limits considered in this analysis.

Minimum flow		Allocation limit		
Option	% 7-d MALF	Option	% 7-d MALF	Description
250 l/s primary,	36%	930.3 l/s	136%	Current minimum flow (36% of MALF), current actual allocation (135% MALF)
300 l/s secondary	44%	750 l/s	109%	Current minimum flow (36% of MALF), current Schedule 2A allocation (109% MALF)
1,050 l/s first supplementary		685 l/s	100%	Current minimum flow (36% of MALF), allocation at 100% MALF
1,350 l/s secondary supplementary		550 l/s	80%	Current minimum flow (36% of MALF), allocation at 80% MALF
		410 l/s	60%	Current minimum flow (36% of MALF), allocation at 60% MALF
		275 l/s	40%	Current minimum flow (36% of MALF), allocation at 51% MALF
		140 l/s	20%	Current minimum flow (36% of MALF), allocation at 20% MALF
350 l/s primary,	51%	750 l/s	109%	Minimum flow of 51% of MALF, current Schedule 2A allocation (109% MALF)
400 l/s secondary,	58%	685 l/s	100%	Minimum flow of 51% of MALF, allocation at 100% MALF
1,140 l/s first supplementary		550 l/s	80%	Minimum flow of 51% of MALF, allocation at 80% MALF
1,440 l/s secondary supplementary		410 l/s	60%	Minimum flow of 51% of MALF, allocation at 60% MALF
		275 l/s	40%	Minimum flow of 51% of MALF, allocation at 40% MALF
		140l/s	20%	Minimum flow of 51% of MALF, allocation at 20% MALF
450 l/s primary	66%	750 l/s	109%	Minimum flow of 66% of MALF, current Schedule 2A allocation (109% MALF)
500 l/s secondary,	73%	685 l/s	100%	Minimum flow of 66% of MALF, allocation at 100% MALF
1,250 l/s first supplementary		550 l/s	80%	Minimum flow of 66% of MALF, allocation at 80% MALF
1,550 l/s secondary supplementary		410 l/s	60%	Minimum flow of 66% of MALF, allocation at 60% MALF
		275 l/s	40%	Minimum flow of 66% of MALF, allocation at 40% MALF
		140 l/s	20%	Minimum flow of 66% of MALF, allocation at 20% MALF
550 l/s primary,	77%	750 l/s	109%	Minimum flow of 77% of MALF, current Schedule 2A allocation (109% MALF)
600 l/s secondary	84%	685 l/s	100%	Minimum flow of 77% of MALF, allocation at 100% MALF
1,350 l/s first supplementary		550 l/s	80%	Minimum flow of 77% of MALF, allocation at 80% MALF
1,650 l/s secondary supplementary		410 l/s	60%	Minimum flow of 77% of MALF, allocation at 60% MALF
		275 l/s	40%	Minimum flow of 77% of MALF, allocation at 40% MALF
		140 l/s	20%	Minimum flow of 77% of MALF, allocation at 20% MALF

Table 27 DHRAM classes used in the assessment of alternative minimum flow/allocation

Class	Points range	Description
1	0	Un-impacted condition
2	1-4	Low risk of impact
3	5-10	Moderate risk of impact
4	11-20	High risk of impact
5	21-30	Severely impacted condition

Table 28 Comparison of the hydrological effects of different minimum flow/allocation limit combinations in the Kākaunui River.

	Allocation	Monthly		Min/max means		Date/timing		Pulse count/duration		Rate of change		
Min flow	limit	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	Risk grade
Observed		0	0	0	0	0	0	0	0	0	0	Unimpacted condition
250/300	930.3	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	750	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	685	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	550	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	410	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	275	0	0	0	0	0	0	0	0	0	0	Unimpacted condition
	135	0	0	0	0	0	0	0	0	0	0	Unimpacted condition
350/400	750	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	685	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	550	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	410	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	275	0	0	0	0	0	0	0	0	0	0	Unimpacted condition
	135	0	0	0	0	0	0	0	0	0	0	Unimpacted condition
450/500	750	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	685	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	550	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	410	0	0	0	0	0	0	0	0	0	0	Unimpacted condition
	275	0	0	0	0	0	0	0	0	0	0	Unimpacted condition
	135	0	0	0	0	0	0	0	0	0	0	Unimpacted condition
550/600	750	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	685	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	550	0	1	0	0	0	0	0	0	0	0	Low risk of impact
	410	0	0	0	0	0	0	0	0	0	0	Unimpacted condition
	275	0	0	0	0	0	0	0	0	0	0	Unimpacted condition
	135	0	0	0	0	0	0	0	0	0	0	Unimpacted condition

