Management Flows for Aquatic Ecosystems in the Waiwera River/Te Waiwhero River

October 2024

Otago Regional Council

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Executive summary

The Waiwera River/Te Waiwhero is a small river rising in the hill country of South Otago. Most of its catchment is farmed, with sheep and beef dominating the upper and middle catchment, while dairy farming dominates much of the lower catchment.

The Waiwera River/Te Waiwhero catchment is within the Lower Clutha Rohe within the Clutha/Mata-Au Freshwater Management Unit (FMU). The current minimum flow and allocation in the Waiwera River/Te Waiwhero catchment was added to the Regional Plan: Water (RPW) by Plan Change 3C, which became operative on 8 August 2015. Schedule 2A of the RPW specifies a minimum flow for primary allocation at the Waiwera at Maws Farm of 280 l/s (1 October to 30 April) or 400 l/s (1 May to 30 September). Schedule 2A specifies that if the 280 l/s minimum flow is breached due to abstraction, flow must return to 310 l/s before taking can recommence. The primary allocation limit specified for the Waiwera River/Te Waiwhero catchment in Schedule 2A is 150 l/s.

This report presents information to inform water management decision-making in the Waiwera River/Te Waiwhero catchment. This includes hydrological information, data on aquatic values, application of instream habitat modelling to guide flow-setting processes, and consideration of the current state of the Waiwera River/Te Waiwhero River compared to the proposed objectives for the Lower Clutha Rohe set out in the proposed Otago Land and Water Regional Plan.

Flow statistics for the Waiwera River at Maws Farm based on the analysis of Lu (2023) are summarised below:

	Flow statistics (l/s)		
	Mean	**Median**	**7d MALF (Jul-Jun)**
Naturalised flows	2,285	1,126	231
Observed flows	2,280	1,124	225
ORC 2006	3,100		310

There are five takes from the Waiwera River/Te Waiwhero catchment that have a total primary allocation of 148.7 l/s and there is an additional resource consent to take up to 100 l/s of supplementary water when flows exceed 600 l/s.

In a survey in March 2017, the composition of the periphyton community varied markedly between sites in the Waiwera/Te Waiwhero catchment. The periphyton at many sites was dominated by thin black-brown films, while long filamentous algae (>20 mm) exceeded 30% cover at three sites on the mainstem and cover by short filamentous algae (<20 mm) exceeded 30% at three sites on the mainstem.

Prior to 2004, the common mayfly *Deleatidium* was the most abundant macroinvertebrate taxa collected at the monitoring site in the Waiwera River/Te Waiwhero catchment. The net-spinning caddis fly *Hydropsyche*, chironomid midges and various cased caddis flies (*Pycnocentrodes, Pycnocentria,* *Olinga*) were also among the most abundant taxa in the Waiwera River/Te Waiwhero at times. However, subsequent to 2004, the mudsnail *Potamopyrgyus* has consistently been the most abundant taxon at this site, along with the net-spinning caddis fly *Hydropsyche*, chironomid midges, segmented worms (Oligochaeta) and the cased caddis fly (*Pycnocentrodes*). MCI and SQMCI scores on five of the last six monitoring occasions have put the monitoring site in D-band of the NOF and below the national bottom line, while SQMCI scores have been in D-band on all of the last six occasions. Previous assessments concluded that the macroinvertebrate community in the Waiwera/Te Waiwhero catchment is impacted by periphyton and fine sediment accumulation.

Six species of indigenous freshwater fish have been recorded from the Waiwera River/Te Waiwhero catchment. Of these species, Tuna/longfin eels are defined as at risk, declining, and two are classified as threatened, nationally vulnerable (kanakana/lamprey, Pomahaka galaxias). The other species present (shortfin eel, upland bully and common bully) are classified as not threatened.

Brown trout are the only introduced fish collected from the Waiwera River/Te Waiwhero catchment. The Waiwera River/Te Waiwhero supports a locally important sport fishery which receives a relatively low level of angler effort.

Flows of 168-194 l/s would provide 80% habitat retention (relative to naturalised flows) for most macroinvertebrate taxa considered, although the mayfly *Deleatdium* which has historically been abundant in the Waiwera River/Te Waiwhero is predicted to have 80% habitat retention at just 76 l/s. Flows of between 118 and 175 l/s are predicted to retain 90% of the habitat available at the naturalised MALF for tuna/longfin eel life-stages while flows of 157 l/s are predicted to retain 90% of the habitat available at the naturalised MALF for Kanakana/lamprey. Flows of approximately 120 l/s are predicted to provide 90% habitat retention for adult non-migratory galaxias.

