Management Flows for Aquatic Ecosystems in the Waianakarua River

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Otago Regional Council

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Executive summary

The Waianakarua River rises in the Horse Range and Kakaunui Mountains in North Otago. The catchment is 262 km^2 consisting of extensively grazed grasslands and scrub, native forest, and plantation forestry. Land use in the lower catchment is more intensive, with dairy farms operating near the mouth of the river and on the South Branch upstream of State Highway 1 (SH1).

The Waianakarua catchment is within the North Otago Freshwater Management Unit (FMU). The current minimum flow and allocation in the Waianakarua catchment was added to the RPW by Plan Change 1B, which was notified on 20 December 2008. Schedule 2A of the RPW specifies a minimum flow for primary allocation at Browns Pump of 200 l/s (1 October to 30 April) or 400 l/s (1 May to 30 September). The primary allocation limit specified for the Waianakarua catchment in Schedule 2A is 190 l/s.

The purpose of this report is to present information to inform water management decision-making in the Waianakarua catchment. This includes hydrological information (including 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 Waianakarua River compared to the proposed objectives for the North Otago FMU set out in the proposed Otago Land and Water Regional Plan.

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

Site		Flow statistics (l/s)			
		Mean	Median	7d MALF (Jul-Jun)	7d MALF (Oct-Apr)
Mainstem (Browns Pump)	Naturalised flows	3,257	1,150	310	325
	Observed flows	-	-	273	282
North Branch (SH1)	Naturalised flows	2,346	829	223	234
South Branch (SH1)	Naturalised flows	859	303	82	86

There are seven resource consents for primary water takes from the Waianakarua River, with one from the North Branch (30 l/s), two from the South Branch (43.6 l/s) one from the mainstem at Browns Pump (65 l/s), and two from the mainstem downstream of the Browns Pump site (69 l/s). Thus, the total primary allocation is 207.6 l/s. In addition, there is a permit for a non-consumptive take of 10 l/s from a tributary of the North Branch (Glenburnie Stream) to operate a micro-hydro scheme. The water taken under this permit is returned to Glenburnie Stream approximately 90 m downstream of the point of take. In addition, three supplementary allocation blocks (block size 100 l/s) have been fully allocated with minimum flows of 311, 411, and 511 l/s, respectively. A fourth supplementary allocation block (611 l/s) has been partially allocated (33 l/s at the time of writing).

The periphyton community at Browns Pump is typically dominated by thin to medium light brown films/mats (diatoms). Medium to thick black/dark brown mat (cyanobacteria mats), are present on occasion and warning signs have been installed at major access points. Filamentous algae form nuisance blooms during periods of stable flows. Chlorophyll *a* concentrations at Browns Pump exceed the periphyton objective for the North Otago FMU in the proposed LWRP as well as the national bottom line for periphyton (trophic state).

The common mayfly *Deleatidium* is consistently among the most abundant macroinvertebrate taxa collected at sites in the Waianakarua catchment, although the net-spinning caddis fly *Hydropsyche* (*Aoteapsyche*), orthoclad chironomid midges (Orthocladiinae), various cased caddis flies (*Pycnocentrodes, Olinga*) and the mudsnail *Potamopyrgyus* are among the most abundant taxa at times. MCI scores for Brown's Pump are in C-band, while SQMCI scores and ASPM scores are in B-band. The Browns Pump site is in the lower reaches of the catchment, just upstream of tidal influence, and are likely to be affected by high periphyton biomasses.

The Waianakarua River supports a highly diverse community of indigenous fish with thirteen 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), and kanakana/lamprey (threatened – nationally vulnerable). Brown trout are the only introduced fish species that have been collected from the Waianakarua catchment. The Waianakarua River supports a locally important sport fishery with a low level of angler usage.

An instream habitat model developed by Water Ways Consulting Ltd for the mainstem of the Waianakarua River between the confluence of the North and South Branches and Browns Pump during the summer of 2022-2023 has been applied to consider the effects of different flows on the physical characteristics of the Waianakarua River and habitat for periphyton, macroinvertebrates and fish.

The current minimum flow in the Waianakarua catchment (200 l/s) is predicted to maintain between 53% (food producing habitat) and 89% (the common mayfly *Deleatidium*) of habitat for macroinvertebrates at the naturalised 7-d MALF. It is predicted to maintain 43% of habitat for torrent fish, 49% of bluegill bully habitat, and 43% of habitat for common smelt compared to the naturalised 7-d MALF. The current minimum flow is predicted to achieve >80% habitat retention for other indigenous species considered and between 80-88% habitat retention for the various brown trout life-stages considered.

Flows of 176 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 Waianakarua catchment, and a flow of 274 l/s is predicted to provide 80% habitat retention in the Waianakarua River. Flows of 269 l/s, 136 l/s and 67 l/s are predicted to provide 80% habitat retention for bluegill, redfin and upland bullies. Flows of 129 l/s, 125 l/s, and 169 l/s would provide 80% habitat retention for inanga, Canterbury galaxias, and common smelt, respectively. Habitat for kanakana/lamprey were predicted to be highest at low flows.

The existing minimum flow and allocation limit are predicted to result in a hydrograph that is unimpacted relative to naturalised flows (based on the DHRAM score). However, periphyton biomass in the Waianakarua River at Browns 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 can affect periphyton accrual and may contribute to high periphyton biomass and exceedance of these objectives. However, the natural characteristics of the Waianakarua (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 lower South Branch and mainstem) contribute to the high biomasses observed in the Waianakarua catchment. The effects of climate change may exacerbate the current high biomass of periphyton observed in the Waianakarua River.

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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.
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-d Mean Annual Low Flow (7-d MALF)	The average of the lowest seven-day low flow for each 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).
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.
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).
Seven-day low flow	The lowest seven-day low flow in any 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.

Taking	The taking of water is the process of abstracting water for any purpose and for any period of time.

1 Introduction

The Waianakarua River is a medium-sized river (catchment area 262 km^2), which rises in the Horse Range and Kakanui Mountains in North Otago. Much of the catchment consists of extensively grazed grasslands and scrub, native forest, and plantation forestry. Land use in the lower catchment is more intensive, with dairy farms operating near the mouth of the river and on the South Branch upstream of State Highway 1 (SH1).

The Waianakarua catchment is within the North Otago Freshwater Management Unit (FMU). The current minimum flow and allocation in the Waianakarua catchment was added to the RPW by Plan Change 1B, which was notified on 20 December 2008. Schedule 2A of the RPW specifies a minimum flow for primary allocation at Browns Pump of 200 l/s (1 October to 30 April) or 400 l/s (1 May to 30 September). The primary allocation limit specified for the Waianakarua catchment in Schedule 2A is 190 l/s. Previous assessments undertaken for the Waianakarua were presented in ORC (2006).

The Waianakarua is recognised as a kāinga nohoanga and kāinga mahinga kai where tuna (eels), kanakana (lamprey), inaka (whitebait), pānako (a type of fern), and aruhe (bracken fernroot) were gathered.

Water abstraction in the Waianakarua catchment is in the lower reaches, with the most upstream consumptive take on the South Branch, 9 km upstream of the river mouth. Most of this water is used by dairy farms on the flat lands in the coastal part of the catchment.

Water quality in much of the Waianakarua catchment is very good with very low concentrations of ammoniacal nitrogen, dissolved reactive phosphorus and turbidity (Olsen, 2013). Concentrations of nitrate-nitrite nitrogen were very low in the North Branch and upper South Branch, but high concentrations have been observed in the lower reaches of the South Branch and mainstem (Olsen, 2013).

1.1 Purpose of the report

The purpose of this report is to present information to inform water management decision-making in the Waianakarua catchment. This includes hydrological information (including 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 Waianakarua River compared to the proposed objectives for the North Otago FMU set out in the proposed Otago Land and Water Regional Plan.

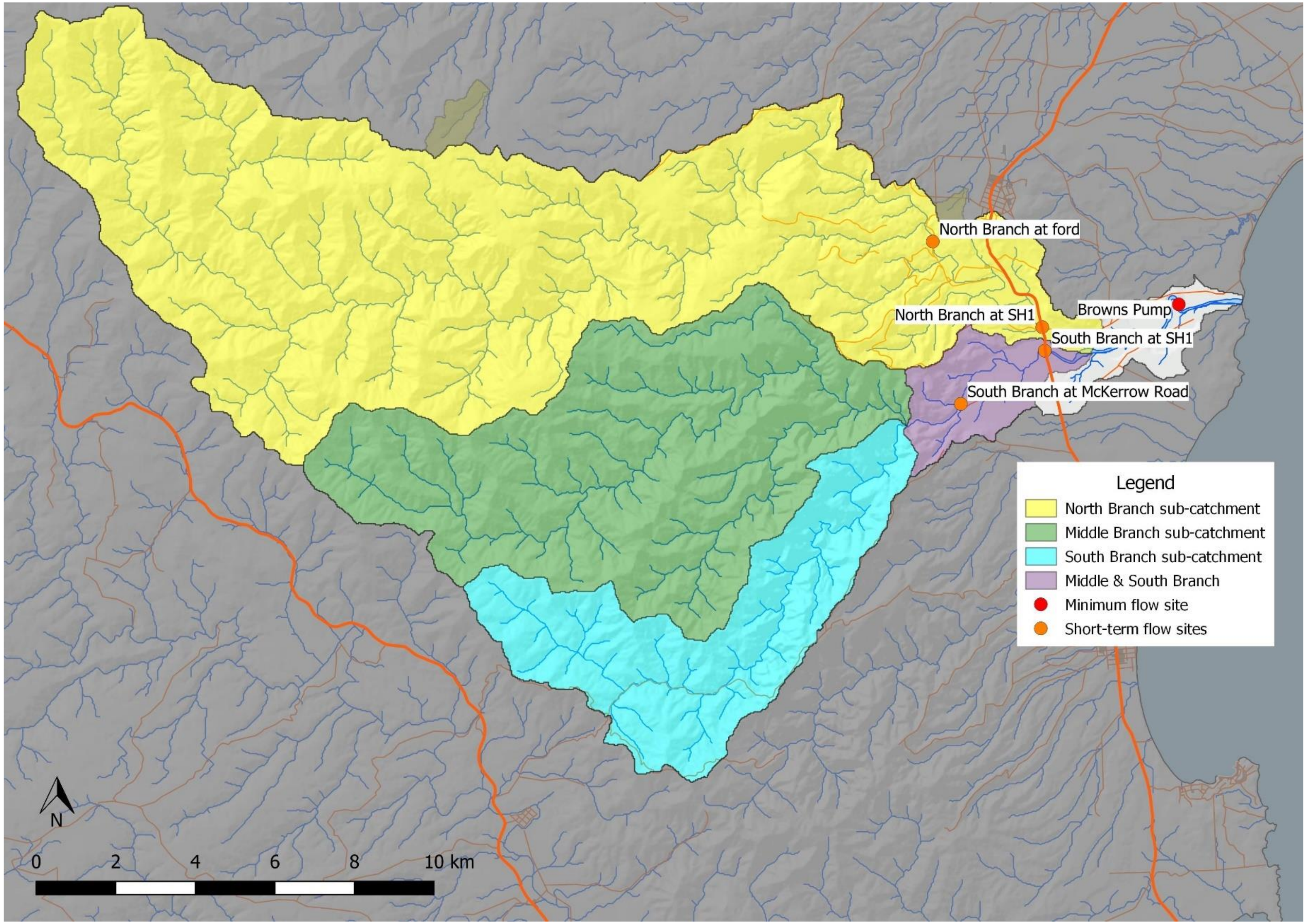

Figure 1 Map of the Waianakarua catchment showing the sub-catchments and flow recorder site.

2 Background information

2.1 Catchment description

The Waianakarua River consists of three branches - South, Middle and North - and has a total catchment area of 262 km^2. The headwaters of the South (35 km^2) and Middle branches (69 km^2) arise in the Horse Range and join about 6 km upstream of SH1 (**Error! Reference source not found.**). The North Branch (catchment area: 142 km^2) arises in the eastern Kakanui Mountains and joins the South Branch about 1 km downstream of SH1, before entering the Pacific Ocean a further 6 km downstream (**Error! Reference source not found.**).

2.1.1 Climate

The climate within the Waianakarua 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).

The mean annual air temperature at Herbert Forest (1981-2010) was 10.4°C, with monthly means ranging from 5.4°C in July and 15.2°C in January (Table 1).

Table 1 Mean temperature statistics (mean, minimum daily, maximum daily) for Herbert Forest (NZTM E1425422 N4987563) weather station between 1981 and 2010

	Month												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Herbert Forest													
Mean	15.2	14.6	13.3	10.8	8.5	6	5.4	6.7	8.8	10.5	11.8	13.7	**10.4**
Min	9.4	9	7.6	4.7	2.9	0.6	-0.1	0.9	2.9	4.8	6	8.3	**4.8**
Max	20.9	20.3	19.1	16.9	14	11.5	11	12.5	14.7	16.2	17.7	19	**16.2**

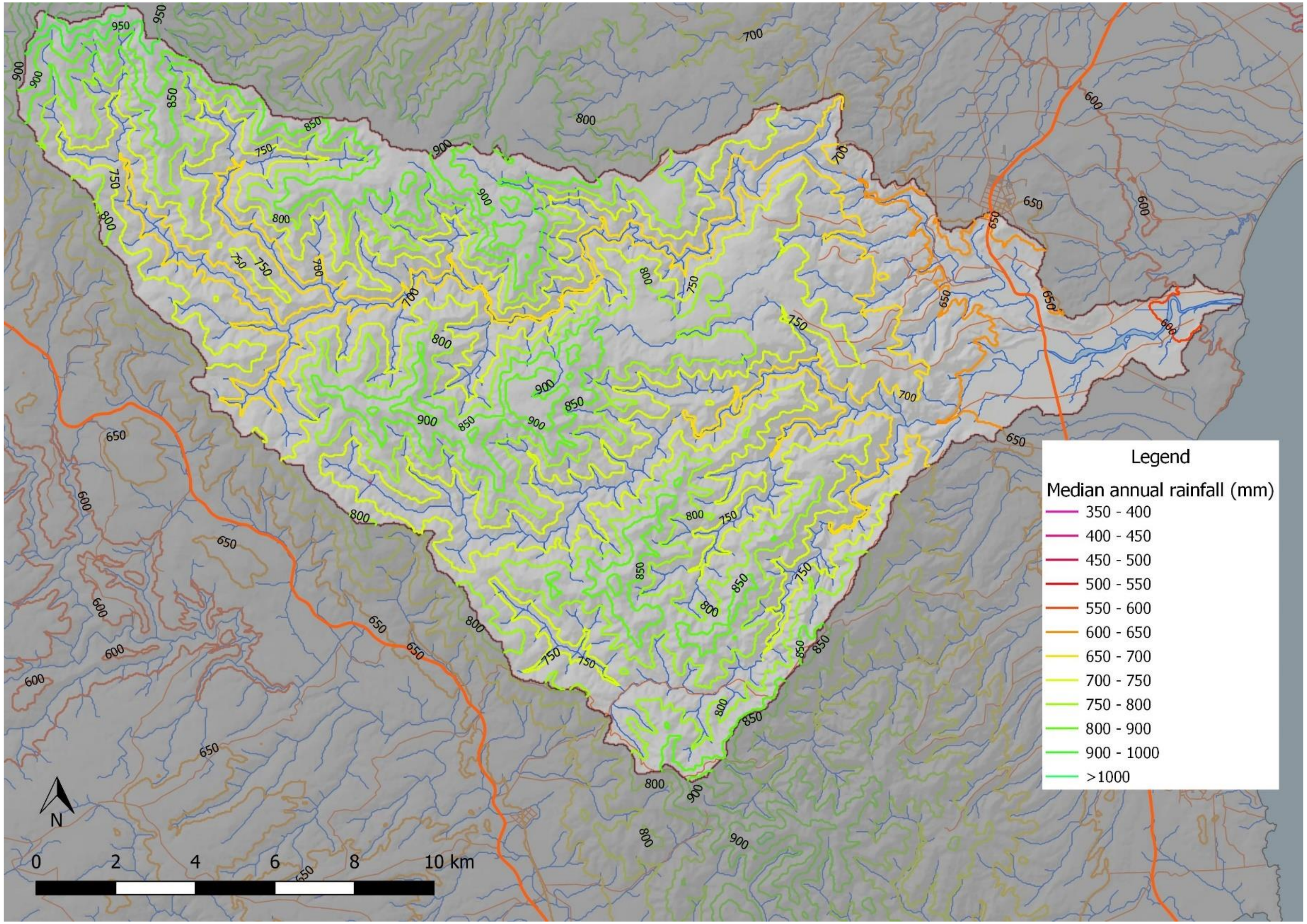

Figure 2 Distribution of rainfall (annual median rainfall) in the Waianakarua catchment.