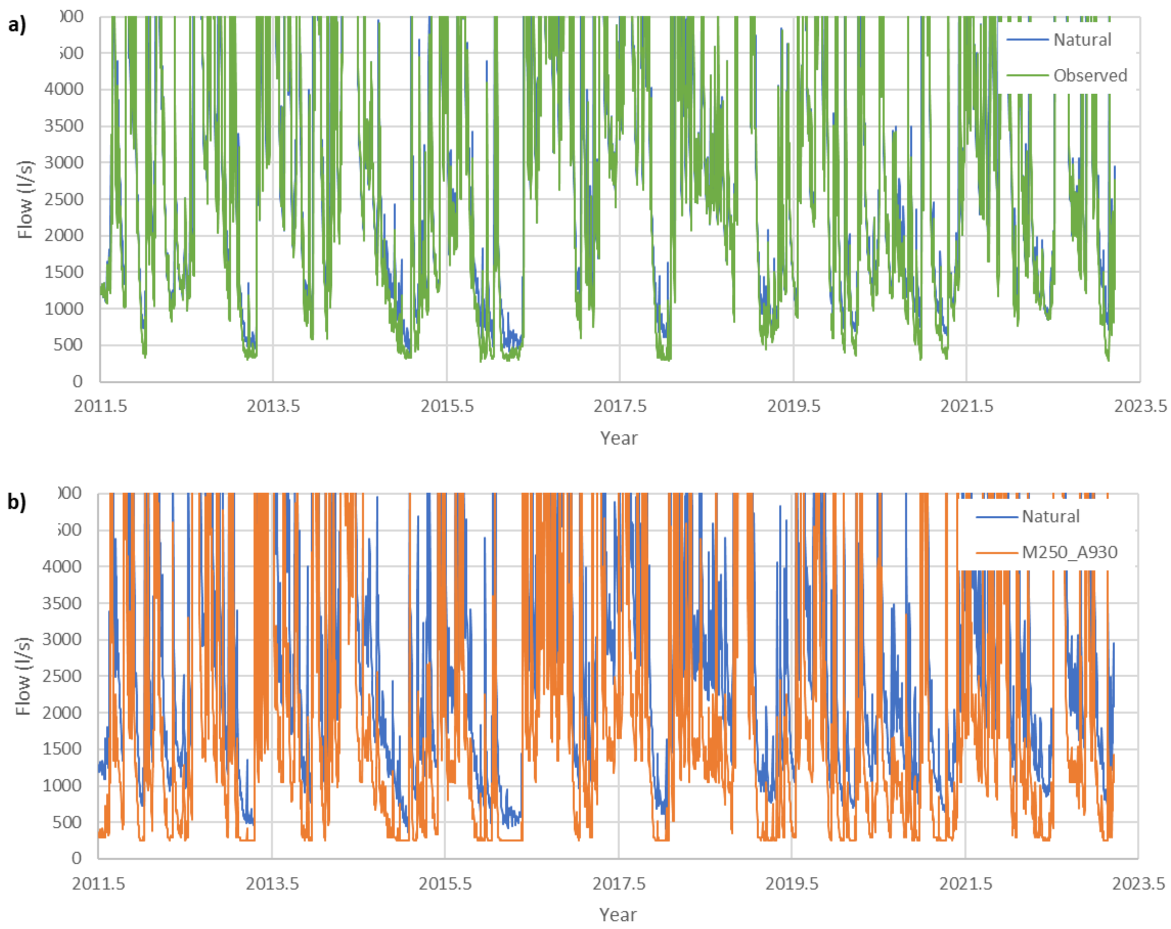

Figure 23 Hydrographs of a) observed flows and b) an allocation scenario with primary minimum flow of 250 l/s and a secondary minimum flow of 300 l/s and allocation of 930.3 l/s (the current min flow and allocation scenario).

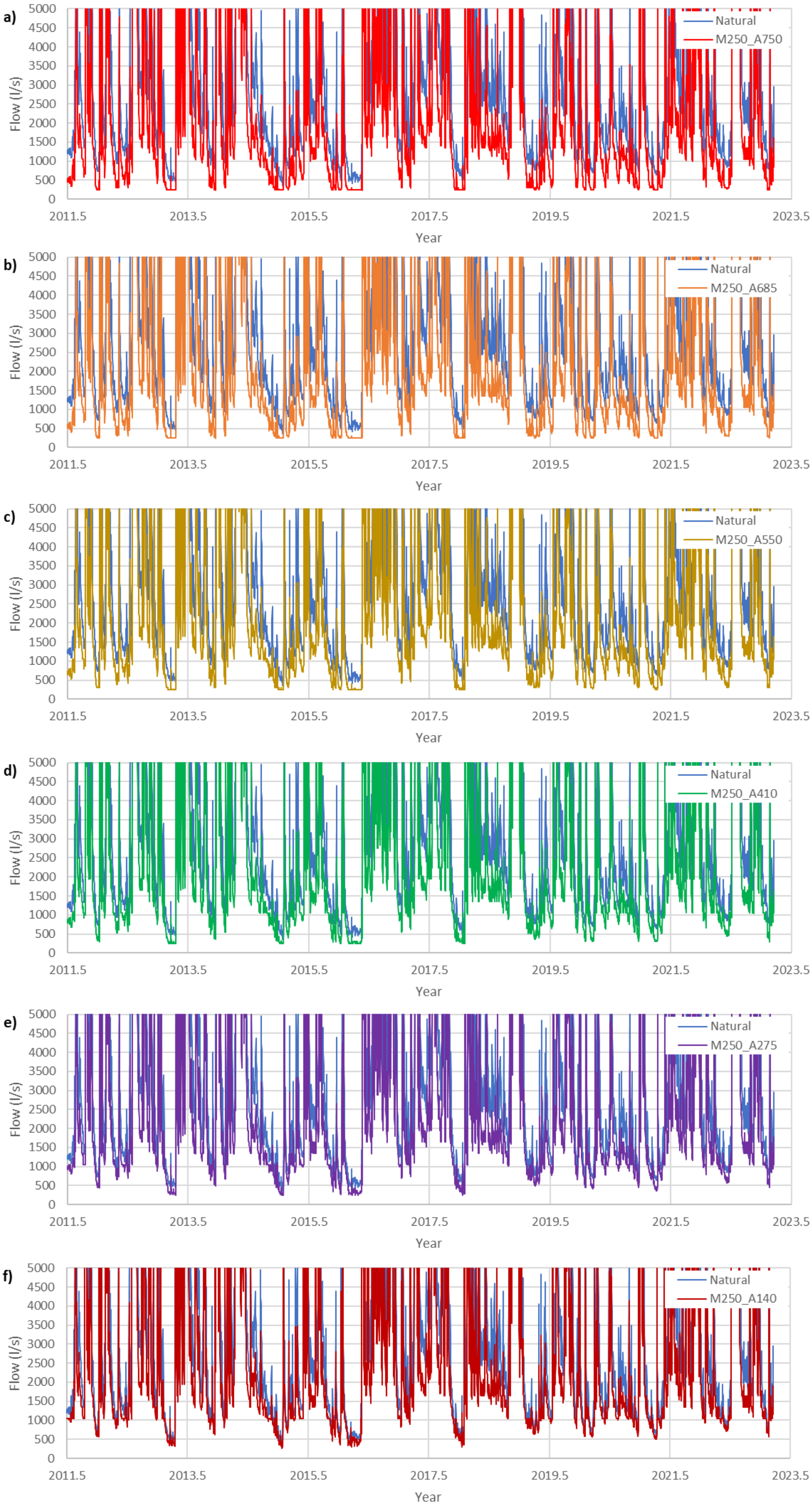

Figure 24 Hydrographs of allocation scenarios with primary minimum flow of 250 l/s and a secondary minimum flow of 300 l/s. a) Current allocation limit 750 l/s, b) allocation limit of 685 l/s, c) allocation limit of 550 l/s, d) allocation limit of 410 l/s, e) allocation limit of 275 l/s, f) allocation limit of 140 l/s.