A flow of 143 l/s would retain 70% of adult trout habitat at the 7-d MALF, while a flow of 172 l/s would maintain 80%. For juvenile trout, flows of between 75 and 126 l/s would retain 70% of the habitat at the 7-d MALF, while flows of 112-157 l/s would maintain 80% of juvenile habitat at the 7-d MALF.

The current minimum flow of 280 l/s was 90% of the 7-d MALF based on the ORC (2006) report. However, the updated hydrological analysis of Lu (2023) suggests that the 7-d MALF is 231 l/s, suggesting that the current minimum flow is set at 121% of the 7-d MALF. This has been reflected in the flows in the Waiwera River/Te Waiwhero at Maws Farm being at or below the summer minimum flow 20% of the time (8 August 2015-23 August 2023). Flows have been at or below the winter minimum flow 4% of the time during winter months over the same period.

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). The small degree of hydrological alteration, along with the results of instream habitat modelling, indicate that the risk of adverse ecological outcomes arising from water abstraction is low. Therefore the observation that macroinvertebrate indices in the Waiwera River/Te Waiwhero at Maws Farm do not meet either the Land & Water Regional Plan (LWRP) objectives for the Lower Clutha FMU, nor the national bottom line, is unlikely to be a result of water abstraction, but rather reflects water and habitat quality, including the biomass of periphyton and fine sediment accumulation.

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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. Most MALF values reported here are calculated using flows from the irrigation season (October-April) only. This is to avoid the effect of winter low flows that may occur due to water being "locked up" in snow and ice in the upper catchment. However, if significant winter low flows do not occur, estimates of 7-d MALF calculated using data from the full hydrological year or from the irrigation season should be very similar.
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 Waiwera River/Te Waiwhero is a small river, which rises between the Wisp and Kaihiku Ranges in South Otago. The Waiwera/Te Waiwhero catchment is , with the upper catchment is dominated by sheep and beef farming, while dairy farming dominates much of the lower catchment. There are also several deer farms in the catchment.

The Waiwera River/Te Waiwhero catchment is within the Lower Clutha Rohe within the Clutha/Mata-Au Freshwater Management Unit (FMU). The current minimum flow and allocation in the Waiwera River/Te Waiwhero catchment was added to the Regional Plan: Water (RPW)by Plan Change 3C, which was notified on 13 December 2014 and became operative on 8 August 2015. Schedule 2A of the RPW specifies a minimum flow for primary allocation at the Waiwera at Maws Farm (Figure 1) of 280 l/s (1 October to 30 April) or 400 l/s (1 May to 30 September). Schedule 2A specifies that if the 280 l/s minimum flow is breached by taking, flow must return to 310 l/s before taking can recommence. The primary allocation limit specified for the Waiwera River/Te Waiwhero catchment in Schedule 2A is 150 l/s.

Water abstraction in the Waiwera River/Te Waiwhero catchment consists of takes for stock water, and dairy shed supply from the Kuriwao Stream, while there are takes from the Waiwera/Te Waiwhero downstream of the Kaihiku Stream for irrigation, stock water, and dairy shed supply.

Water quality in much of the Waiwera River/Te Waiwhero catchment is poor, with deposited fine sediment implicated in the poor ecological state of the catchment (Ozanne 2017).

1.1 Purpose of the report

The purpose of this report is to present information to inform water management decision-making in the Waiwera River/Te Waiwhero catchment. This includes hydrological information, data on aquatic values, application of instream habitat modelling to guide flow-setting processes, and consideration of the current state of the Waiwera River/Te Waiwhero River compared to the proposed objectives for the Lower Clutha Rohe set out in the proposed Otago Land and Water Regional Plan (LWRP).

2 Background information

2.1 Catchment description

The Waiwera River/Te Waiwhero River flows for approximately 98 km from from the Wisp and Kaihiku Ranges to enter the Clutha River/Mata-Au approximately 6 km downstream of Clydevale and 16 km upstream of Balclutha/Iwikatea. The catchment has a total area of 207 km^2 (Figure 1).