2.1.2 Geological setting

The geology of the upper Waianakarua catchment consists mainly of semischist (Forsyth 2001). Some sandstones and mudstones are present in the lower catchment, just upstream of SH1, although alluvium overlies basement rock in most of the lower catchment (Forsyth 2001). An area of igneous rocks (Deborah volcanics) is located immediately to the north of Waianakarua Road, although most of this area drains into the Bow Alley Creek catchment to the north of the Waianakarua catchment (Forsyth 2001).

All three branches of the upper Waianakarua River consist of confined, meandering channels cutting into schist bedrock, with a mixed gravel and bedrock bed (ORC, 2008). In the lower catchment, the channel is mostly a mobile single-thread channel, with some partially braided sections incised into an elevated gravel floodplain (ORC, 2008). Gravel extraction takes place in several locations in the North Branch (Sharpes Bend and upstream of Graves Dam), a 1 km section of the South Branch upstream of the SH1 bridge, and at two locations downstream of the confluence of the North and South branches (ORC, 2008). Historical river management activities have included channel realignment and willow planting (ORC, 2008).

2.1.3 Vegetation and land use

Vegetation cover in the upper Waianakarua catchment is mainly tussock and scrub, much of which is extensively grazed (Figure 3). Much of the catchments of the Middle and South Branches consist of mixed native bush, with some plantation forestry in the hill country immediately to the west of SH1 (Figure 3). In comparison, the catchment of the North Branch consists of a greater proportion of plantation forestry, although with substantial areas of native bush and scrub (Figure 3). Much of the intensive agriculture in the catchment occurs in the lower catchment between SH1 and the coast, with some areas on the alluvial terraces to the south of the Middle Branch (Figure 3). Most of the land administered by the Department of Conservation in the Waianakarua catchment is present in the Middle (35.6 km^2) and South Branches (10.3 km^2), representing about 52% of the total land area in the Middle Branch and 30% of the total land area in the South Branch. In comparison, there is little conservation land present in the North Branch (0.3 km^2, 0.2% of the total land area).

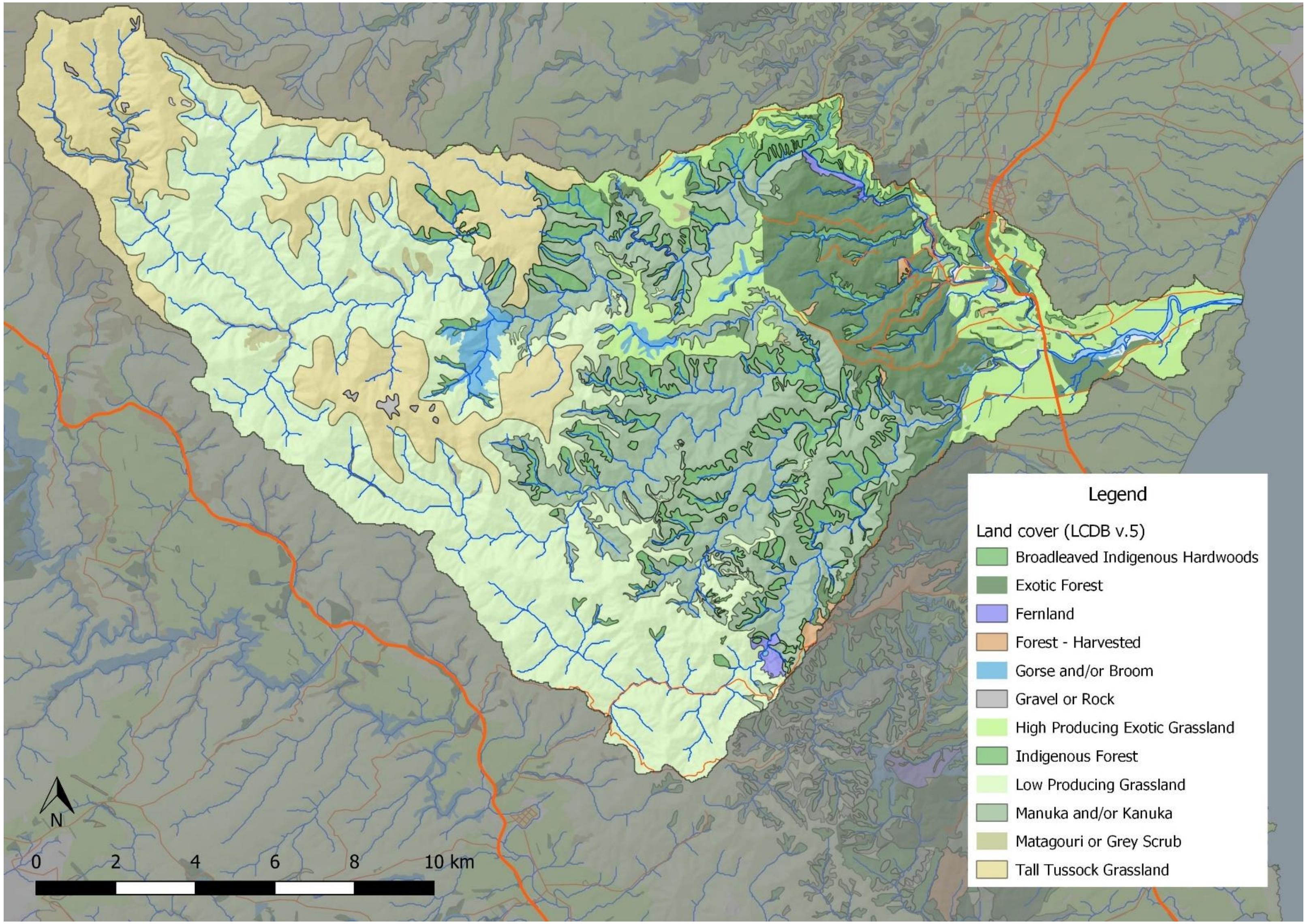

Figure 3 Land cover in the Waianakarua catchment.

3 Regulatory setting

3.1 Regional Plan: Water (RPW)

The current minimum flow and allocation in the Waianakarua catchment was added to the RPW by Plan Change 1B, which was notified on 20 December 2008.

Schedule 2A of the RPW specifies a minimum flow for primary allocation at Browns Pump of 200 l/s (1 October to 30 April) or 400 l/s (1 May to 30 September). The primary allocation limit specified for the Waianakarua catchment in Schedule 2A is 190 l/s. Primary allocation at the time of writing is 207.6 l/s (see Section 4.1.2). These values were based on analyses presented in ORC (2006).

In addition, Schedule 2B of the RPW specifies a minimum flow for the first supplementary allocation block of 311 l/s at Browns Pump, with a supplementary allocation block size of 100 l/s. At the time of writing, the first supplementary allocation block is fully allocated (see Section 4.1.2). The supplementary minimum flow for each subsequent supplementary block increases by 100 l/s, meaning that the second supplementary allocation block has a minimum flow of 411 l/s at Browns Pump. At the time of writing, the second and third supplementary allocation blocks have been fully allocated (see Section 4.1.2). At the time of writing, 33.5 l/s of the fourth supplementary allocation blocks has been allocated (see Section 4.1.2).

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 Waianakarua 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 attributes.

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

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

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 attributes.

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 Flow statistics

A continuous flow recorder has been installed in the Waianakarua River at Browns Pump since April 2005. This site is located approximately 1.85 km upstream of where it enters the Pacific Ocean. A further site was established in the South Branch at the rail bridge (14 November 2014 – 4 September 2015).

Lu (2023) used available flow data for the Waianakarua River at Browns Pump and water use data to produce a 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 and Table 4 and Lu (2023) is attached as Appendix A.

Table 3 Flow statistics for sites in the Waianakarua catchment from Lu (2023).

Site		Flow statistics (l/s)		
		Mean	Median	7d MALF (Jul-Jun)
Waianakarua at Browns Pump	Naturalised flows	3,257	1,150	310
	Observed flows	-	-	273
	ORC (2006)	1,713		300
North Branch (SH1)	Naturalised flows	2,346	829	223
South Branch (SH1)	Naturalised flows	859	303	82

Table 4 Low flow frequency analysis for naturalised and observed flows in the Waianakarua River at Browns Pump from Lu (2023).

Location	5-year low flow Q7, 5 (l/s)	10-year low flow Q7, 10 (l/s)	20-year low flow Q7, 20 (l/s)
Mainstem	212	178	154
North Branch (SH1)	152	128	111
South Branch (SH1)	56	47	41

4.1.1 Flow variability

The average number of events per year that exceed three times the median flow (FRE3) in the Waianakarua River at Browns Pump is 6.7 events per year (Lu 2023).

4.1.2 Water allocation

Primary allocation

There are seven resource consents for primary water takes from the Waianakarua River, with one from the North Branch (30 l/s), two from the South Branch (43.6 l/s) one from the mainstem at Browns Pump (65 l/s), and two from the mainstem downstream of the Browns Pump site (69 l/s). Thus, the total primary allocation is 207.6 l/s.

In addition to these primary permits, there is a permit for a non-consumptive take of 10 l/s from a tributary of the North Branch (Glenburnie Stream) s to operate a micro-hydro scheme. The water taken under this permit is returned to Glenburnie Stream approximately 90 m downstream of the point of take.

Supplementary Block 1

There are four resource consents for supplementary water takes in the first supplementary allocation block from the Waianakarua River, with two from the South Branch (38 l/s), one from the mainstem at Browns Pump (40 l/s) and one from the mainstem downstream of the Browns Pump site (22 l/s). The combined maximum take authorised by these consents was 100 l/s.

Supplementary Block 2

There are four resource consents for supplementary water takes in the second supplementary allocation block from the Waianakarua River, with three from the South Branch (91.5 l/s combined) and one from the mainstem at Browns Pump (8.5 l/s). Thus, the second supplementary block is fully allocated.

Supplementary Block 3

There is one resource consent for supplementary water takes in the third supplementary allocation block from the South Branch of the Waianakarua (100 l/s). Thus, the third supplementary block is fully allocated.

Supplementary Block 4

There is one resource consent for supplementary water takes in the third supplementary allocation block from the South Branch of the Waianakarua (33.5 l/s). Thus, 33.5 l/s is allocated from the fourth supplementary block.

4.1.3 Seasonal water use

Water use in the Waianakarua catchment is typically highest between November and March (Figure 4)

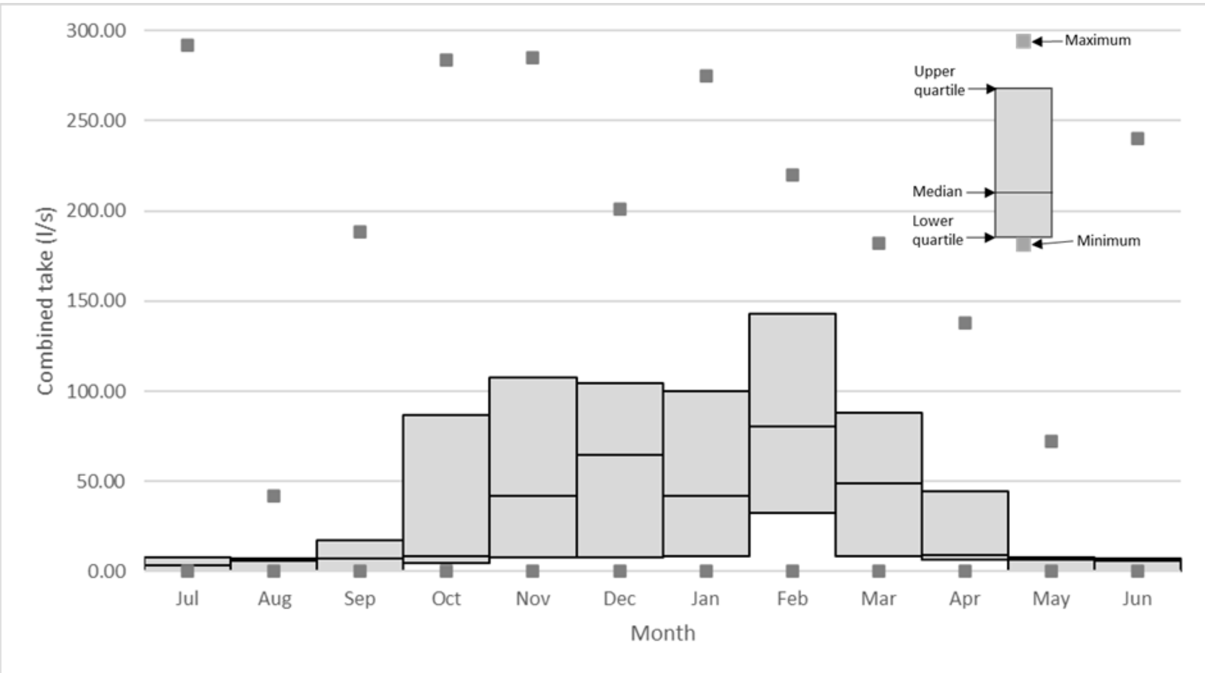

Figure 4 Monthly water abstraction (gap-filled) for the Waianakarua River catchment. Boxes represent the monthly interquartile range (25th-75th percentile range), with the central line being the monthly median value. Smaller squares represent minimum/maximum values.

Table 5 Active reource consents in the Waianakarua catchment. Orange = North Branch, green = South Branch, dark blue = mainstem upstream of Browns Pump, light blue = downstream of Browns Pump

Consent Number	Consent Holder	Max rate (l/s)	Min flow (l/s)	Activity	Type
Primary					
RM16.329.01	Road Metals Company Ltd	30		Gravel washing	Primary
RM15.120.01	Southbrook Dairy Limited	9.6	200	Irrigation	Primary
RM14.107.01	Southbrook Dairy Limited	34	200	Irrigation	Primary
RM14.087.01	MC Holland Farming Limited	65	200	Irrigation	Primary
2003.204.V1	Sea View Dairies Ltd	51	200	Irrigation	Primary
RM13.342.01	Crop & Grass Farms Limited	18	200	Irrigation	Primary
Supplementary Block 1					
RM14.259	DCR Properties Ltd	25	311	Irrigation	Supplementary Block 1
2007.658	Southbrook Dairy Limited	13	311	Irrigation	Supplementary Block 1
2003.593.V1	Crop & Grass Farms Limited	22	311	Irrigation	Supplementary Block 1
RM11.376.01	MC Holland Farming Limited	40	311	Irrigation	Supplementary Block 1
Supplementary Block 2					
RM14.259	DCR Properties Ltd	18	411	Irrigation	Supplementary Block 2
2007.658	Southbrook Dairy Limited	7	411	Irrigation	Supplementary Block 2
RM11.376.01	MC Holland Farming Limited	8.5	411	Irrigation	Supplementary Block 2
RM16.251.01	Southbrook Dairy Limited	66.5	411	Irrigation	Supplementary Block 2
Supplementary Block 3					
RM16.251.01	Southbrook Dairy Ltd	100	511	Irrigation	Supplementary Block 3
Supplementary Block 4					
RM16.251.01	Southbrook Dairy Ltd	33.5	611	Irrigation	Supplementary Block 4
Non-consumptive					
RM13.458	Geoffrey Alan King	10	-	Hydro electric	Non-consumptive

5 Water temperature

Water temperature is a fundamental factor affecting all aspects of stream systems. 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 Waianakarua 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).