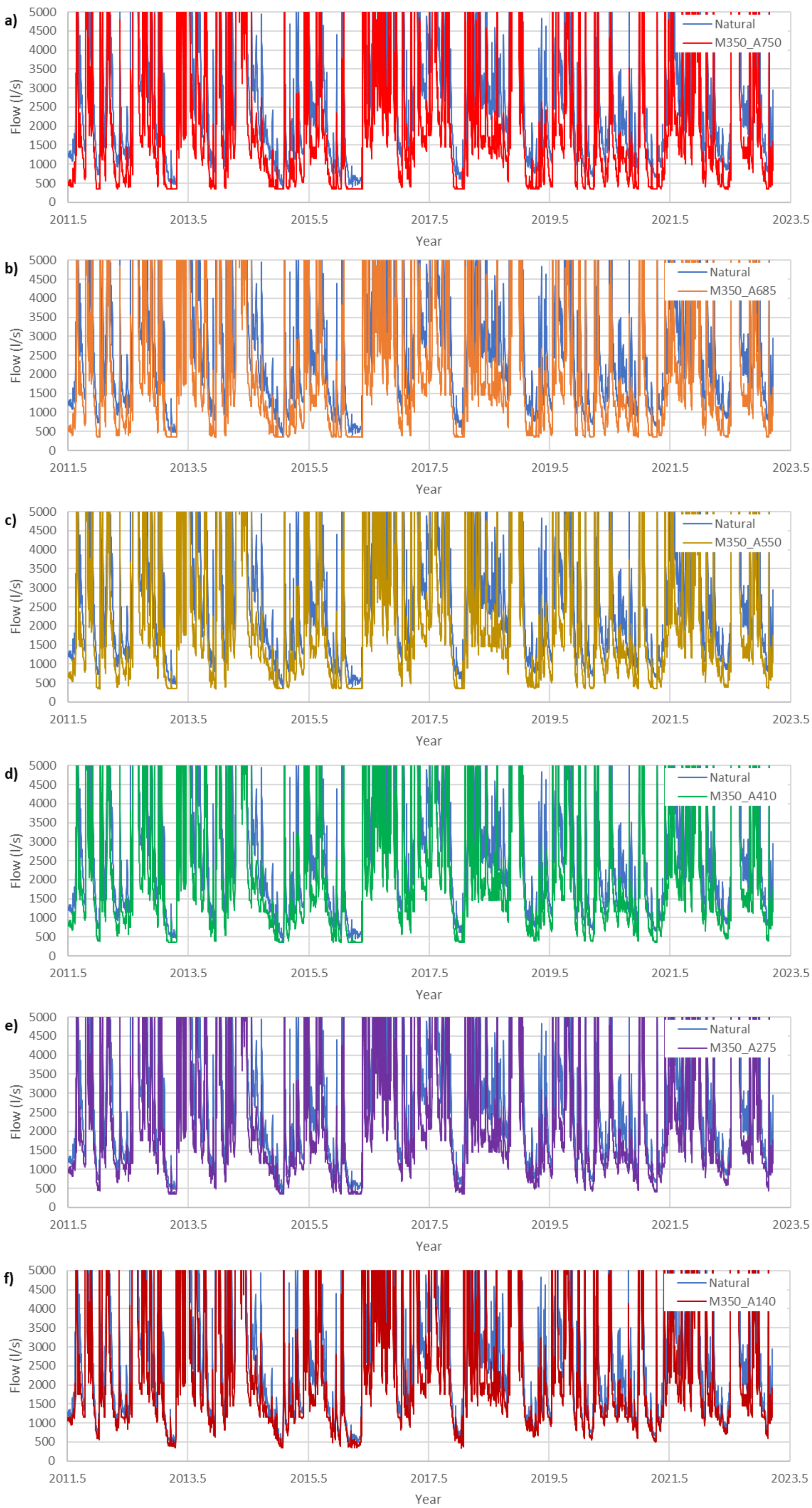

Figure 25 Hydrographs of allocation scenarios with primary minimum flow of 350 l/s and a secondary minimum flow of 400 l/s. a) Current allocation limit 750 l/s, b) allocation limit of 685 l/s, c) allocation limit of 550 l/s, d) allocation limit of 410 l/s, e) allocation limit of 275 l/s, f) allocation limit of 140 l/s.