2.1.1 Climate

The climate within much of the Waiwera River/Te Waiwhero catchment is classified as 'cool-dry' (mean annual temperature <12°C, mean annual effective precipitation ≤500 mm). However, the upper reaches of the Kuriwao are classified as '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 across the catchment, with an annual median of up to 1,500 mm of rain falling in the higher elevation areas in the upper catchment, while median annual rainfall in the lower catchment is 650-700 mm (Figure 1).

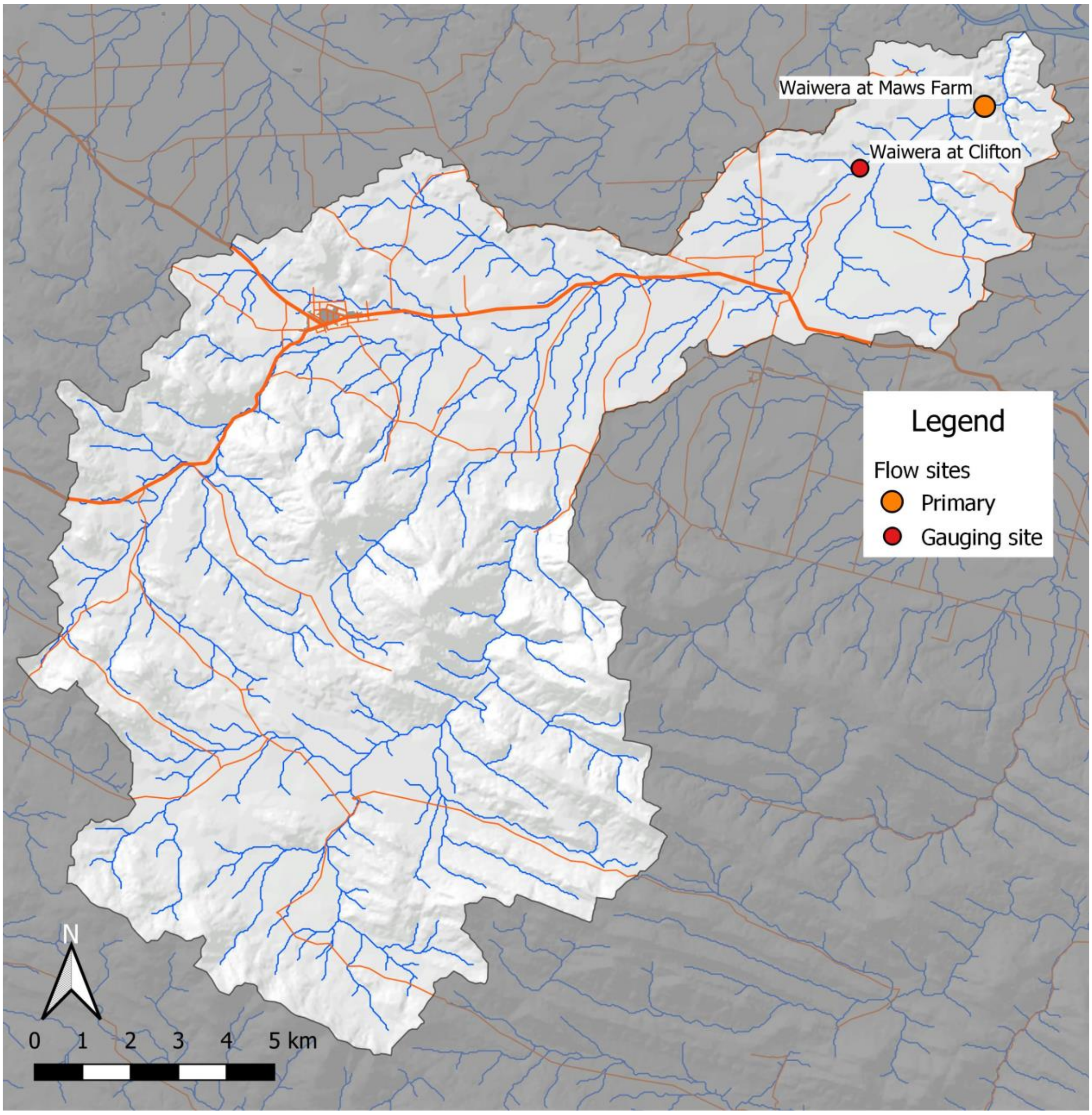

Figure 1 Map of the Waiwera River/Te Waiwhero catchment showing monitoring sites.