Water temperatures in the lower Waianakarua River were within acute and chronic thermal criteria for brown trout (Figure 5). Most indigenous fish species with available thermal tolerance data are more tolerant of high temperatures than trout (Olsen et al. 2012). Of the indigenous species present in the Waianakarua catchment, common smelt are probably the most sensitive, with an interim acute criterion of 26°C and interim chronic criterion of 26°C (Olsen et al. 2012). However, water temperatures in the lower Waianakarua River were well within these criteria (Figure 5).

These data suggest that thermal environment of the lower Waianakarua is suitable for all the indigenous and introduced fish species found in the catchment.

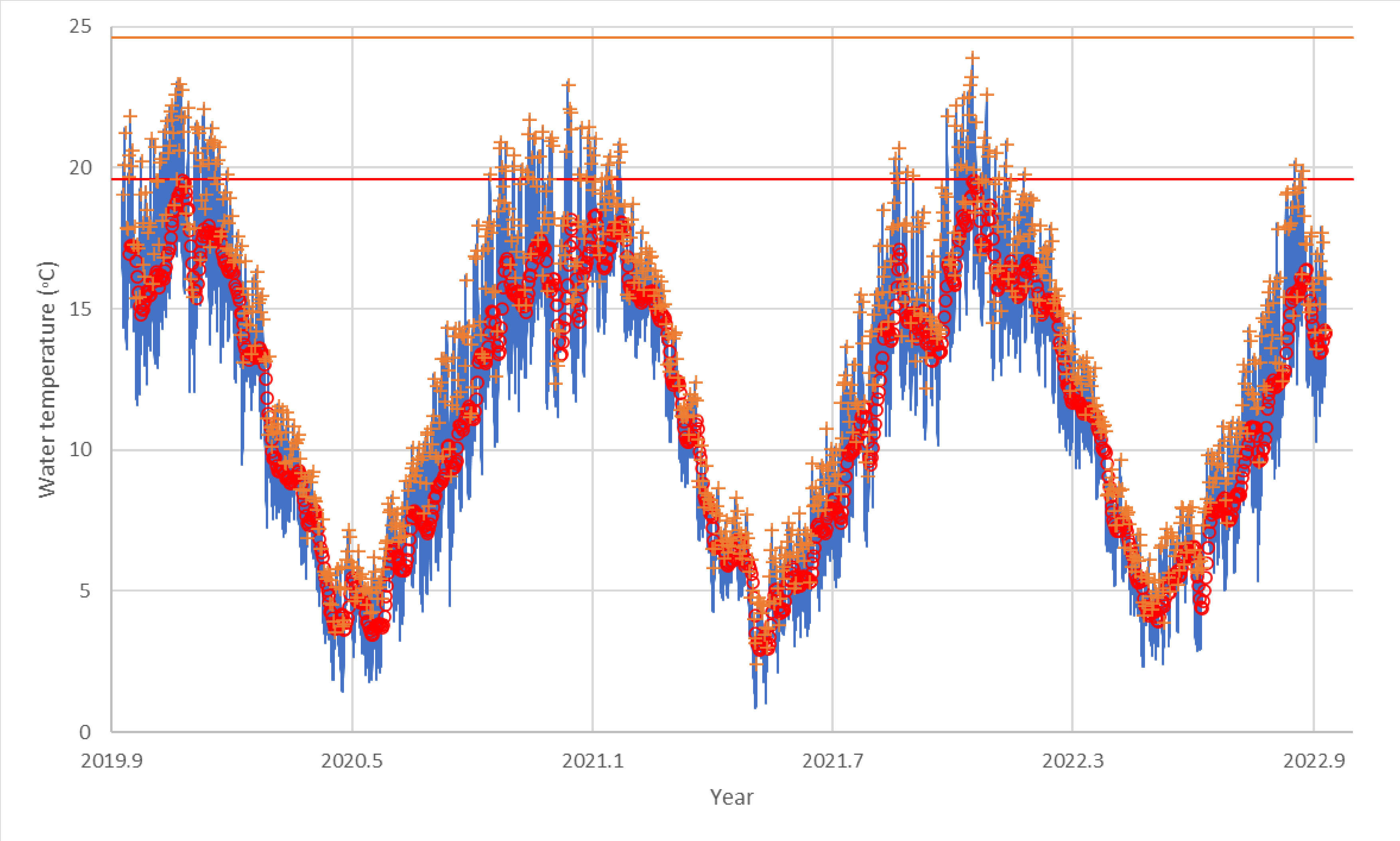

Figure 5 **Water temperature in the Waianakarua River at Browns Pump between December 2019 and December 2022. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red circles are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.**

Otago Regional Council

6 The aquatic ecosystem of the Waianakarua 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).

The periphyton community at Browns Pump is typically dominated by thin to medium light brown films/mats, likely native diatoms which are generally considered a desirable component of the periphyton community. Medium to thick black/dark brown mat, which are likely to be benthic cyanobacteria mats, are present on occasion. Blooms of benthic cyanobacteria are known to occur throughout the Waianakarua catchment and warning signs have been installed at major access points.

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.

Chlorophyll *a* concentrations at Browns Pump exceeded 200 mg/m^2 on six occasions (19%) of sampling occasions over the June 2019 – 2022 period (Figure 6), placing this site in Band D of the National Objective Framework of the NPS-FM (NOF), which exceeds the national bottom line for periphyton (trophic state).

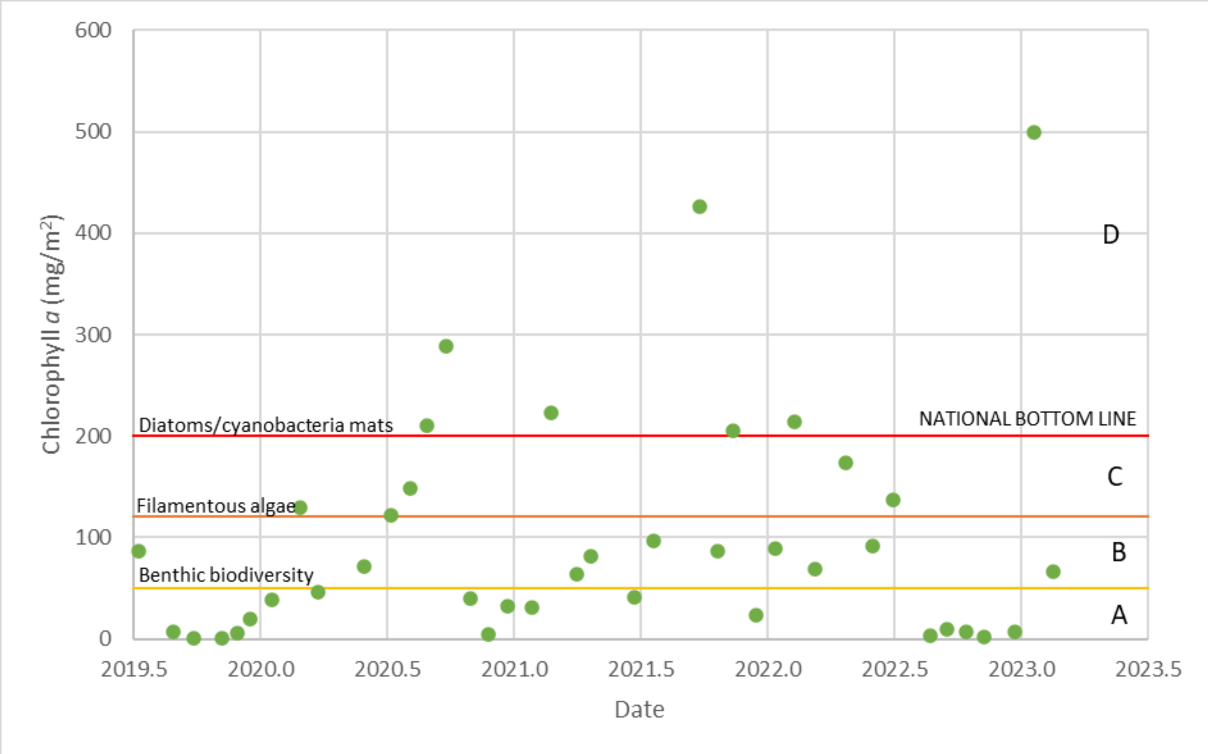

Figure 6 Chlorophyll *a* concentrations in the Waianakarua River at Browns Pump over the period 2019-2022. The periphyton biomass attribute is applied such that no more than three values can exceed the numeric attribute state in any three-year period (8% exceedence, based on monthly sampling over a 3-year 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).

The common mayfly *Deleatidium* is consistently among the most abundant macroinvertebrate taxa collected at sites in the Waianakarua catchment (Olsen 2013). The net-spinning caddis fly *Hydropsyche* (*Aoteapsyche*), orthoclad chironomid midges (Orthocladiinae), various cased caddis flies (*Pycnocentrodes, Olinga*) and the mudsnail *Potamopyrgyus* are among the most abundant taxa in the Waianakarua River at times (Olsen 2013).

MCI scores for Brown's Pump (Range: 103-123, mean = 109, N=15), which would put this site in C-band of the NOF (Figure 7). Given that the Brown's Pump site is in the very lowest reaches of the catchment, just upstream of tidal influence, these MCI scores are probably the lowest observed within the catchment (as observed in Olsen 2013) and are likely to be indicative of the high periphyton biomass and the water quality observed at this site (Olsen 2013). SQMCI scores for Brown's Pump have been highly variable over the last 15 years but have averaged B-band (Figure 7; Range: 4.22-7.42, mean = 5.59, N=15). In contrast ASPM scores for Brown's Pump have been consistently in the B-band over the last 15 years (Figure 7; Range: 0.43-0.56, mean = 0.49, N=15).

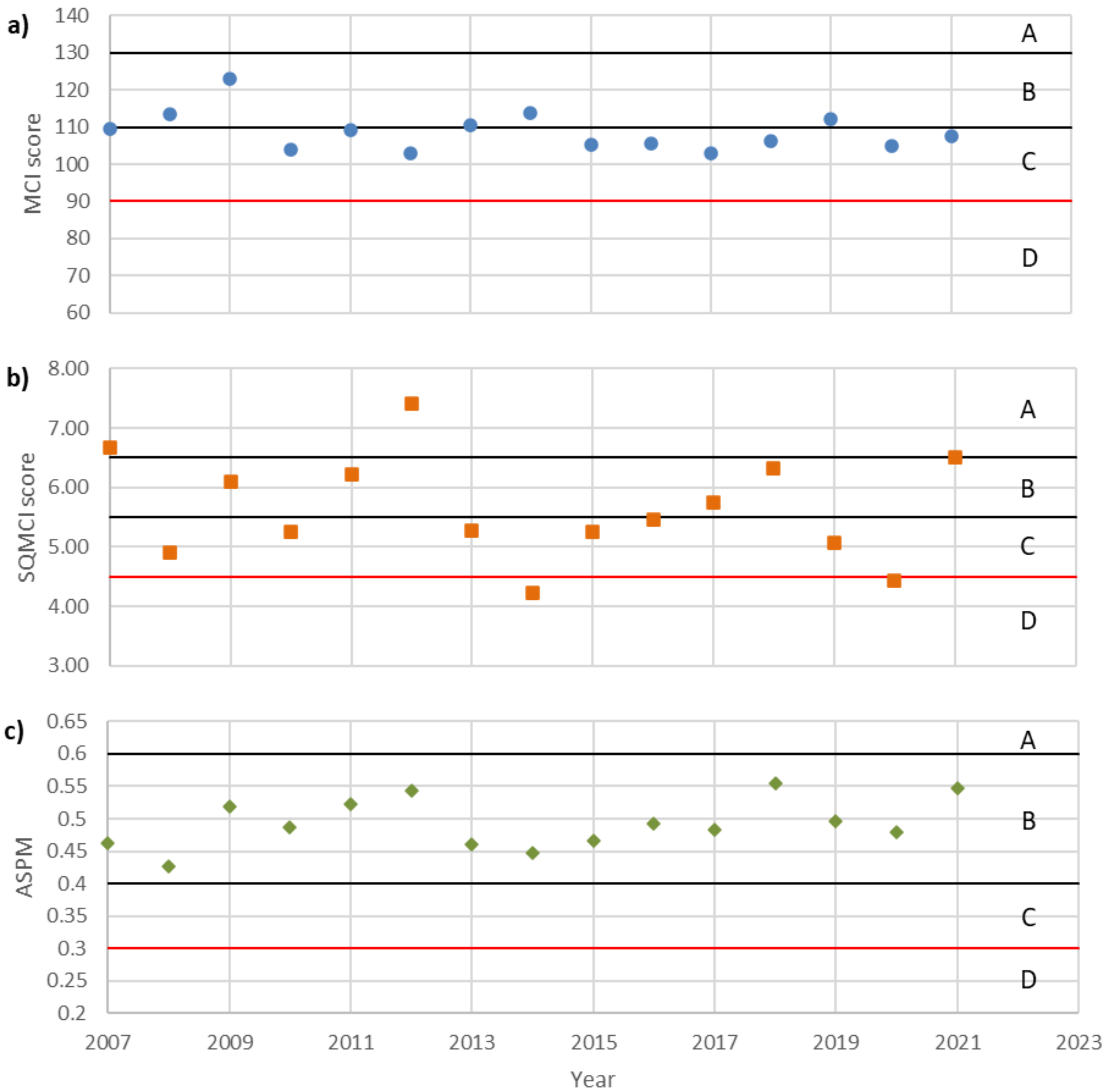

Figure 7 Macroinvertebrate indices for the Waianakarua River at Browns Pump between 2007 and 2021. a) Macroinvertebrate community index (MCI), b) semi-quantitative MCI (SQMCI) and c) average score per metric (ASPM). Each plot includes thresholds for attribute states based on Tables 14 and 15 of the National Objectives Framework.

Table 6 Trends in macroinvertebrate metrics in Waianakarua River at the Browns Pump state of the environment monitoring site between 2007 and 2022. Analysis 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.

Metric	Z	P	Trend
MCI	-1.4857	0.137	Very likely declining
SQMCI	0.9383	0.348	Likely improving
ASPM	2.0966	0.036	Extremely likely improving

6.3 Fish

6.3.1 Indigenous fish

Thirteen species of indigenous freshwater fish have been recorded from the Waianakarua catchment, (Table 8). This represents a high level of indigenous biodiversity, and the species present include several species that are at risk or threatened – tuna/longfin eel, torrentfish, bluegill bully, kōaro, inanga and Canterbury galaxias are classified as at risk – declining, while kanakana/lamprey are classified as threatened – nationally vulnerable (Dunn et al. 2017). Most of these species have been collected as far upstream as the lower reaches of the North and South Branches, although diversity drops with distance from the coast, as is expected as species with weaker swimming and/or climbing abilities (e.g. common smelt, inanga) drop out of the community.

6.3.2 Introduced fish

Brown trout are the only introduced fish species that have been collected from the Waianakarua catchment (Table 8).