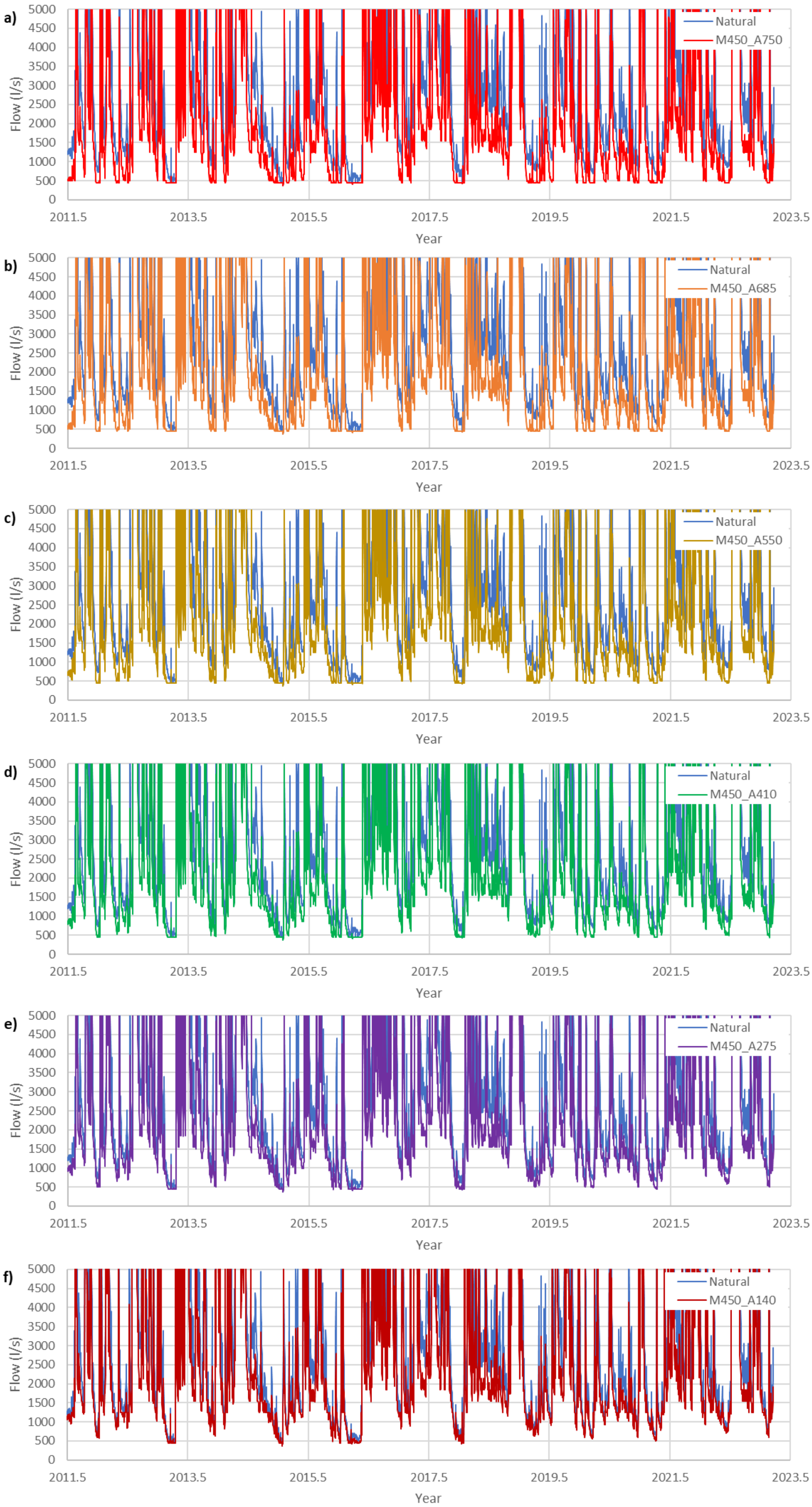

Figure 26 Hydrographs of allocation scenarios with primary minimum flow of 450 l/s and a secondary minimum flow of 500 l/s. a) Current allocation limit 750 l/s, b) allocation limit of 685 l/s, c) allocation limit of 550 l/s, d) allocation limit of 410 l/s, e) allocation limit of 275 l/s, f) allocation limit of 140 l/s..