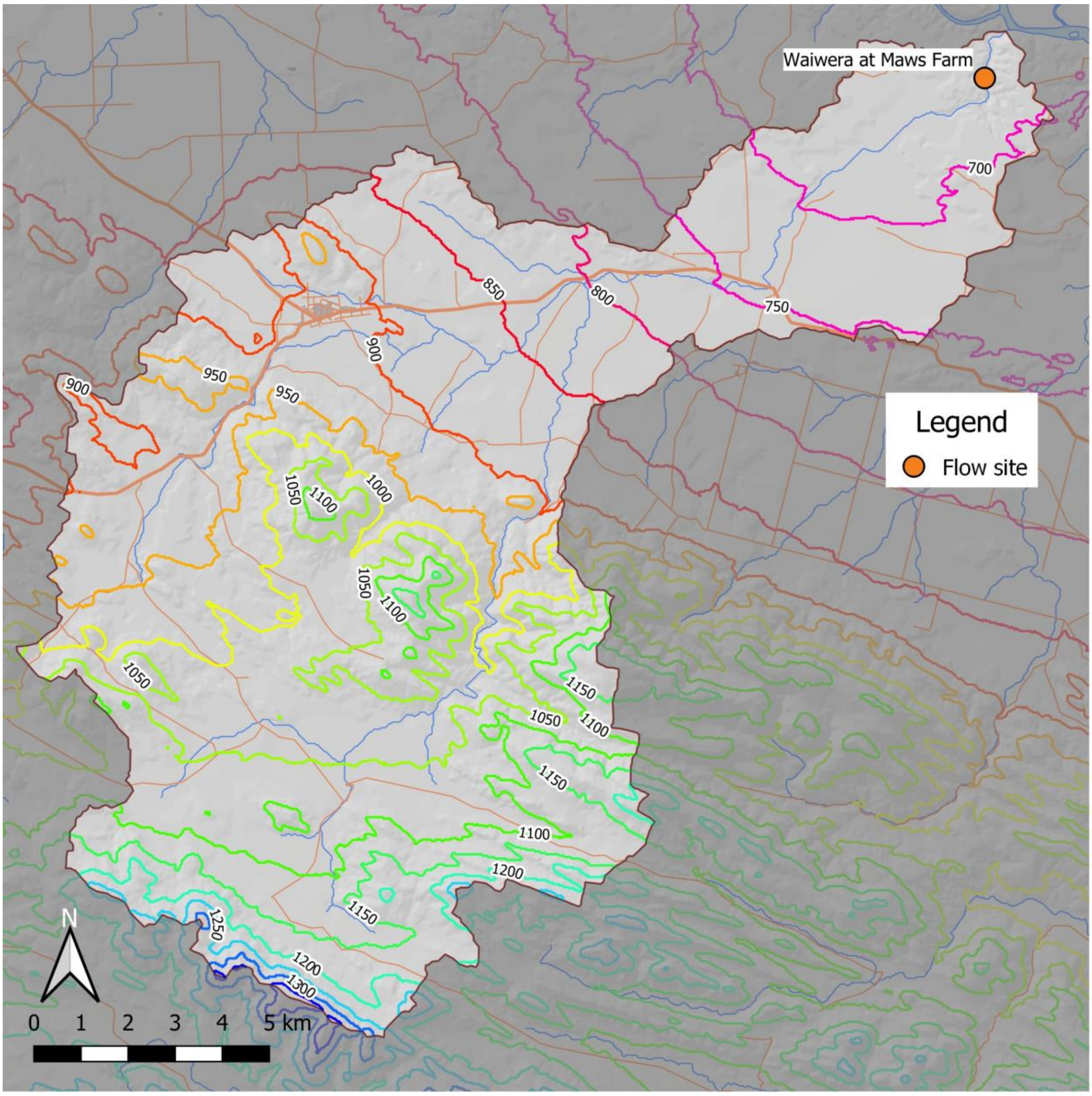

Figure 2 Distribution of rainfall (annual median rainfall) in the Waiwera River/Te Waiwhero catchment.