The Waianakarua River supports a locally important sport fishery (Central South Island Fish & Game Council 2022). Table 7 presents angler effort in the Waianakarua River, recorded during National Angler Surveys conducted in 1994/95, 2007/08 and 2014/15. Overall angler usage is relatively low, with angling effort occurring the early part of the fishing season (October to January; Unwin, 2016).

Table 7 Angler effort on the Waianakarua River based on the National Angler Survey (Unwin, 2016)

	National Angler Survey			
Catchment	**1994/95**	**2001/02**	**2007/08**	**2014/15**
Waianakarua		140 ± 140		280 ± 230

Table 8 Fish species recorded from the Waianakarua River catchment. Locations: NB = North Branch, SB = South Branch, MS = mainstem. P = present, P* = present as far upstream as the SH1 bridges

Family	Common name	Species	Threat classification	Location		
				NB	SB	MS
Anguillidae	Shortfin eel	*Anguilla australis*	Not threatened	P*	-	P
	Longfin eel	*Anguilla dieffenbachii*	Declining	P	P*	P
Cheimarrichthyidae	Torrentfish	*Cheimarrichthys fosteri*	Declining	P	P*	P
Eleotridae	Upland bully	*Gobiomorphus breviceps*	Not threatened	P	P	P
	Common bully	*Gobiomorphus cotidianus*	Not threatened	P	P	P
	Bluegill bully	*Gobiomorphus hubbs*	Declining	P	-	P
	Redfin bully	*Gobiomorphus huttoni*	Not threatened	-	-	P
Galaxidae	Kōaro	*Galaxias brevipinnis*	Declining	-	P	
	Inanga	*Galaxias maculatus*	Declining	-	-	P
	Canterbury galaxias	*Galaxias vulgaris*	Declining	P	-	P
Geotriidae	Lamprey	*Geotria australis*	Nationally vulnerable	P*	P	P
Pleuronectidae	Black flounder	*Rhombosolea retiaria*	Not threatened	-	-	P
Retropinnidae	Common smelt	*Retropinna retropinna*	Not threatened	-	-	P
Salmonidae	Brown trout	*Salmo trutta*	Introduced and naturalised	-	P	P

6.4 Current ecological state

The current minimum flow and allocation in the Waianakarua catchment was added to the RPW by Plan Change 1B, which was notified on 20 December 2008. Thus, the current minimum flow and allocation limit have been in effect for many years and is reflected in the current state of the Waianakarua River. Therefore, comparison of the current state of the Waianakarua 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 9 below.

6.4.1 Ecosystem health

In addition to the ecosystem health and human contact values identified in Table 9, 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 9. 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 Waianakarua catchment relative to these attributes.

Table 9 presents the current attribute state for Browns Pump and the South Branch at SH1 (limited attributes) and compares the current state 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 attributes, but not for periphyton (Table 9). Periphyton biomass at Browns Pump exceeds the national bottom line (≤8% of values exceeding 200 mg/m^2).

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 Waianakarua River flows through a dry catchment characterised by high summer temperatures and long daylight hours that experiences long periods of low flows, thereby favouring periphyton accrual processes at such times. There is limited storage within the Waianakarua 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 very high water clarity in the Waianakarua at low flows, light availability is not expected to be affected appreciably by flow at low flows, and so 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 of the South Branch and mainstem of the Waianakarua River; Olsen 2013).

6.4.2 Water quality

Most water quality parameters considered were in A-band (Table 9), which is consistent with the findings of a previous catchment water quality study that water quality in the Waianakarua catchment is generally very good (Olsen 2013). The exception to this was the faecal indicator bacterium *Escherichia coli (*E. coli), which exceeded the target attribute state for the 95th percentile and percentage of values exceeding 540 cfu/100 mL (Table 9).

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

Table 9 Comparison of the current attribute state at two sites in the Waianakarua River based on State of the Environment data collected between 1 July 2017 and 30 June 2022 (Ozanne, Borges & Levy, 2023).

Value	Attribute	Target attribute state	Current attribute state	
			Browns Pump	South Branch at SH1
Ecosystem health – (all biophysical components)				
EH - Aquatic life:	Periphyton (trophic state) (chlorophyll *a*)	B	D 19% exceedance 220 mg/m^2	-
	Fish index of biotic integrity	A	A Mean (5-y): 58.4	-
	Macroinvertebrate Community Index (MCI) score	C	C 5-y median: 106	-
	Quantitative Macroinvertebrate Community Index (QMCI) score	C	B* 5-y median: 5.59*	-
	Macroinvertebrate Average Score Per Metric (ASPM)	C	B 5-y median: 0.50	-
EH – Water quality	Ammonia (toxicity)	A	A Median: 0.002 95th %: 0.006	A Median: 0.003 95th %: 0.006
	Nitrate (toxicity)	A	A Median: 0.300 95th %: 0.590	A Median: 0.370 95th %: 0.761
	Dissolved oxygen	A or B	Not able to be determined	-
	Suspended fine sediment - Visual clarity	A	A 5.96 m	A 6.86 m
	Dissolved reactive phosphorus	B	A Median: 0.002 95th %: 0.011	A Median: 0.002 95th %: 0.006
EH - Habitat	Deposited fine sediment (% cover)	A	A Median: 0	-
EH – Ecological processes	Ecosystem metabolism (both gross primary production and ecosystem respiration)	C	Not able to be determined	-
Human contact	*Escherichia coli*	A	D Median: 98 95th percent: 1,518 % >260: 20% % >540: 11%	D Median: 101 95th percent: 2,864 % >260: 19% % >540: 12%
	Escherichia coli (E. coli) (primary contact sites) - 95th percentile	A	D 95th percent: 1,518	D 95th percent: 2,864
	Suspended fine sediment - Visual clarity (metres)	A	A 5.96 m	A 6.86 m

* This value should be interpreted with caution, as it is based on SQMCI scores (coded abundance data), which should be comparable to a QMCI score calculated for the same sample.

6.4.3 Contribution of flows to ecological outcomes

The assessment of the current ecological state in the Waianakarua catchment with the target attribute state in the proposed LWP indicates that the current state for most attributes meets or exceeds the target attribute state for the North Otago FMU with two exceptions: periphyton biomass and *E. coli* (Table 9).

Periphyton biomass has a direct relationship to the duration of low flows. Periphyton accrual may be enhanced during periods of low flows under the combined effects of reduced biomass removal (through scouring by suspended particles or through by snapping of filaments), enhanced rates of cell division. However, while the effect of water allocation in the Waianakarua reduces the magnitude of flows, the run-of-the-river abstraction (i.e. abstraction without damming) in the Waianakarua does not affect the frequency of high-flow events, which are expected to be a major factor controlling periphyton in the Waianakarua River.

The relationship between *E. coli* and flow is complex. Faecal microbes such as *E. coli* are mobilised from land and channel sources during storm flows and high flows, greater water depths, and reduced water clarity during such events will reduce microbial die-off resulting from exposure to UV light (Wilkinson et al. 2011). In contrast, during periods of low flows, there is little transport of microbes and shallow water depths, clear water and low water velocities favour die-off of microbes (Wilkinson et al. 2011). On this basis, with all other factors held constant, the reduction of flows resulting from water abstraction is expected to increase microbial die-off and reduce mobilisation and transport of in-channel stores. Thus, it is considered that water abstraction is unlikely to contribute to the observed exceedance of *E. coli* attributes in the Waianakarua catchment.

7 Instream Habitat Assessment

7.1 Instream habitat modelling in Waianakarua 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 a number of 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 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 Waianakarua River between the confluence of the North and South Branches and Browns Pump 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 Waianakarua catchment were modelled (Table 10) to understand the full range of potential effects of flow regime changes in the Waianakarua 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 10 Habitat suitability curves used in instream habitat modelling in the Waianakarua River.

Group	HSC name	HSC source
Periphyton	Cyanobacteria	Ex Heath et al. (2013)
	Diatoms	unpublished NIWA data
	Long filamentous	unpublished NIWA data
	Short filamentous	unpublished NIWA data
Macroinvertebrates	Food producing	Waters (1976)
	Mayfly nymph (*Deleatidium*)	Jowett (1991)
	Net-spinning caddis fly (*Aoteapsyche*)[1]	Jowett (1991)
	Sand-cased caddis fly (*Pycnocentrodes*)	Jowett (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)
	Kanakana/lamprey	Jowett & Richardson (2008)
	Common smelt	Jowett & Richardson (2008)
Sports fish	Brown trout adult	Hayes & Jowett (1994)
	Juvenile trout T1	Wilding
	Brown trout (< 100 mm)	Jowett & Richardson 2008
	Brown trout yearling	Raleigh *et al.* (1986)
	Brown trout spawning	Shirvell & Dungey (1983)

[1] Recent taxonomic revision has classified this taxon as belonging to the genus *Hydropsyche* in the sub-genus *Aoteapsyche*, but referred to here as *Aoteapsyche* for consistency with Jowett (1991)

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 Waianakarua River (Figure 8).

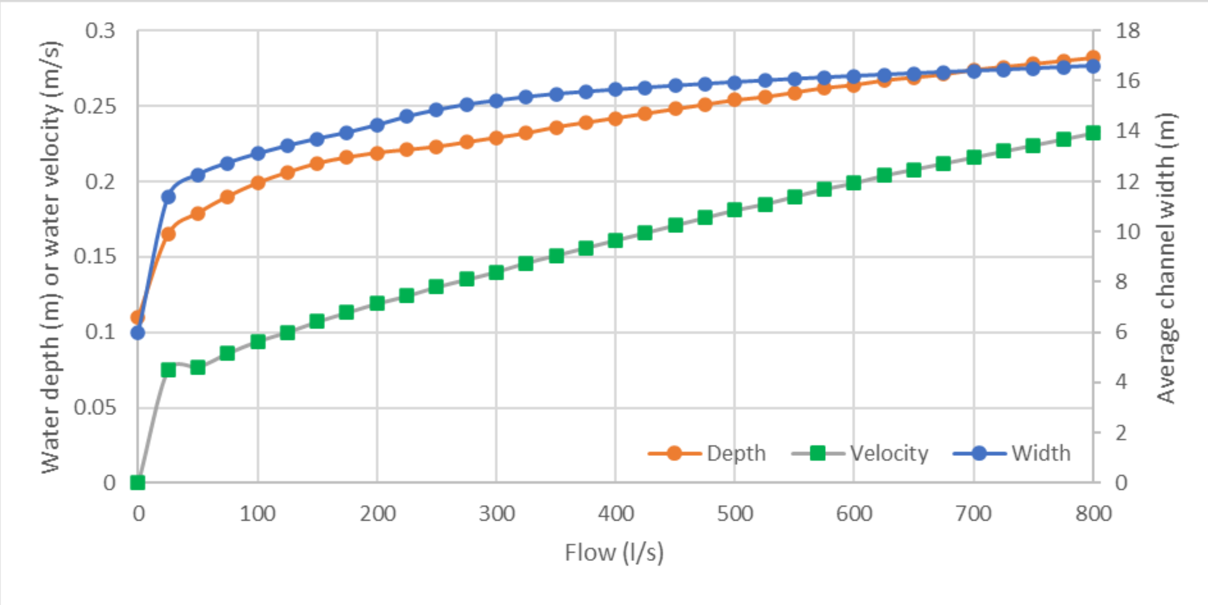

Figure 8 Changes in mean channel width, mean water depth and mean water velocity with changes in flow in the survey reach of the Waianakarua River.

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 as flows increased above 25 l/s (Figure 9). Habitat quality for native diatoms was predicted to be low but increase with increasing flow across the modelled flow range (Figure 9). 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 at 25 l/s and to decline with increasing flows across the modelled flow range (Figure 9).

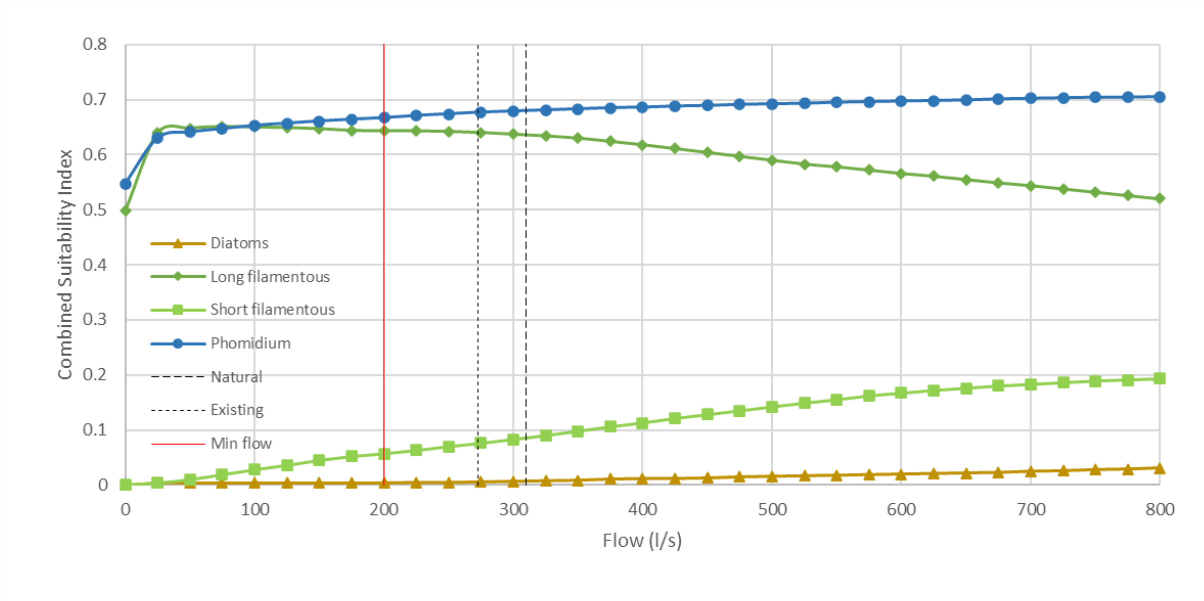

Figure 9 Variation in instream habitat quality for periphyton relative to flow in the survey reach of the Waianakarua River.

Table 11 Flow requirements for periphyton habitat in the Waianakarua 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	Optimum flow (l/s)	Flow at which % habitat retention occurs (l/s)				Habitat retention at 200 l/s
		120%	150%	200%	300%	
Cyanobacteria (*Phormidium*)	-	-	-	-	-	54%
Diatoms	>800	-	-	-	-	101%
Short filamentous	>800	-	-	-	-	66%
Long filamentous	-	-	-	-	-	98%

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 the most consistently abundant macroinvertebrates in the Waianakarua River (Olsen 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 is abundant in the Waianakarua River (Olsen 2013). The stony-cased caddis *Pycnocentrodes* can be amongst the most common macroinvertebrate taxa in moderate to slow-moving streams and is abundant in the Waianakarua River at times (Olsen 2013). 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 10). Flows required to achieve different levels of habitat retention for each of the macroinvertebrate taxa are presented in Table 12.