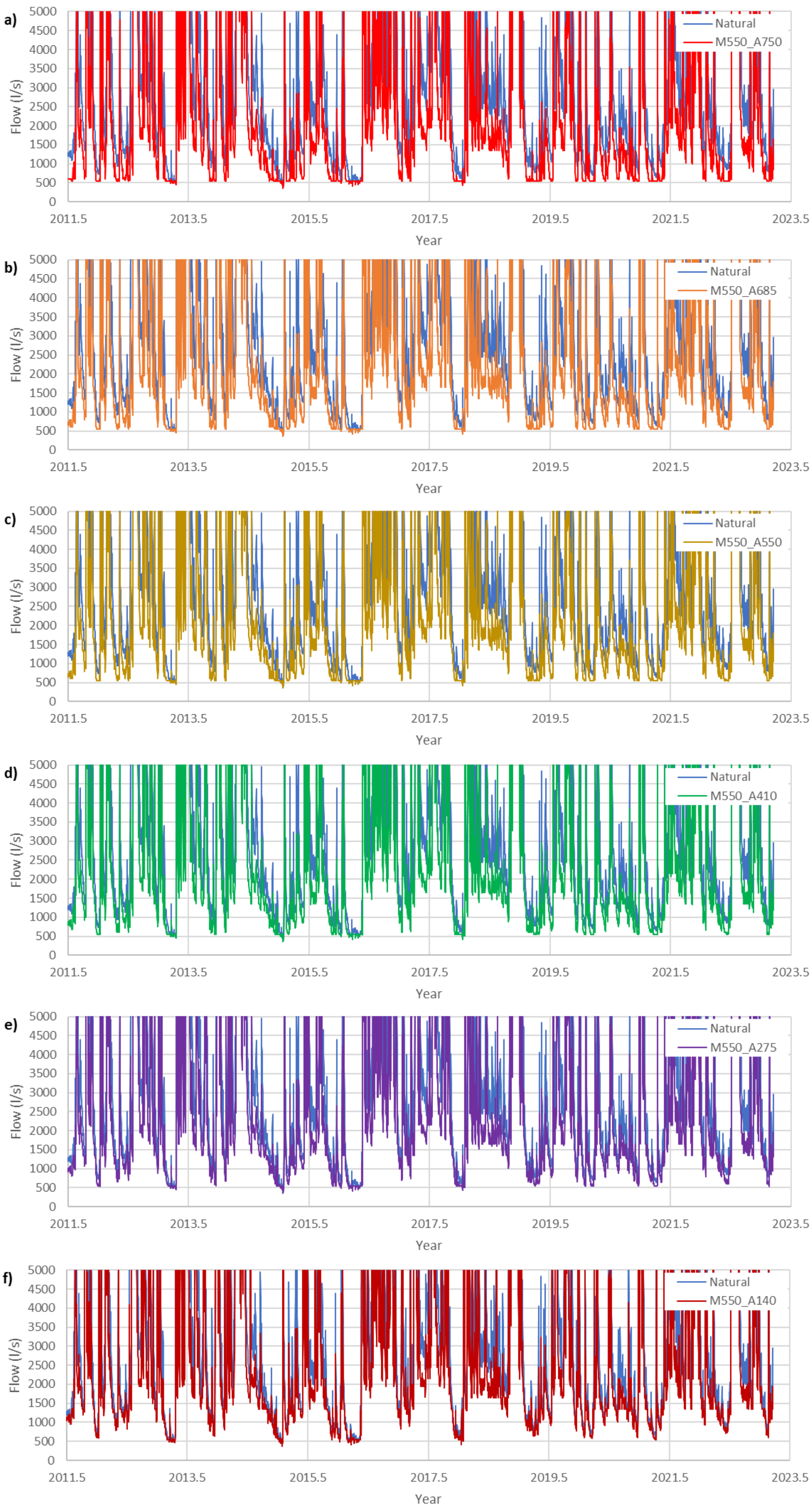

Figure 27 Hydrographs of allocation scenarios with primary minimum flow of 500 l/s and a secondary minimum flow of 550 l/s. a) Current allocation limit 750 l/s, b) allocation limit of 685 l/s, c) allocation limit of 550 l/s, d) allocation limit of 410 l/s, e) allocation limit of 275 l/s, f) allocation limit of 140 l/s..

8.1. Consideration of existing minimum flows & allocation

The minimum flow is the flow below which any resource consent holder must cease taking water from that river and the allocation limit is the maximum rate (or volume) of water abstraction. Schedule 2A of the RPW specifies minimum flows of 250 l/s for primary allocation, 300 l/s for secondary allocation in summer (1 October to 30 April) or 400 l/s in winter (1 May to 30 September). Actual primary/secondary allocation in the Kākaunui River is 930.3 l/s.

The existing minimum flow and allocation limit are predicted to result in a hydrograph that has a low risk of impact relative to naturalised flows (based on the DHRAM score). However, periphyton biomass in the Kākaunui River at McCones exceeds both the LWRP objectives for the North Otago FMU and the national bottom line (based on Table 2 of the NOF; NPSFM 2022). Water abstraction and use can affect periphyton accrual and may contribute to high periphyton biomass and exceedance of these objectives. However, the natural characteristics of the Kākaunui River (high summer temperatures, long daylight hours, high water clarity and long periods of low flows) along with other factors (such as high nitrogen concentrations) contribute to the high biomasses observed in the Kākaunui catchment.

Some of the macroinvertebrate indices for sites in the Kākaunui are below the national bottom line, including at upstream sites in the Kākaunui at Clifton Falls and the Kauru at Kauru Hill Rd 700m Upstream. Water abstraction and use can affect periphyton, which can affect the composition of macroinvertebrate communities. In addition, high water temperatures observed in the Kākaunui catchment (see Section 5) are expected to influence macroinvertebrate community composition, favouring taxa that are tolerant of high water temperatures. Such taxa also tend to be tolerant of organic pollution and have low MCI scores as a consequence.

8.2. Potential effects of climate change in the Kākaunui catchment

The potential effects of future climate change are subject to considerable variation depending on future emission scenarios. This assessment is based on the assessment of Macara *et al*. (2019) using two scenarios (RCP4.5 and RCP8.5[11]) for the period 2031-2050.

The projected effects of climate change, such as reduced snowpack, higher temperatures (and therefore evapotranspiration), and reduced summer rainfall, are expected to increase the probability, magnitude and duration of low flow events in the Kākaunui catchment (Table 29). Climate change may reduce habitat suitability for sensitive species (via increased water temperatures, reduced flows) and increase the risk of periphyton proliferations (through increased water temperatures, longer accrual periods). This may affect the baseline state for periphyton biomass (i.e. the periphyton biomass that would be achievable under natural conditions). Given that periphyton biomass exceeds the target

[11] Future climate change projections are considered under four emission scenarios, called Representative Concentration Pathways (RCPs) by the IPCC. RCP 4.5 is a mid-range scenario where greenhouse gas concentrations stabilise by 2100, while RCP8.5 is a "business as usual" scenario with greenhouse gas emissions continuing at current rates.

attribute state in the Kākaunui River at McCones, such changes may reduce the achievability of periphyton objectives in the Kākaunui catchment.

Water temperatures in the Kākaunui River exceeded thermal criteria for sensitive macroinvertebrate taxa at both the Clifton Falls and McCones monitoring sites (Section 0) and this may account for the low macroinvertebrate indices (MCI, QMCI) observed at these sites (Section 6.2). The predicted increases in air temperatures (Table 29) are expected to exacerbate the existing thermal environment in the Kākaunui River.

Table 29 Potential effects of climate change on the Kākaunui catchment based on the assessment of Macara et al. (2019) using two scenarios (RCP4.5 and RCP8.5) for the period 2031-2050.