2.1.2 Geological setting

The geology of the Waiwera River/Te Waiwhero catchment is complex. The Southland Syncline and multiple faults (including the Hillfoot and Livingstone Faults) cross the catchment in a northwest-southeast direction (Turnbull & Allibone 2003). The basement rock in the catchment is composed of sandstones, siltstones, and mudstones of the Dun Mountain-Maitai, Murihiku and Caples (Schist) Terranes (Turnbull & Allibone 2003).

2.1.3 Vegetation and land use

Landcover in the Waiwera/Te Waiwhero catchment predominantly consists of high-producing grasslands, with areas of exotic forestry and low-producing grasslands in the middle reach, and small remnants of the historical tussock grasslands (Figure 3

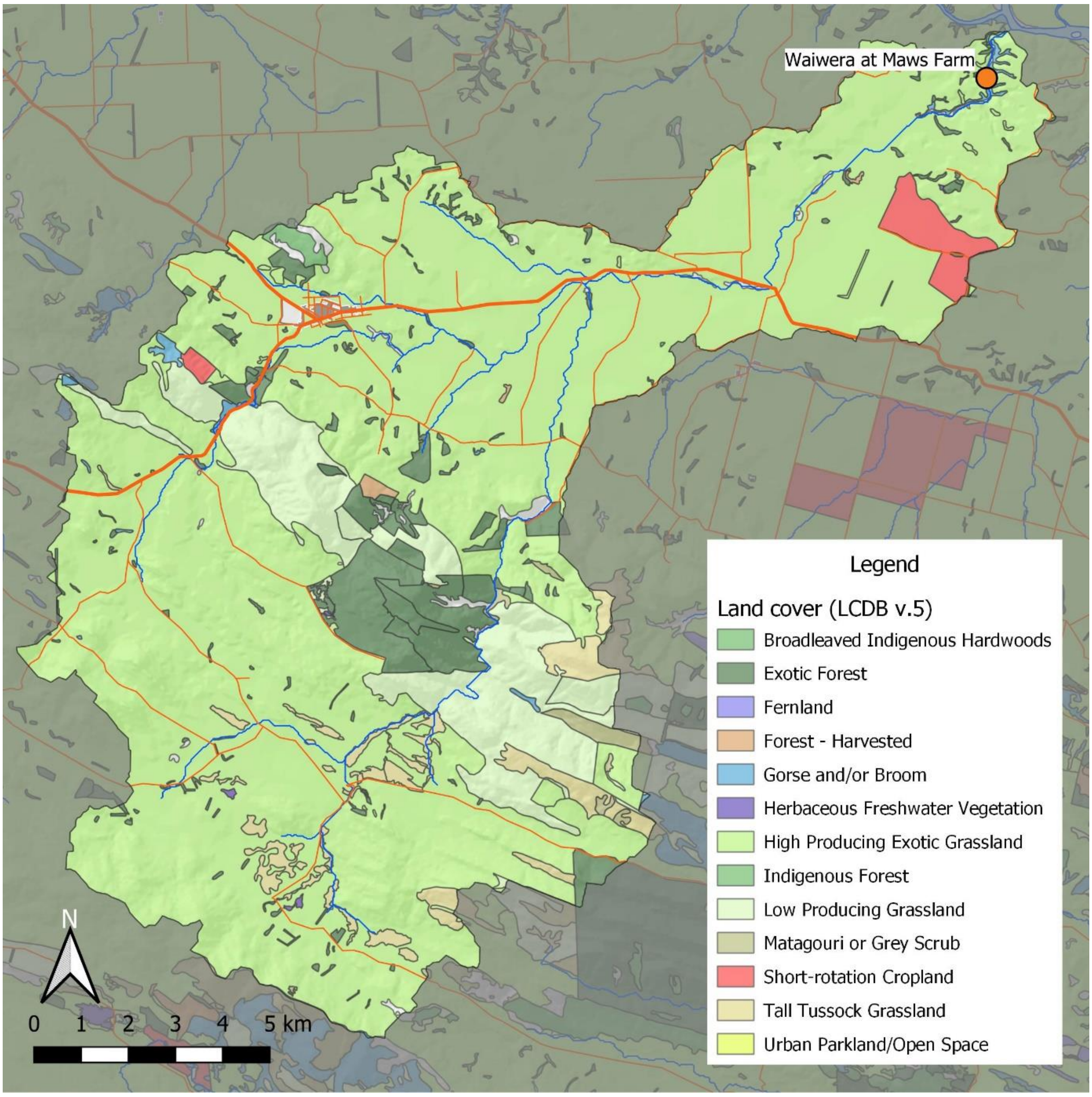

Figure 3). Land use in the upper catchment is dominated by sheep and beef farming, while dairy farming dominates much of the lower catchment (Figure 4). There are also several sheep farms and deer farms in the Waiwera River/Te Waiwhero catchment.