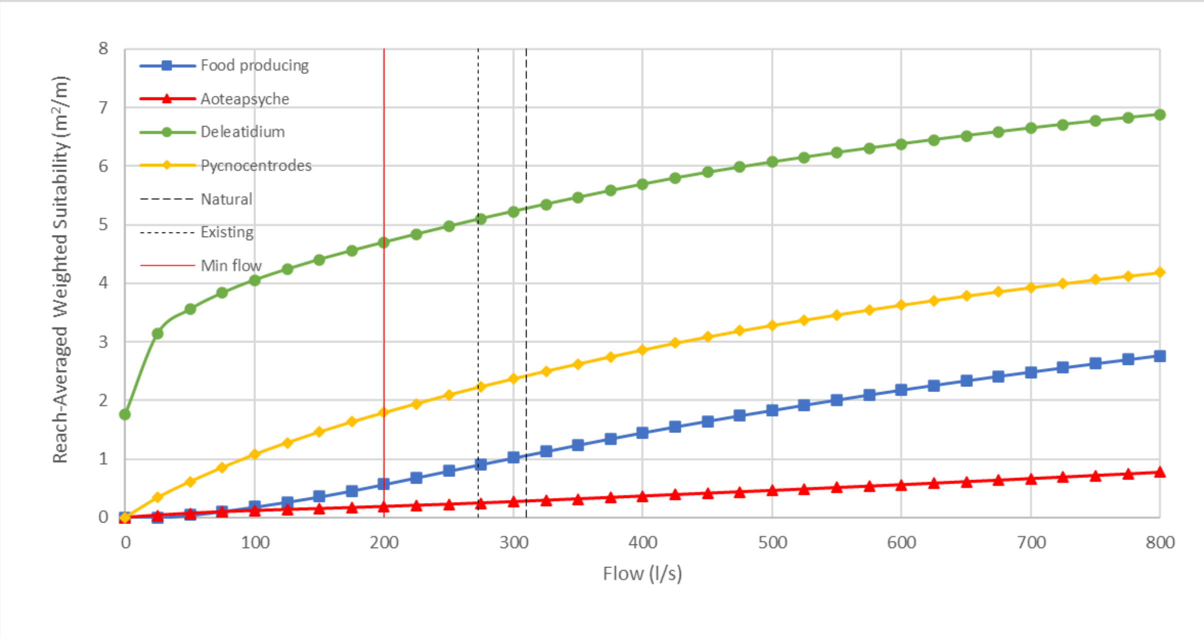

Figure 10 Variation in instream habitat for common macroinvertebrates relative to flow in the survey reach of the Waianakarua River.

Table 12 Flow requirements for macroinvertebrate habitat in the Waianakarua 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	Optimum flow (l/s)	Flow at which % habitat retention occurs (l/s)				Habitat retention at 200 l/s
		60%	70%	80%	90%	
Food producing habitat	>800	215	239	262	286	53%
Common mayfly *Deleatidium*	>800	26	62	123	209	89%
Net-spinning caddis fly (*Aoteapsyche*)	>800	174	211	247	279	67%
Cased caddis fly (*Pycnocentrodes*)	>800	149	185	224	265	74%

7.4 Indigenous fish

Habitat for tuna/longfin eel (<300 mm and >300 mm), torrentfish, bluegill bully and common smelt is predicted to increase across the modelled flow range (Figure 10). Habitat for redfin bully is predicted to increase with increasing flow to 600 l/s and decline gradually at higher flows (Figure 10). Habitat for upland bully is predicted to increase with increasing flow to 275 l/s, before gradually declining above 600 l/s (Figure 10). Habitat for inanga is predicted to increase with increasing flow to 250 l/s and decline gradually at flows above 600 l/s (Figure 10). Habitat for Canterbury galaxias is predicted to increase with increasing flow to 350 l/s before stabilizing at higher flows (Figure 10). Habitat for kanakana/lamprey is predicted to decline with increasing flows (Figure 10). Flows required to achieve different levels of habitat retention for indigenous fish species are presented in Table 13.

Table 13 Flow requirements for indigenous fish habitat in the Waianakarua 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	Optimum flow (l/s)	Flow at which % habitat retention occurs (l/s)				Habitat retention at 200 l/s
		60%	70%	80%	90%	
Tuna/longfin eel <300 mm	>800	94	131	176	233	84%
Tuna/longfin eel >300 mm	>800	2	24	103	201	90%
Torrentfish	>800	235	255	274	292	43%
Bluegill bully	>800	224	247	269	290	49%
Redfin bully	-	54	90	136	204	90%
Upland bully	-	23	37	67	137	95%
Canterbury galaxias	-	44	72	125	213	89%
Inanga	-	61	90	129	180	93%
Common smelt	>800	231	249	269	290	43%
Kanakana/lmprey	0	-	-	-	-	101%

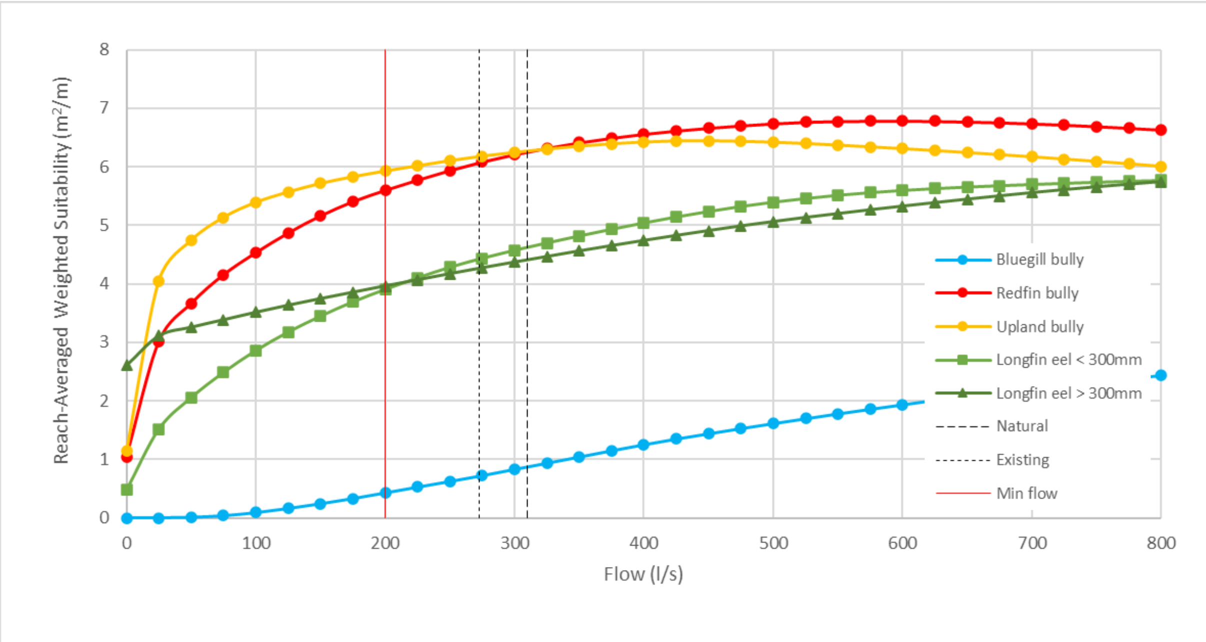

Figure 11 Variation in instream habitat for bully species and longfin eel size-classes relative to flow in the survey reach of the Waianakarua River.

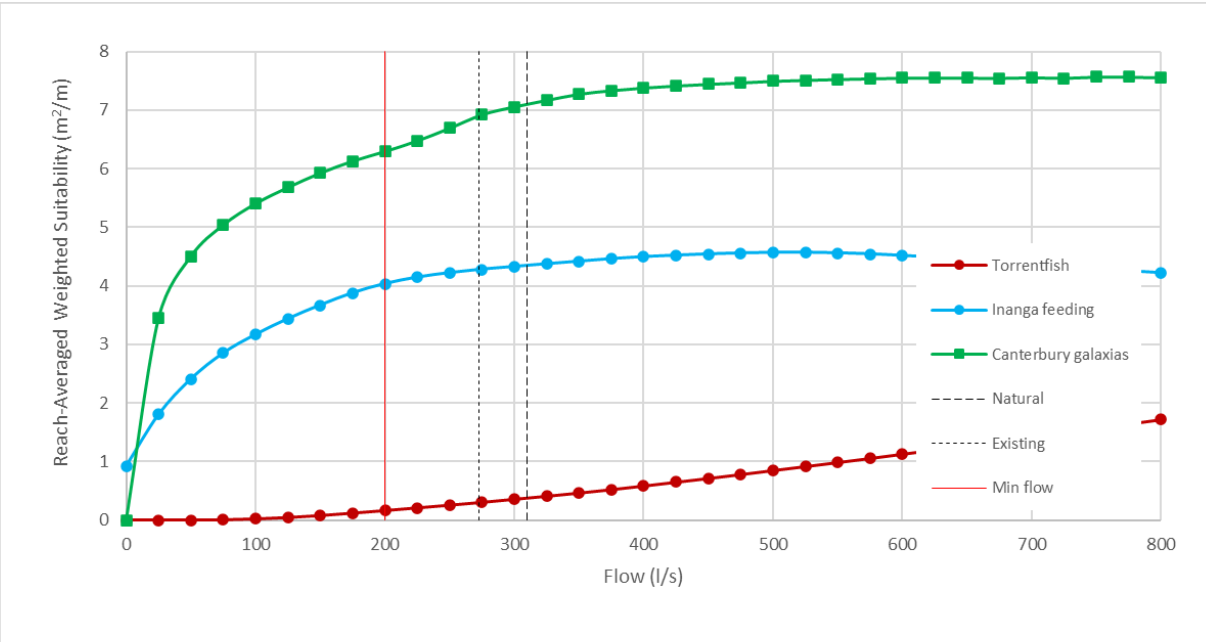

Figure 12 Variation in instream habitat for torrentfish, inanga and Canterbury galaxias relative to flow in the survey reach of the Waianakarua River.

7.5 Sports fish

Habitat for brown trout adult, juveniles and spawning is predicted to increase with flow across the modelled range (Figure 10). Flows required to achieve different levels of habitat retention for each of these species/life-stages are presented in Table 14.

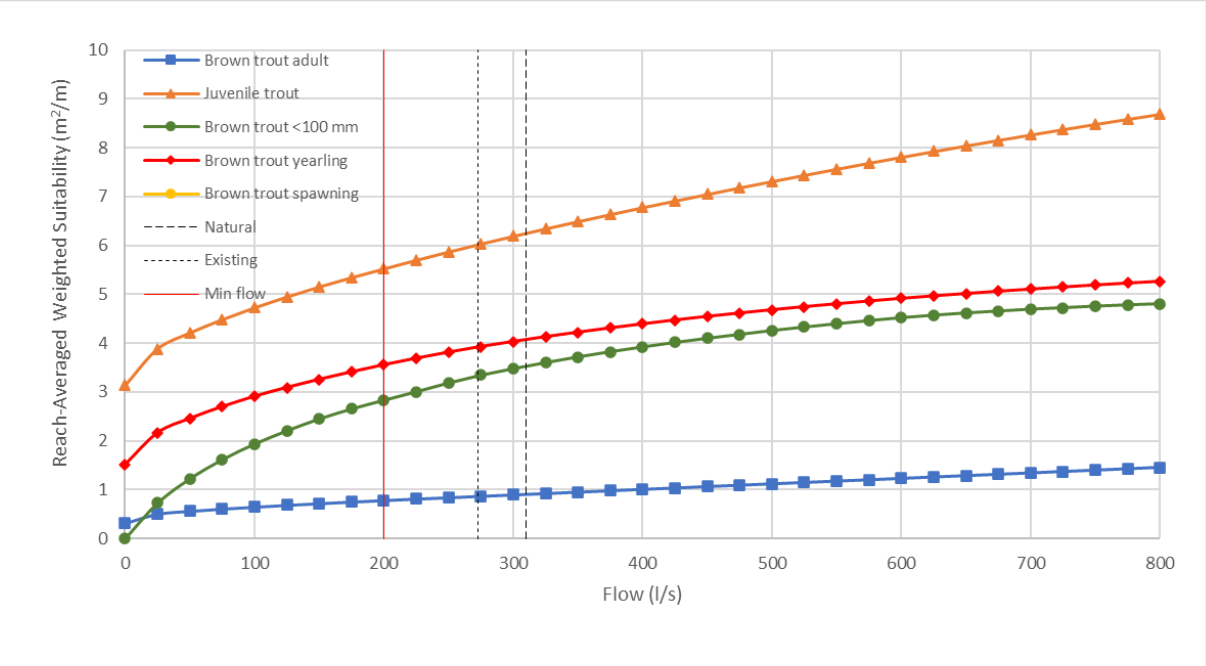

Figure 13 Variation in instream habitat for sportsfish relative to flow in the survey reach of the Waianakarua River.

Table 14 Flow requirements for sportsfish habitat in the Waianakarua 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	Optimum flow (l/s)	Flow at which % habitat retention occurs (l/s)				Habitat retention at 200 l/s
		60%	70%	80%	90%	
Brown trout adult	>800	42	92	155	230	86%
Brown trout (< 100 mm)	>800	117	152	199	249	80%
Brown trout yearling	>800	49	93	150	220	87%
Juvenile trout	>800	21	65	131	215	88%
Brown trout spawning	>800	205	232	258	284	58%

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.

Flows of 176 l/s are predicted to retain 80% of the habitat for tuna/longfin eel available at the naturalised MALF (Table 15). Torrentfish are among the most flow-demanding indigenous fish species in the Waianakarua catchment, a flow of 274 l/s would provide 80% habitat retention in the Waianakarua River, while the current minimum flow is predicted to retain 43% of the habitat for torrentfish at the naturalised MALF (Table 15). Flows of 269 l/s, 136 l/s and 67 l/s would provide 80% habitat retention for bluegill, redfin and upland bullies, respectively, while the current minimum flow retains 49%, 90% and 95% of the habitat for these species at the naturalised MALF, respectively (Table 15). Flows of 129 l/s, 125 l/s, and 169 l/s would provide 80% habitat retention for inanga, Canterbury galaxias, and common smelt, respectively, while the current minimum flow retains 93%, 89% and 43% of the habitat for these species at the naturalised MALF, respectively (Table 15). Habitat for kanakana/lamprey were predicted to be highest at low flows, and the current minimum flow retains 101% of the habitat available at the naturalised MALF (Table 15).

Flows of 123-262 l/s would provide 80% habitat retention (relative to naturalised flows) for macroinvertebrates, with the mayfly *Deleatdium* likely to be particularly abundant in the Waianakarua River and predicted to have 80% habitat retention at 123 l/s (Table 15).

Given that the Waianakarua River supports a local significant fishery (Central South Island Fish & Game Council 2022), an appropriate management objective for trout may be to maintain the existing habitat which occurs at the existing minimum flow (200 l/s), which would retain 80-88% of the habitat for the various life-stages of trout relative to naturalised flows (Table 15).

Table 15 Flow requirements for habitat objectives in the Waianakarua 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 200 l/s
Food producing habitat	All year	Life-supporting capacity	80% relative to naturalised	262	53%
Common mayfly *Deleatidium*	All year	Life-supporting capacity	80% relative to naturalised	123	89%
Net-spinning caddisfly *Aoteapsyche*	All year	Life-supporting capacity	80% relative to naturalised	247	67%
Stony-cased caddisfly *Pycnocentrodes*	All year	Life-supporting capacity	80% relative to naturalised	224	74%
Tuna/longfin eel	All year	Life-supporting capacity, indigenous biodiversity, mahika kai	80% relative to naturalised	176	84-90%
Torrent fish	All year	Life-supporting capacity, indigenous biodiversity	80% relative to naturalised	274	43%
Bluegill bully	All year	Life-supporting capacity, indigenous biodiversity	80% relative to naturalised	269	49%
Redfin bully	All year	Life-supporting capacity, indigenous biodiversity	80% relative to naturalised	136	90%
Upland bully	All year	Life-supporting capacity, indigenous biodiversity	80% relative to naturalised	67	95%
Canterbury galaxias	All year	Life-supporting capacity, indigenous biodiversity	80% relative to naturalised	125	89%
Inanga	All year	Life-supporting capacity, indigenous biodiversity	80% relative to naturalised	129	93%
Common smelt	All year	Life-supporting capacity, indigenous biodiversity	80% relative to naturalised	269	43%
Kanakana/lamprey	All year	Life-supporting capacity, indigenous biodiversity, mahika kai	80% relative to naturalised	-	101%
Brown trout adult	All year	Sports fish	80% relative to naturalised	155	86%
Juvenile trout	All year	Sports fish	80% relative to naturalised	131-199	80-88%
Brown trout spawning	Winter	Sports fish	Current winter minimum	400	-

8 Assessment of alternative minimum flows and allocation limits

Four minimum flows were considered representing different proportions of the 7-day MALF along with four allocation limits (Table 16). 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 naturalised flows estimated by adding measured water take (based on water metering data for water users in the upstream of the Browns Pump flow monitoring site[2]) back onto the observed flows in the Waianakarua River at Browns Pump. For each simulation, supplementary allocation blocks of 100 l/s were included, with minimum flows of 311 l/s, 411 l/s and 511 l/s and a fourth supplementary block of 33 l/s (current allocation) with a minimum flow of 611 l/s.