Variable	Projected effect	Potential effect on hydrology of Kākaunui River	Potential ecological consequences
Temperature	• Increased mean temperatures (0.5-1°C) • Increased annual mean maximum temperature (0.5-1.5°C) • Small increase in number of hot days (>30°C) (increase by 2-4 days per annum) • Reduced frost days (5-10 fewer frost days per annum)	• Increased evapotranspiration • Faster flow recession • Increased irrigation demand	• Higher water temperatures, reduced suitability for sensitive species • Faster accrual of periphyton biomass
Rainfall	• Little change in annual mean rainfall (±5%) • Reduced summer mean rainfall (-5 - -10%) • Similar risk of low rainfall events • Small increase in peak rainfall intensity	• Increased likelihood and/or magnitude of low flow events • Potential increase in magnitude of high flow events	• Increased chance of periphyton biomass reaching nuisance levels
Snow	• Small reduction in snow days	• Reduced snowpack • Earlier and/or shorter spring snowmelt • Larger winter floods	• Earlier onset of low-flow conditions
Hydrology	• 5-20% reduction in Q95 flow • Reduced reliability for irrigators	• Lower low flows • May increase demand for water take during higher flows	• Altered habitat suitability for some species

8.3. Minimum flow sites

Minimum flows currently apply at two minimum flow sites in the lower Kākaunui River – Mill Dam and McCones – in addition to the Clifton Falls site in the upper catchment. In the Environment Court hearing, the McCones flow site was added as a minimum flow site to capture the hydrological effects of water abstraction downstream of Mill Dam. However, the Mill Dam minimum flow site was retained recognising the uncertainties associated with the (then) recently established McCones hydrological monitoring site. Given that McCones has been in place since 2003, the Mill Dam minimum flow site is now unnecessary and it is recommended that the Mill Dam site is removed as a minimum flow site and that the McCones site is the minimum site on the lower Kākaunui River along with the Clifton Falls site in the upper catchment that applies to winter takes (1 May-30 September).

Water takes from the Kauru River are currently subject to minimum flows in the mainstem of the Kākaunui River, but there is not a minimum flow in the Kauru River itself. Consideration should be given to making the Kauru River at Kauru Hill Rd 700m Upstream a minimum flow site given the naturally intermittent flows in the Kauru River and the presence of the critically threatened lowland longjaw galaxias.

Flows in Island Stream are managed by residual flows on individual consents. This makes sense given the very small size of Island Stream (with a naturalised MALF representing approximately 3% of the naturalised MALF of the Kākaunui River at McCones).

All water permits for primary allocation on the Waiareka Creek are held by the North Otago Irrigation Company and include a condition that requires the provision of "operational flows" at Taipo Road. This, along with the fact that Waiareka Creek flows into the Kākaunui Estuary rather than the Kākaunui River itself, supports the continuation of the current approach to flow management in the Waiareka Creek.

9. Conclusions

The Kākaunui catchment has a long history of water abstraction. It is one of the first catchments in Otago to have a minimum flow, with a 200 l/s minimum flow at the Mill Dam hydrological monitoring site in effect since the late 1970s. Currently, a minimum flow of 250 l/s (1 October to 30 April) applies to primary permits in the Kākaunui catchment, while a minimum flow of 300 l/s applies to secondary permits. The primary/secondary allocation limit for the Kākaunui catchment in Schedule 2A is 750 l/s, while consented primary/secondary allocation is 930.3 l/s.

The flow statistics based on the analysis of Lu (2023) are summarised below:

Site		Flow statistics (l/s)		
		Mean	**Median**	**7d MALF (Jul-Jun)**
Kakanui River at Clifton Falls	Naturalised flows	3,528	1,714	551
	Observed flows	3,507	1,698	523
Kakanui River at Mill Dam	Naturalised flows	5,293	2,394	685
	Observed flows	5,170	2,284	501
Kakanui River at McCones	Naturalised flows	5,650	2,645	712
	Observed flows	5,497	2,512	462
Kauru River at Kauru Hill Rd 700m Upstream	Naturalised flows	1,425	575	122
	Observed flows	1,421	572	119
Island Stream	Naturalised flows	323	227	24
Waiareka Creek	Naturalised flows	503	-	126
	Observed flows	496	-	114

Medium and thick light brown mats were the most common periphyton cover at the McCones monitoring site, while benthic cyanobacteria mats were also frequently abundant. Blooms of benthic cyanobacteria are known to occur throughout the Kākaunui catchment and signs have been installed at major access points warning of the potential presence of toxin-producing cyanobacteria. Filamentous algae have also been abundant at the McCones monitoring site at times and can be associated with the high chlorophyll *a* concentrations observed at this site.

Macroinvertebrate communities in the Kākaunui River at McCones were dominated by the mudsnail *Potamopyrgus* and chironomid midges, while oligochaete worms and various caddis flies have been abundant at times. In comparison the macroinvertebrate community at Clifton Falls has been dominated by the mudsnail *Potamopyrgus* and the common mayfly *Deleatidium*. The macroinvertebrate community in the Kauru at Kauru Hill Rd 700m Upstream has been dominated by the mudsnail *Potamopyrgus*, the common mayfly *Deleatidium*, chironomid midges and oligochaete worms. Macroinvertebrate indices for McCones put this site in the 'poor to 'fair' water/habitat quality classes, while scores for the Clifton Falls site are consistent with 'fair' to 'good' water/habitat quality.

The Kākaunui catchment supports a highly diverse community of indigenous fish with 14 indigenous fish species recorded including several species that are at risk or threatened – longfin eel (at risk – declining), torrentfish (at risk – declining), bluegill bully (at risk – declining), kōaro (at risk – declining), inanga (at risk – declining), Canterbury galaxias (at risk – declining), kanakana/lamprey (threatened – nationally vulnerable), and lowland longjaw galaxias (threatened – nationally critical) (Dunn et al. 20018). Brown trout are the only introduced fish species present in the Kākaunui River, although perch and tench have been recorded from the Island Stream and Waiareka Creek sub-catchments.

An instream habitat model developed for the mainstem of the Kākaunui River was applied to consider the effects of different flows on the physical characteristics of the Kākaunui River and habitat for periphyton, macroinvertebrates and fish. The current minimum flow in the Kākaunui catchment (250 l/s) is predicted to maintain between 21% (food-producing habitat) and 72% (the common mayfly *Deleatidium*) of habitat for macroinvertebrates at the naturalised 7-d MALF. It is predicted to maintain 14% of habitat for torrentfish, 17% of bluegill bully habitat, and 67-77% of habitat for lowland longjaw galaxias compared to the naturalised 7-d MALF. The current minimum flow is predicted to achieve >56% habitat retention for other indigenous species considered and between 55-70% habitat retention for the various brown trout life-stages considered.