Table 16 Minimum flow and allocation limits considered in this analysis.

Minimum flow		Allocation limit		
Option	% 7-d MALF	Option	% 7-d MALF	Description
200 l/s	62%	190 l/s	58%	Current minimum flow and allocation limit (58% of MALF).
		160 l/s	50%	Current minimum flow and allocation at 50% of MALF.
		120 l/s	37%	Current minimum flow and allocation at 37% of MALF.
		80 l/s	25%	Current minimum flow and allocation at 25% of MALF.
230 l/s	71%	190 l/s	58%	Minimum flow of 71% MALF and current allocation limit (58% of MALF).
		160 l/s	50%	Minimum flow of 71% MALF and allocation at 50% of MALF
		120 l/s	37%	Current minimum flow and allocation at 37% of MALF.
		80 l/s	25%	Minimum flow of 71% MALF and allocation at 25% of MALF.
260 l/s	80%	190 l/s	58%	Minimum flow of 80% MALF and current allocation limit (58% of MALF).
		160 l/s	50%	Minimum flow of 80% MALF and allocation at 50% of MALF
		120 l/s	37%	Current minimum flow and allocation at 37% of MALF.
		80 l/s	25%	Minimum flow of 80% MALF and allocation at 25% of MALF.
290 l/s	89%	190 l/s	58%	Minimum flow of 80% MALF and current allocation limit (58% of MALF).
		160 l/s	50%	Minimum flow of 80% MALF and allocation at 50% of MALF
		120 l/s	37%	Current minimum flow and allocation at 37% of MALF.
		80 l/s	25%	Minimum flow of 80% MALF and allocation at 25% of MALF.

[2] The naturalised flows used in these simulations should be treated with caution as they rely on water take data of unknown quality provided by water users.

The degree of hydrological alteration resulting from each of the minimum flow/allocation scenarios 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[3] is calculated. The results of these simulations are presented in Table 18.

Table 17 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

All scenarios considered, including the existing minimum flow and allocation limit, are predicted to result in a hydrograph that is unimpacted relative to naturalised flows (Table 18; Figure 14, Figure 15, Figure 16 and Figure 17).

[3] 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 18 Comparison of the hydrological effects of different minimum flow/allocation limit combinations in the Waianakarua River.

Min flow	Allocation	Monthly		Min/max means		Date/timing		Pulse count/duration		Rate of change		Risk grade
		CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	
Observed[4]		0	0	0	0	0	0	0	0	0	0	Unimpacted
200	190	0	0	0	0	0	0	0	0	0	0	Unimpacted
	160	0	0	0	0	0	0	0	0	0	0	Unimpacted
	120	0	0	0	0	0	0	0	0	0	0	Unimpacted
	80	0	0	0	0	0	0	0	0	0	0	Unimpacted
230	190	0	0	0	0	0	0	0	0	0	0	Unimpacted
	160	0	0	0	0	0	0	0	0	0	0	Unimpacted
	120	0	0	0	0	0	0	0	0	0	0	Unimpacted
	80	0	0	0	0	0	0	0	0	0	0	Unimpacted
260	190	0	0	0	0	0	0	0	0	0	0	Unimpacted
	160	0	0	0	0	0	0	0	0	0	0	Unimpacted
	120	0	0	0	0	0	0	0	0	0	0	Unimpacted
	80	0	0	0	0	0	0	0	0	0	0	Unimpacted
290	190	0	0	0	0	0	0	0	0	0	0	Unimpacted
	160	0	0	0	0	0	0	0	0	0	0	Unimpacted
	120	0	0	0	0	0	0	0	0	0	0	Unimpacted
	80	0	0	0	0	0	0	0	0	0	0	Unimpacted

[4] Observed flows are the flows measured at the Waianakarua at Browns Pump flow monitoring site, which reflects actual water take and use upstream of this location

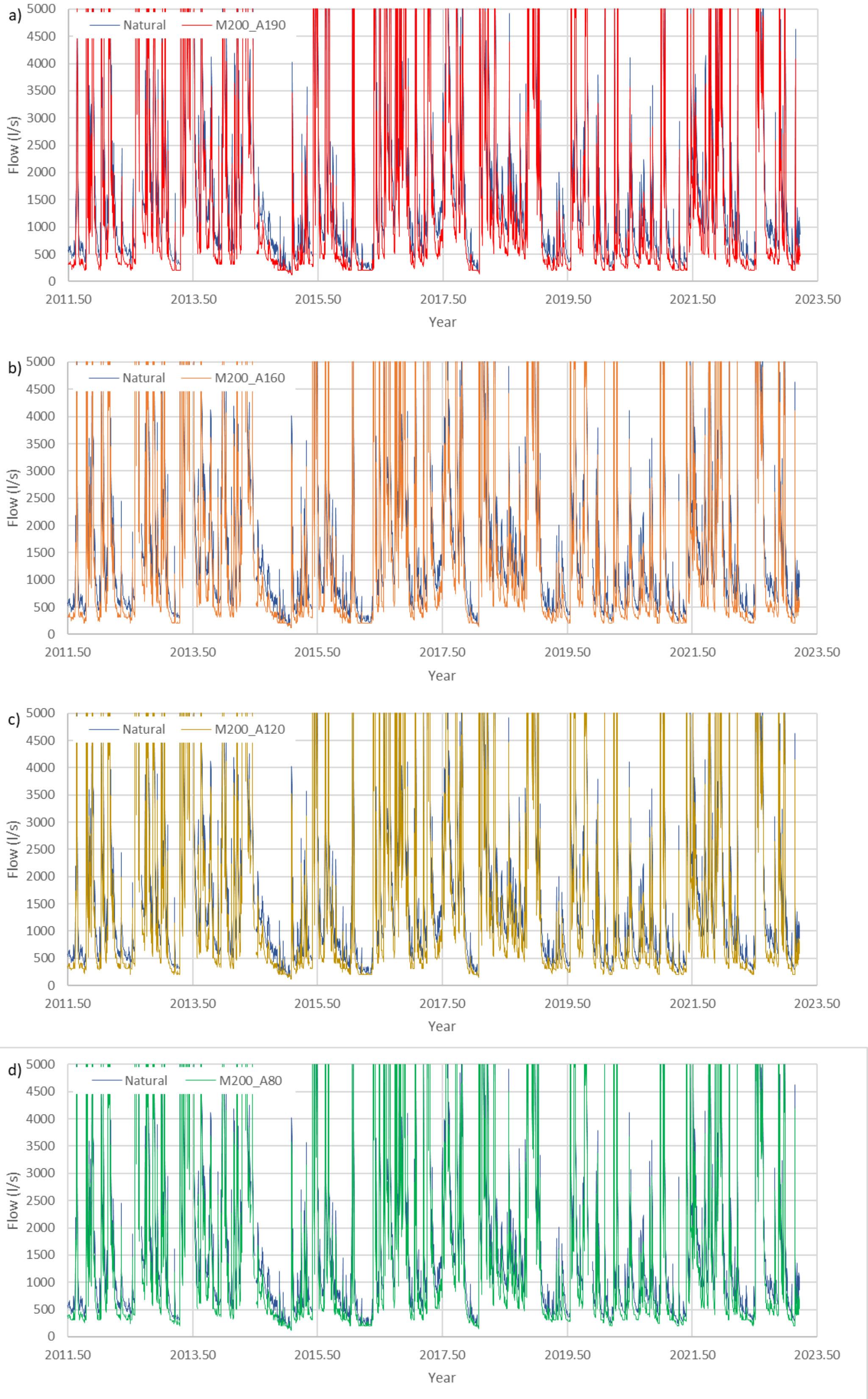

Figure 14 Hydrographs of allocation scenarios with a minimum flow of 200 l/s. a) Current allocation limit 190 l/s, b) allocation limit of 160 l/s, c) allocation limit of 120 l/s, d) allocation limit of 80 l/s.

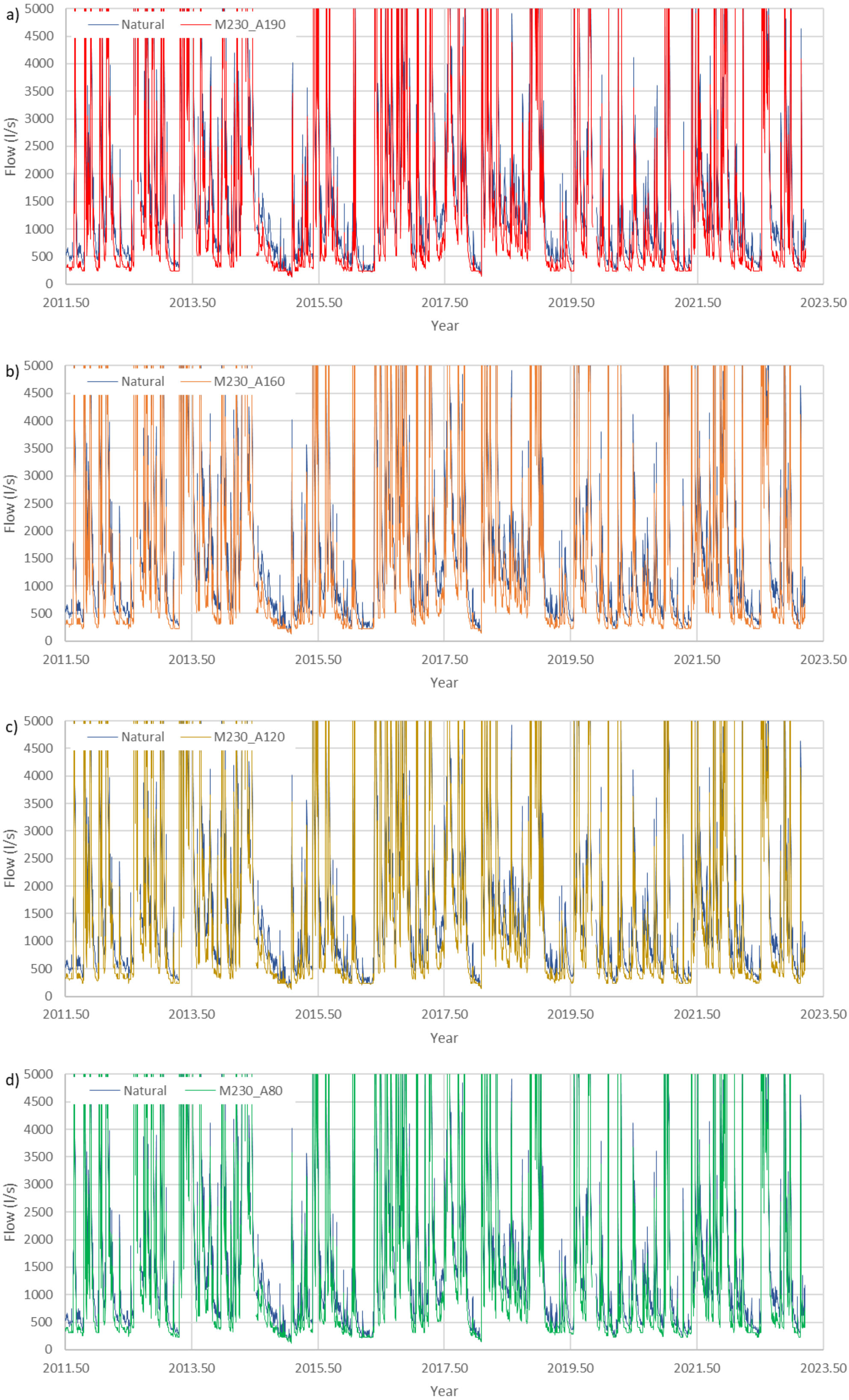

Figure 15 Hydrographs of allocation scenarios with a minimum flow of 230 l/s. a) Current allocation limit 190 l/s, b) allocation limit of 160 l/s, c) allocation limit of 120 l/s, d) allocation limit of 80 l/s.

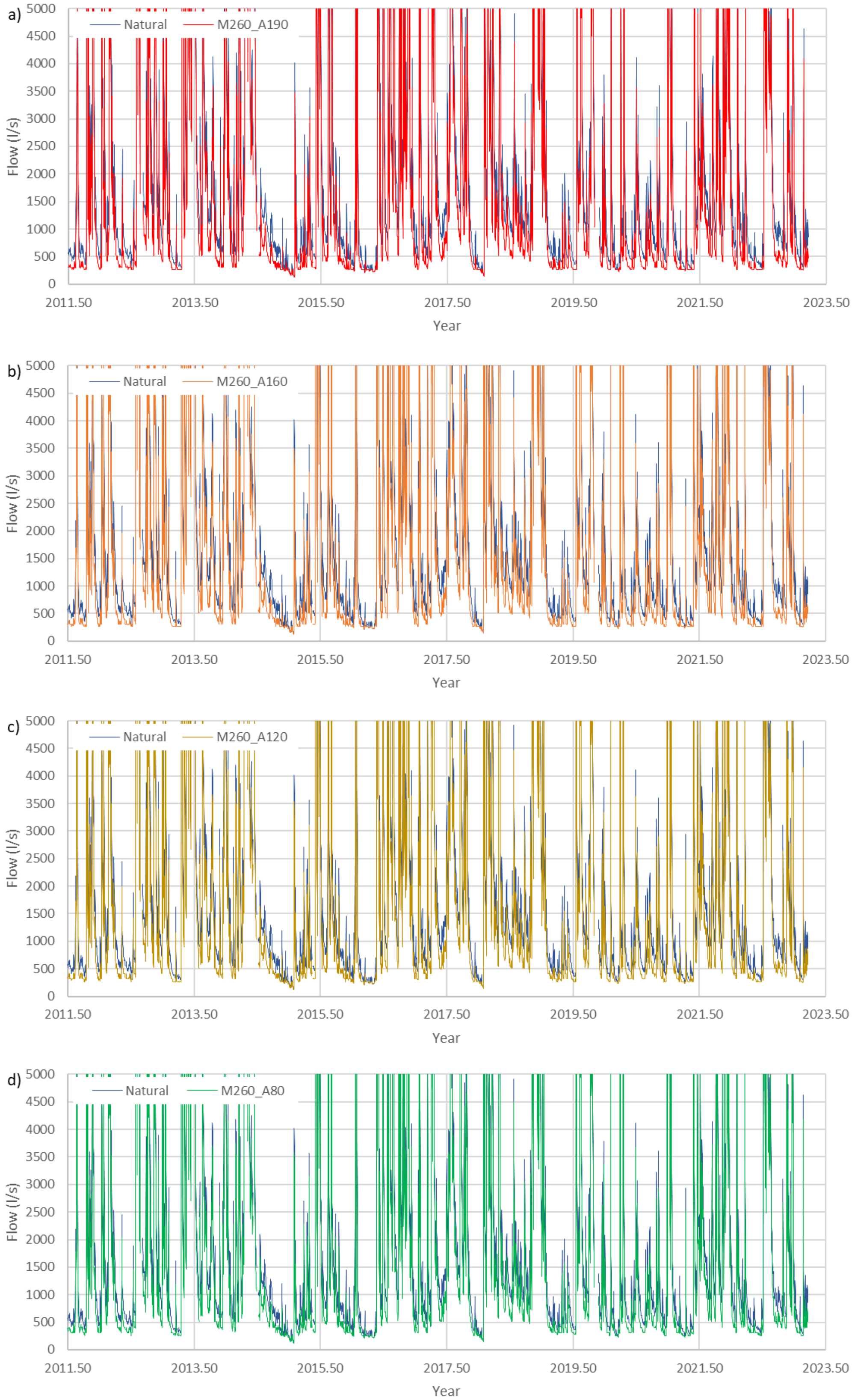

Figure 16 Hydrographs of allocation scenarios with a minimum flow of 260 l/s. a) Current allocation limit 190 l/s, b) allocation limit of 160 l/s, c) allocation limit of 120 l/s, d) allocation limit of 80 l/s.

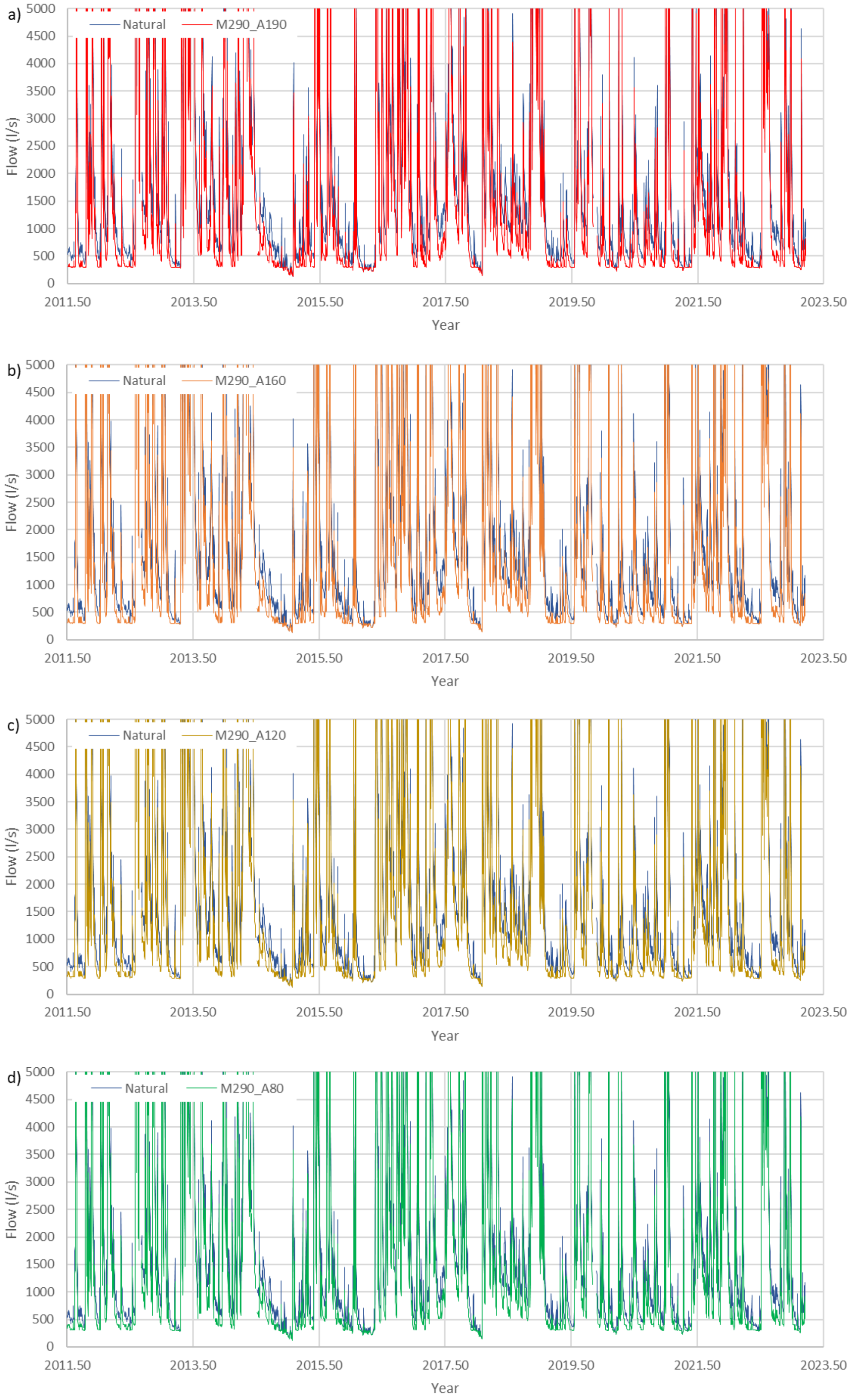

Figure 17 Hydrographs of allocation scenarios with a minimum flow of 290 l/s. a) Current allocation limit 190 l/s, b) allocation limit of 160 l/s, c) allocation limit of 120 l/s, d) allocation limit of 80 l/s.

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 a minimum flow for primary allocation at Browns Pump of 200 l/s (1 October to 30 April) or 400 l/s (1 May to 30 September) and allocation of 190 l/s.

The existing minimum flow and allocation limit are predicted to result in a hydrograph that is unimpacted relative to naturalised flows (based on the DHRAM score). However, periphyton biomass in the Waianakarua River at Browns 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 Waianakarua (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 lower South Branch and mainstem) contribute to the high biomasses observed in the Waianakarua catchment.

8.2 Potential effects of climate change in the Waianakarua 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) 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 Waianakarua catchment (Table 19). 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 attribute state in the Waianakarua River at Browns Pump, such changes may reduce the achievability of periphyton objectives in the Waianakarua catchment.

Table 19 Potential effects of climate change on the Waianakarua 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 Waianakarua 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

9 Conclusions

Minimum flows of 200 l/s (1 October to 30 April) or 400 l/s (1 May to 30 September) apply at Browns Pump to primary allocation in the Waianakarua catchment. The primary allocation limit specified for the Waianakarua catchment in Schedule 2A is 190 l/s. These restrictions have been in place since 2008.

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

Site		Flow statistics (l/s)			
		Mean	Median	7d MALF (Jul-Jun)	7d MALF (Oct-Apr)
Mainstem	Naturalised flows	3,257	1,150	310	325
	Observed flows	-	-	273	282
North Branch (SH1)	Naturalised flows	2,346	829	223	234
South Branch (SH1)	Naturalised flows	859	303	82	86

There are seven resource consents for primary water takes from the Waianakarua River, with one from the North Branch (30 l/s), two from the South Branch (43.6 l/s) one from the mainstem at Browns Pump (65 l/s), and two from the mainstem downstream of the Browns Pump site (69 l/s). Thus, the total primary allocation is 207.6 l/s. In addition to these primary permits, there is a permit for a non-consumptive take of 10 l/s from a tributary of the North Branch (Glenburnie Stream) to operate a micro-hydro scheme. The water taken under this permit is returned to Glenburnie Stream approximately 90 m downstream of the point of take. In addition, three supplementary allocation blocks (block size 100 l/s) have been fully allocated with minimum flows of 311, 411, and 511 l/s, respectively. A fourth supplementary allocation block (611 l/s) has been partially allocated.

The periphyton community at Browns Pump is typically dominated by thin to medium light brown films/mats (diatoms), although medium to thick black/dark brown mat (cyanobacteria mats), are present on occasion and warning signs have been installed at major access points. Filamentous algae can form nuisance blooms during periods of stable flows. Chlorophyll *a* concentrations at Browns Pump exceed the periphyton objective for the North Otago FMU in the proposed LWRP as well as the national bottom line for periphyton (trophic state).

Macroinvertebrate communities in the Waianakarua River are usually dominated by the common mayfly *Deleatidium*, although various caddis flies, chironomid midge larvae and the mudsnail *Potamopyrgyus* can be abundant at times. MCI scores for Brown's Pump are in C-band, while SQMCI scores and ASPM scores are in B-band. Macroinvertebrate indices at Browns Pump site reflect the position of this site (lower reaches just upstream of tidal influence), and the high periphyton biomass observed at this site.

The Waianakarua River supports a highly diverse community of indigenous fish with thirteen 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), and kanakana/lamprey (threatened – nationally vulnerable). Brown trout are the only introduced fish species that have been collected from the Waianakarua catchment.

An instream habitat model developed for the mainstem of the Waianakarua River was applied to consider the effects of different flows on the physical characteristics of the Waianakarua River and habitat for periphyton, macroinvertebrates and fish. The current minimum flow in the Waianakarua catchment (200 l/s) is predicted to maintain between 53% (food producing habitat) and 89% (the common mayfly *Deleatidium*) of habitat for macroinvertebrates at the naturalised 7-d MALF. It is predicted to maintain 43% of habitat for torrent fish, 49% of bluegill bully habitat, and 43% of habitat for common smelt compared to the naturalised 7-d MALF. The current minimum flow is predicted to achieve >80% habitat retention for other indigenous species considered and between 80-88% habitat retention for the various brown trout life-stages considered.

Flows of 176 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 Waianakarua catchment, and a flow of 274 l/s is predicted to provide 80% habitat retention in the Waianakarua River. Flows of 269 l/s, 136 l/s and 67 l/s are predicted to provide 80% habitat retention for bluegill, redfin and upland bullies. Flows of 129 l/s, 125 l/s, and 169 l/s would provide 80% habitat retention for inanga, Canterbury galaxias, and common smelt, respectively. Habitat for kanakana/lamprey were predicted to be highest at low flows.

The existing minimum flow and allocation limit are predicted to result in a hydrograph that is unimpacted relative to naturalised flows (based on the DHRAM score). However, periphyton biomass in the Waianakarua River at Browns 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 Waianakarua (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 lower South Branch and mainstem) contribute to the high biomasses observed in the Waianakarua catchment. The effects of climate change may exacerbate the current high biomass of periphyton observed in the Waianakarua River.

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Appendix A

Flow naturalisation of the Waianakarua River

Flow naturalisation of the Waianakarua River

Contents

Author - Lu Xiaofeng 16/03/2023

Reviewer – David Stewart 23/03/2023

This document describes how naturalised flow statistics for the Waianakarua River in North Otago were derived for the flow recorder at Browns, and the North and South Branches of this river at their confluence.

Daily flow time series

The daily flow time series data available for analysis are listed in **Table 1**. The locations of the sites are shown in **Figure 1**.

Table 1: The daily flow time series data available for analysis for the Waianakarua River.

Sites	Start	End	Length (year)
Waianakarua at Browns	19/04/2005	28/02/2023	17.9
Waianakarua at North Branch	17/07/2012	30/04/2013	0.8
Waianakarua South Branch at McKerrows	17/07/2012	30/04/2013	0.8
Waianakarua at South Branch Railway Bridge	14/11/2014	04/09/2015	0.8

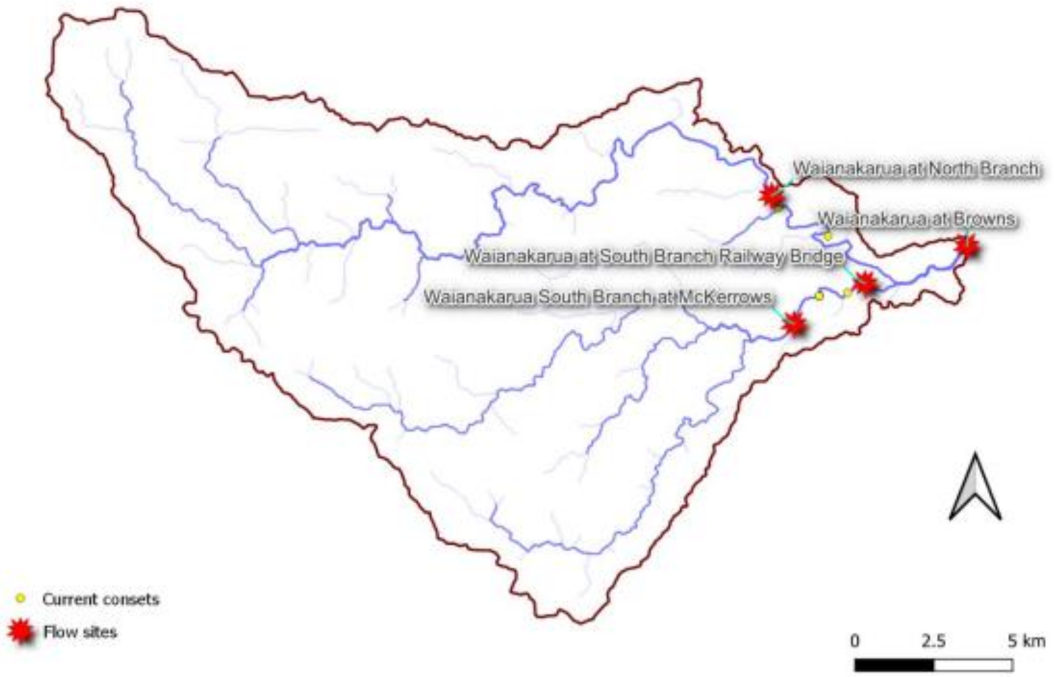

Figure 1: The location of flow recorders on the Waianakarua River in North Otago.

The flow recorders at North Branch and McKerrows are not used in this study as they are not locations of interest. The flow recorder at Railway Bridge in the South Branch is important as it is close to the confluence of the North and South branches. The Browns flow recorder which measures the total flow from both the North and South Branches, is also close to the confluence and used as it is an active site with long-term flow time series available. This data assists in estimating the naturalised flow statistics in the North Branch.

Daily water use time series

Time series data of water use (WU) is needed to naturalise the flow at the Railway Bridge (South) and Browns recorders. All consents must first be identified for the areas upstream of these recorders.

Total water use above Browns flow recorder

Thirty-three consents have been issued in the Waianakarua catchment. Of these, 9 are current, and 24 are expired or surrendered. Of the 9 current consents, 3 are primary consents, 4 are supplementary consents, and 2 consents are non-consumptive, e.g., gravel washing. (See Table A1 in the Appendix). **Figure 2** shows the total WU regime above Waianakarua at Browns.

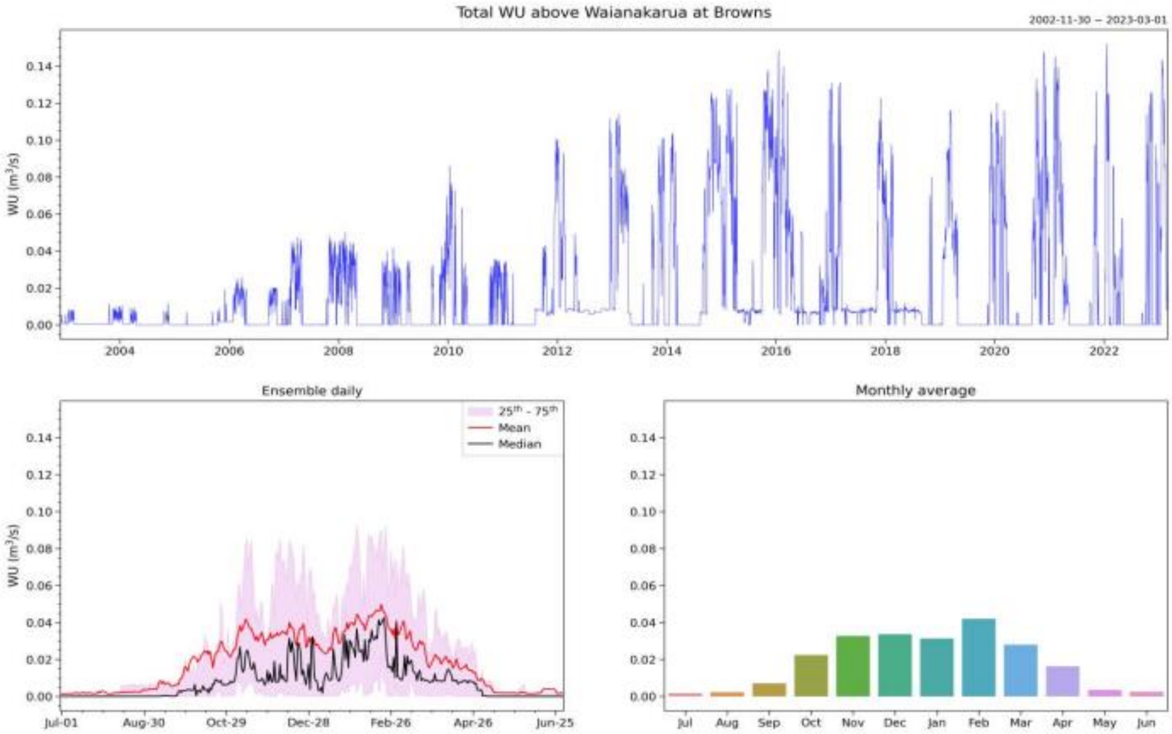

Figure 2: The total water use upstream of the Browns flow recorder on the Waianakarua River.