Flows of 351-463 l/s are predicted to retain 80% of the habitat for tuna/longfin eel available at the naturalised MALF. Torrentfish are among the most flow-demanding indigenous fish species in the Kākaunui catchment, and a flow of 624 l/s is predicted to provide 80% habitat retention in the Kākaunui River. Flows of 600 l/s, 340 l/s and 244 l/s are expected to provide 80% habitat retention for bluegill, common and upland bullies. Flows of 344 l/s, 276 l/s, and 391-449 l/s would provide 80% habitat retention for inanga, Canterbury galaxias and lowland longjaw galaxias, respectively. Habitat for kanakana/lamprey was predicted to be highest at low flows.

The existing minimum flow and allocation limit are predicted to result in flows that are unimpacted or have a low risk of impact relative to naturalised flows (based on the DHRAM score). However, periphyton biomass in the Kākaunui River at McCones exceeds the LWRP objectives for the North Otago FMU and the national bottom line (based on Table 2 of the NOF; NPSFM 2022). Water abstraction and use can affect periphyton accrual and may contribute to high periphyton biomass and exceedance of these objectives. However, the natural characteristics of the Kākaunui (high summer temperatures, long daylight hours, high water clarity and long periods of low flows) along with other factors (such as high nitrogen concentrations observed will also contribute to the high biomasses observed in the Kākaunui catchment. The effects of climate change may exacerbate the current high biomass of periphyton observed in the Kākaunui River.

Increased minimum flows in both the Kākaunui River and Waiareka Creek have the potential to interact with water quality in the Kākaunui Estuary – by potentially diluting nitrogen-enriched groundwater and potentially influencing the opening/closing regime of the estuary. However, minimum flows typically apply for a relatively short period of time over the irrigation season and so will have a limited impact on nitrogen concentrations entering the Kākaunui Estuary. In comparison, reducing the allocation from the upper Kākaunui catchment will increase flows in the lower catchment and should reduce nitrogen concentrations whenever significant abstraction is occurring.

Minimum flows currently apply at two minimum flow sites on the lower Kākaunui River – Mill Dam and McCones – in addition to the Clifton Falls minimum flow site (1 May – 30 September). Given that McCones has been in place since 2003, the Mill Dam minimum flow site is now unnecessary and it is recommended that the Mill Dam site is removed as a minimum flow site and that the McCones site is the minimum site on the lower Kākaunui River along with the Clifton Falls site in the upper catchment that applies to winter takes (1 May-30 September).

Setting a minimum flow on the Kauru at Kauru Hill Rd 700m Upstream that is equivalent to the 7-d MALF at this site (120 l/s) would ensure that the extent of drying would not get any larger than would be expected to occur naturally each year, on average. However, whilst introducing a minimum flow on the Kauru would limit the spatial extent of drying, it would not address the duration of drying in the lower reaches of the Kauru River. However, reducing allocation would reduce the effect of water abstraction on the duration of drying in the lower Kauru River.

10. References

Baker CF, Jowett IG, Allibone RM (2003). Habitat use by non-migratory Otago galaxiids and implications for water management. Science for Conservation 221. Department of Conservation, Wellington. 34 p.

Biggs BJF (2000). New Zealand Periphyton Guideline: Detecting, Monitoring, and Managing Enrichment of Streams. Prepared for Ministry for the Environment. NIWA, Christchurch. 121 p.

Black AC, Rowan JS, Duck RW, Bragg OM & Clelland DE (2005). DHRAM: a method for classifying river flow regime alterations for the EC Water Framework Directive. *Aquatic Conservation: Marine and Freshwater Ecosystems* **15**: 427-446.

Central South Island Fish and Game Council (2022). DRAFT Sports Fish & Game Management Plan for Central South Island Fish and Game Region 2022-2032. Central South Island Fish and Game Council, Temuka. 37 p. plus appendices.

Dunn, N.R.; Allibone, R.M.; Closs, G.P.; Crow, S.K.; David, B.O.; Goodman, J.M.; Griffiths, M.; Jack, D.C.; Ling, N.; Waters, J.M.; Rolfe, J.R. 2018: Conservation status of New Zealand freshwater fishes, 2017. *New Zealand Threat Classification Series 24*. Department of Conservation, Wellington. 11 p.

Forsyth PJ (2001). Geology of the Waitaki area. Institute of Geological and Nuclear Sciences. 1:250,000 geological map 19. 1 sheet and 64 p. Institute of Geological and Nuclear Sciences, Lower Hutt.

Hamill KD. 2001. Toxicity in benthic freshwater cyanobacteria (blue-green algae): first observations in New Zealand. *New Zealand Journal of Marine and Freshwater Research* **35**: 1057−1059.

Hayes, J. W., & Jowett, I. G. (1994). Microhabitat models of large drift-feeding brown trout in three New Zealand rivers. North American Journal of Fisheries Management, (14), pp 710– 725.

Hayes J., Booker, D., Singh, S. & Franklin P. (2021). Default Minimum Flow and Allocation Limits for Otago. Letter to J. Augspuger, Otago Regional Council dated 17 September 2021. Cawthron, Nelson. ID: 2157.

Heath, M. W., Wood, S. A., Brasell, K. A., Young, R. G., & Ryan, K. G. (2013). Development of habitat suitability criteria and in-stream habitat assessment for the benthic cyanobacteria *Phormidium*. River Research and Applications, DOI: 10.1002/rra.2722.

Hilsenhoff, W. L. (1977). Use of Arthropods to Evaluate Water Quality of Streams. Wis. Dep. Nat. Resour. Technical Bulletin, 100.