As shown in **Figure 2**, the patterns before and after the water year 2011/12 are quite different due to data quality issues in the earlier years. In this study, the water use data after 2011/12 is used. The average total WU during the possible irrigation seasons (October - April, inclusive) is 43 L/s after the water year of 2011/12.

Total water use above Railway Bridge (South) flow recorder

There are 14 (current and historical) consents (see Table A2 in the Appendix), and five are current. **Figure 3** shows the total WU regime above the Railway Bridge recorder in the South Branch.

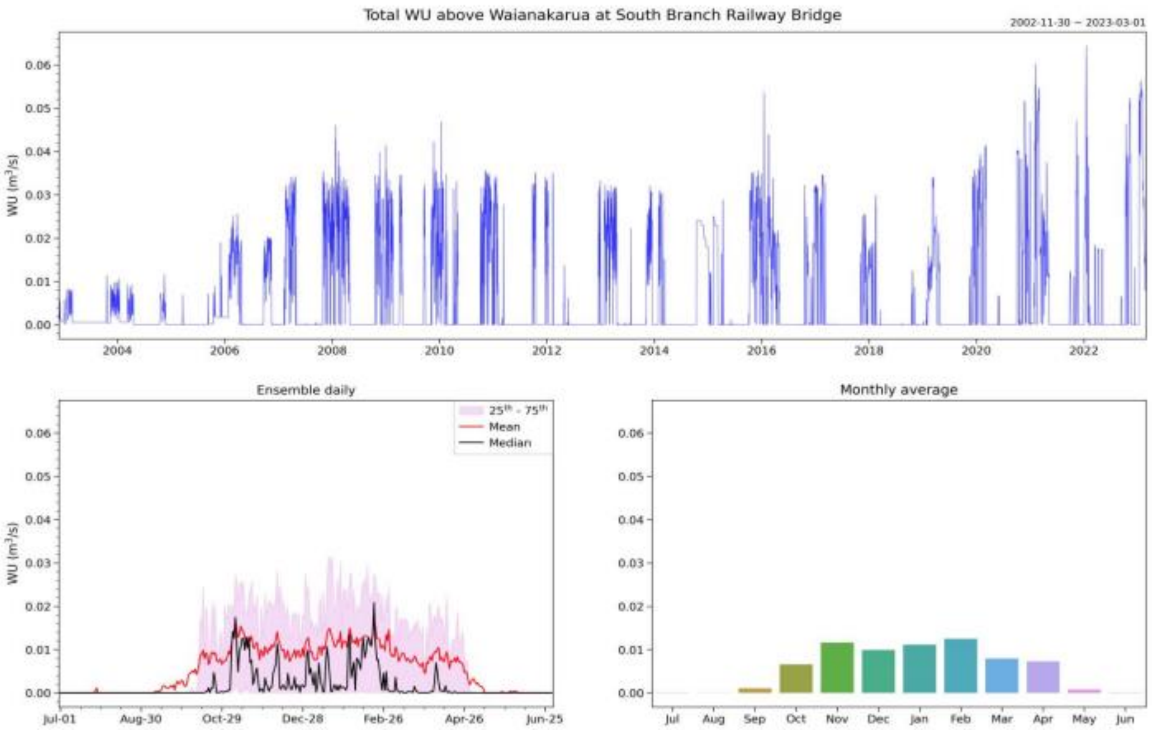

Figure 3: The water use on the Waianakarua River above the Railway Bridge (South) flow recorder.

Due to data quality issue in the earlier years, the water use data after 2007/08 is used in this study. The average water take during the possible irrigation seasons (October - April, inclusive) since 2007/08 is close to 11 L/s.

Flow naturalisation

This section describes how the naturalised flow statistics are estimated for the North and South Branches of the Waianakarua River.

Method

The naturalised flow time series for Browns can be estimated by adding the upstream total WU to the observed flow records.

Similarly, the naturalised flow time series for the Railway Bridge recorder in the South Branch can also be derived this way, but this record is very short. There are two ways this record can be extended.

The first method is to investigate the correlation between the two naturalised flow time series for the different flow sites during overlapping data periods (14/11/2014 – 04/09/2015) using a simple scatter plot shown in **Figure 4**.

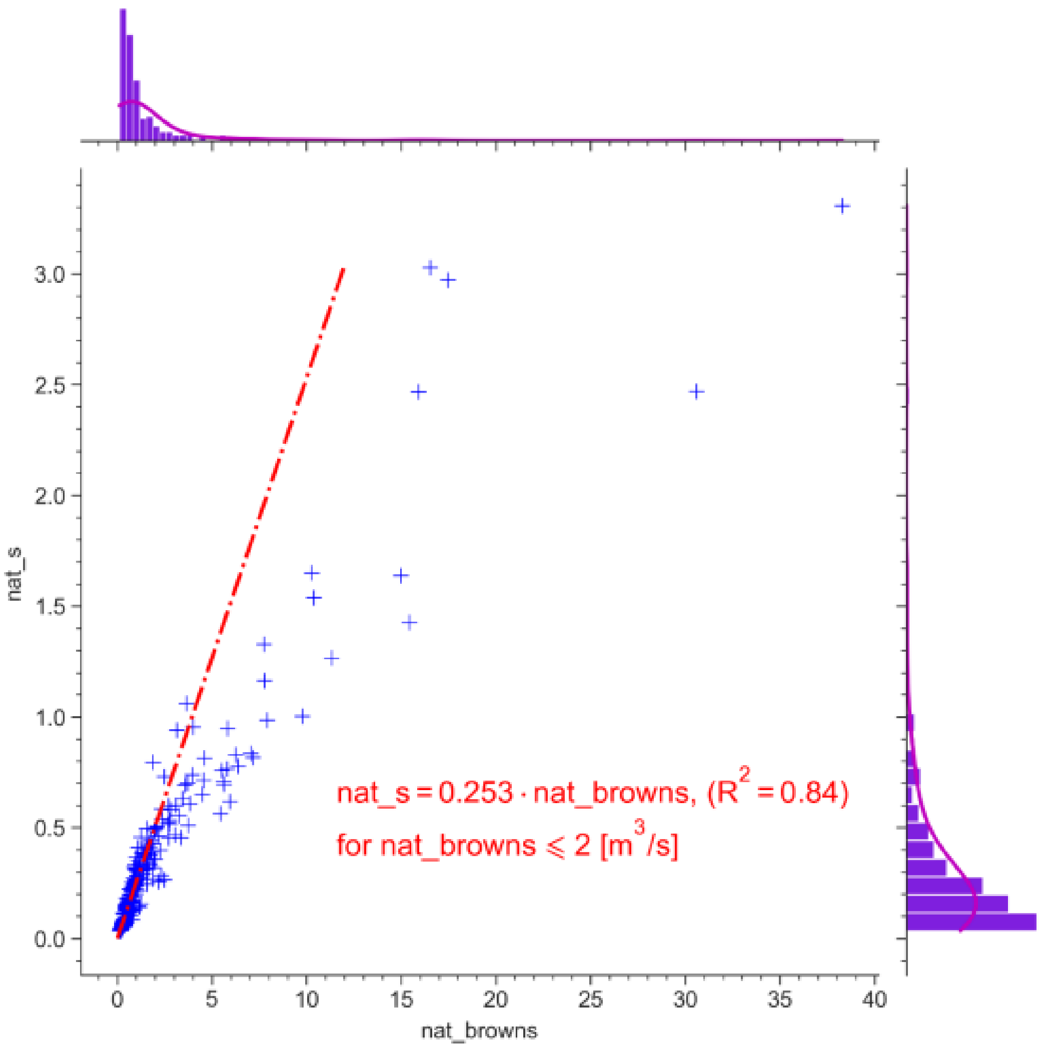

Figure 4: Scatter plot showing the relationship between derived naturalised flows at the Browns and the Railway Bridge (South) flow sites on the Waianakarua River during overlapping time periods.

Figure 4 shows that most points are confined within a range of the naturalised flows at Browns, below 2 m^3/s. The correlation roughly follows a linear relationship below 2 m^3/s and becomes more scattered above this, giving more uncertainty in high-flow ranges.

For this study, producing long-term flow statistics is the key goal including the naturalised seven-day mean annual flow (7dMALF) and long-term median and mean flows for both the North and South Branches. Unfortunately, no flow records are available near the North Branch/South Branch confluence in the North Branch.

The relationship in **Figure 4** was derived for the naturalised flow at Browns below 2 m^3/s. The line of correlation between the two datasets has a slope of 0.253, which can be interpreted as the naturalised flow statistics in the South Branch are 25.3% of the naturalised flows at Browns during low flows. However, as discussed, this method has high uncertainty at higher flows.

The second method to derive naturalised long-term flow statistics for the South Branch flow site is to apply a consistent ratio to the naturalised flow time series of the Browns recorder which has long-term naturalised flow time series easily derived by adding WU to observed flows. A consistent ratio of 0.264 is used, which is the ratio between the derived median flows at South Branch and Browns (using 291 points between *14/11/2014* and *04/09/2015*). This ratio is close to the slope of 0.253 found in method 1 using the linear regression below 2m^3/s. As illustrated in **Figure 4**, both derived naturalised flows are heavily skewed. The median value captures the central location (representing the majority centre) when outliers are present in the dataset. This second method, the naturalised median flow ratio, is used for this analysis.

The flow recorder at Browns is around 3.3 km downstream of the confluence of the North and South Branches. Comparing the upstream area above the confluence with that above the Browns recorder, the assumption made is that the naturalised flows at the confluence are around 98.4% of those at Browns, i.e., Area above confluence / Area above Browns. This leaves 72.0% (i.e., 98.4% - 26.4%) of the naturalised flow statistics in the North Branch

Naturalised flow statistics

Basic flow statistics (Table 2).

Table 2: Naturalised flow statistics for the Browns, South Branch and North Branch of the Waianakarua River (01/07/2011 ~ 28/02/2023).

Site	Mean (m^3/s)	Median (m^3/s)	FRE3 ($year^{-1}$)	7dMALF (m^3/s) (Jul - Jun)	7dMALF (Modified) (m^3/s) (Oct - Apr)
Browns	3.257	1.150	6.7	0.310	0.325
South Branch	0.859	0.303	6.7	0.082	0.086
North Branch	2.346	0.829	6.7	0.223	0.234

Note: the observed 7dMALF at Browns for the same periods across water years and irrigation seasons (Oct-Apr) is calculated to be 0.273, and 0.282 m^3/s.

Low-flow frequency estimations (Table 3)

There are only 12 annual 7dLF values. Therefore, extrapolating the low flow value of a return period over 24 years would have a high margin of error. The 7dLF for up to 20 years is calculated and summarised in **Table 3**.

Table 3: The naturalised 7dLF for different return periods (m^3/s) for three flow sites on the Waianakarua River.

Annual return period (year)	Browns	South Branch	North Branch
1.5	0.340	0.090	0.245
2	0.290	0.076	0.209
3	0.247	0.065	0.178
4	0.225	0.059	0.162
5	0.212	0.056	0.152
10	0.178	0.047	0.128
20	0.154	0.041	0.111

Appendix

Table A1. All consents above the Browns recorder on the Waianakarua River

Consent	Status	Water meter	Allocation type	Category	Consented rate
RM16.329.01	Current			Surface Take	
RM16.251.01	Current	WM0294, WM1451	Supplementary	Surface Take	200
RM15.120.01	Current	WM0294, WM1451	Primary	Surface Take	9.6
RM14.259.01	Current	WM0019	Supplementary	Surface Take	43
RM14.107.01	Current	WM0294, WM1451	Primary	Surface Take	34
RM14.087.01	Current	WM0423, WM0424	Primary	Surface Take	71
RM13.458.01	Current			Surface Take	10
RM11.376.01	Current	WM0619	Supplementary	Surface Take	48.5
2007.658.V1	Current	WM0294, WM1451	Supplementary	Surface Take	20
99442.V2	Expired	WM0423	Primary	Surface Take	40
94429	Expired	WM0727, WM0729		Surface Take	10.4
94327	Expired			Surface Take	
93524	Expired			Surface Take	
93094	Expired			Surface Take	
930	Expired			Surface Take	
1427A	Expired			Surface Take	
2004.408.V1	Expired	WM0727, WM0729	Primary	Surface Take	13

Flow naturalisation of the Waianakarua River

Consent	Status	Water meter	Allocation type	Category	Consented rate
1427B	Expired			Surface Take	
2000.48	Expired	WM0019	Supplementary	Surface Take	25
2002.776	Expired	WM0294	Primary	Surface Take	34
3907	Expired			Surface Take	
2004.421.V2	Expired	WM0423	Primary	Surface Take	30.3
926	Expired			Surface Take	
2006.413	Expired			Surface Take	30
2008.639	Expired	WM0294, WM1451	Primary	Surface Take	9.6
2406	Expired			Surface Take	
2442	Expired			Surface Take	
2007.657	Surrendered	WM0019	Supplementary	Surface Take	18
2003.808	Surrendered		Primary	Surface Take	
2001.26	Surrendered			Surface Take	5
RM16.309.01	Surrendered	WM0727, WM0729	Primary	Surface Take	10.5
2006.208.V2	Surrendered	WM0424	Primary	Surface Take	22.4
RM16.309.02	Surrendered	WM0727, WM0729	Primary	Surface Take	13

Table A2. Consents above the Railway Bridge (South) recorder on the Waianakarua River

Consent	Status	Water meter	Allocation type	Category	Consented rate
2007.658.V1	Current	WM0294, WM1451	Supplementary	Surface Take	20
RM14.107.01	Current	WM0294, WM1451	Primary	Surface Take	34
RM14.259.01	Current	WM0019	Supplementary	Surface Take	43
RM15.120.01	Current	WM0294, WM1451	Primary	Surface Take	9.6
RM16.251.01	Current	WM0294, WM1451	Supplementary	Surface Take	200
2000.48	Expired	WM0019	Supplementary	Surface Take	25
2002.776	Expired	WM0294	Primary	Surface Take	34
2008.639	Expired	WM0294, WM1451	Primary	Surface Take	9.6
2406	Expired			Surface Take	
2442	Expired			Surface Take	
93094	Expired			Surface Take	
93524	Expired			Surface Take	
2003.808	Surrendered	Primary	Surface Take		
2007.657	Surrendered	WM0019	Supplementary	Surface Take	18