Hilsenhoff, W.L. (1987). An Improved Biotic Index of Organic Stream Pollution. *Great Lakes Entomologist*, **20**, 31-39.

Jowett, I. G. (2005). Flow requirements for fish habitat in the 12 Mile Creek, Waikouaiti River, Tokomairiro River, Tuapeka River, and Benger Burn. NIWA Client Report HAM2005- 058, 58 p., plus appendices. Prepared for the Otago Regional Council.

Jowett I.G. & Hayes J.W. (2004). Review of methods for setting water quantity conditions in the Environment Southland draft Regional Water Plan. NIWA Client Report HAM2004-018. NIWA, Hamilton. 86 p.

Jowett, I. G., & Richardson, J. (2008). Habitat use by New Zealand fish and habitat suitability models. NIWA Science and Technology Series, 132 p.

Jowett I & Wilding T (2003). Flow requirements for fish habitat in the Chatto, Lindis, Manuherikia, Pomahaka and Waianakarua Rivers. NIWA Client Report HAM2003-052. 29 p. plus appendix.

Jowett, I. G., Richardson, J., Biggs, B. J. F., Hickey, C. W., & Quinn, J. M. (1991). Microhabitat preferences of benthic invertebrates and the development of generalised Deleatidium spp. Habitat suitability curves, applied to four New Zealand rivers. New Zealand Journal of Marine and Freshwater Research, (25), pp. 187–199.

Lu, X. (2023). Flow Naturalisation for Island Stream in the Kakanui catchment, North Otago. Otago Regional Council, Dunedin. 3 p.

Lu, X. (2023). Flow Naturalisation of the Kakanui River. Otago Regional Council, Dunedin. 12 p.

Lu, X. (2023). Flow Naturalisation of Waiareka Creek at Taipo Road in North Otago. Otago Regional Council, Dunedin. 6 p.

Macara, GR (2015). The Climate and Weather of Otago. 2nd Edition. NIWA Science and Technology Series 67. 42 p.

Macara, G., Woolley J.-M., Zammit, C., Pearce, P., Stuart, S., Wadhwa S., Sood, A. & Collins, D. (2019). Climate change projections for the Otago Region. Prepared for Otago Regional Council. NIWA Client Report 2019281WN. NIWA, Auckland. 136 p.

Olsen, D. A., Tremblay, L., Clapcott, J., & Holmes, R. (2012). Water temperature criteria for native biota. Auckland Council Technical Report 2012/036, 80 p.

Otago Regional Council (2007). Didymo in Otago: A Summary. Otago Regional Council, Dunedin. 40 p. plus appendices.

Ozanne, R., Borges, H., & Levy, A. (2023). State and trends of river, lake, and groundwater quality in Otago – 2017-2022. Otago Regional Council, Dunedin.

Ozanne, R., & Wilson, S. (2013). Kakanui River Water Quality Report. Otago Regional Council, Dunedin. 61 p. plus appendices.

Plew, D., & Barr, N. (2015). Kakanui Estuary Hydrodynamic Model. Prepared for Otago Regional Council. NIWA Client Report CHC2015-064. NIWA, Christchurch. 53 p. plus appendix.

Plew, D. (2016). Influence of Waiareka Creek flows on Kakanui Estuary nutrient concentrations. Prepared for North Otago Irrigation Company. NIWA Client Report 2016088CH. NIWA, Christchurch. 18 p. plus appendices.

Plew, D. & Duncan M. (2017). Waiareka Creek Minimum flow and water permit optimisation. Prepared for North Otago Irrigation Company. NIWA Client Report 2017237CH. NIWA, Christchurch. 55 p.

Raleigh, R. F., Zuckerman, L. D., & Nelson, P. C. (1986). Habitat suitability index models and instream flow suitability curves – brown trout. US Fish and Wildlife Service Biological Report, (82) (10.124), pp. 79.

Shirvell, C. S., & Dungey, R. G. (1983). Microhabitats chosen by brown trout for feeding and spawning in rivers. Transactions of the American Fisheries Society, (112), pp. 355–367.

Stark, J.D. (1985). A macroinvertebrate community index of water quality for stony streams. *Water & Soil Miscellaneous Publication* 87. National Water and Soil Conservation Authority, Wellington, New Zealand), 53 p.

Todd, A. S., Coleman, M. A., Konowal, A.M., May, M. K., Johnson, S., Vieira, N. K. M., & Saunders, J. F. (2008). Development of New Water Temperature Criteria to Protect Colorado's Fisheries. Fisheries, (33), pp. 433–443.

Unwin, M. (2016). Angler usage of New Zealand lake and river fisheries: Results from the 2014/15 National Angling Survey. NIWA Client Report 2016021CH, 59 p., plus appendices. Prepared for Fish & Game New Zealand.

Wagenhoff, A., Shearer, K., Clapcott, J. (2016). A review of benthic macroinvertebrate metrics for assessing stream ecosystem health. Prepared for Environment Southland. Cawthron Report No. 2852. 49 p. plus appendices.

Waters, B. F. (1976). A methodology for evaluating the effects of different streamflows on salmonid habitat. In J. F. Orsborn, & C. H. Allman (Eds.), Proceedings of the Symposium and Speciality Conference on Instream Flow Needs II, pp. 224–234. Bethesda, MD: American Fisheries Society.

Water Ways Consulting (2023). North Otago rivers physical habitat modelling. Report Number 25a-2023. October 2023. Water Ways Consulting, Dunedin. 24 p. plus appendices.

Williams, J., & Goldsmith, M. (2013). Channel morphology of the Kakanui and Kauru rivers, North Otago. Otago Regional Council, Dunedin. 24 p. plus appendices.

Wood, S. A., Selwood, A. I., Rueckert, A., Holland, P. T., Milne, J. R., Smith, K. F., Smits, B., Watts, L., & Cary, C. S. (2007). First report of homoanatoxin-a and associated dog neurotoxicosis in New Zealand. Toxicon, (50), pp. 292–301.