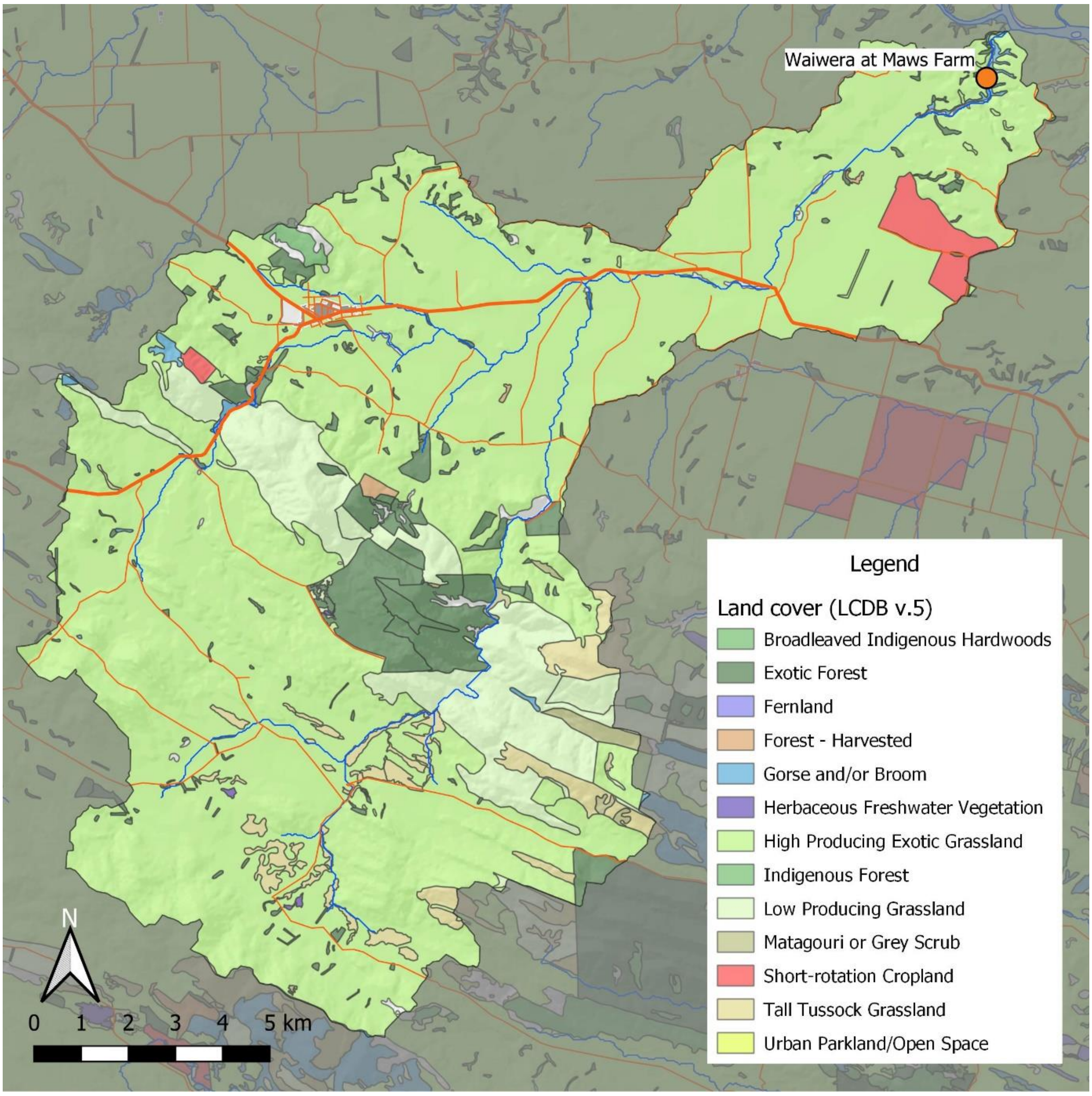

Figure 3 Land cover in the Waiwera River/Te Waiwhero catchment.

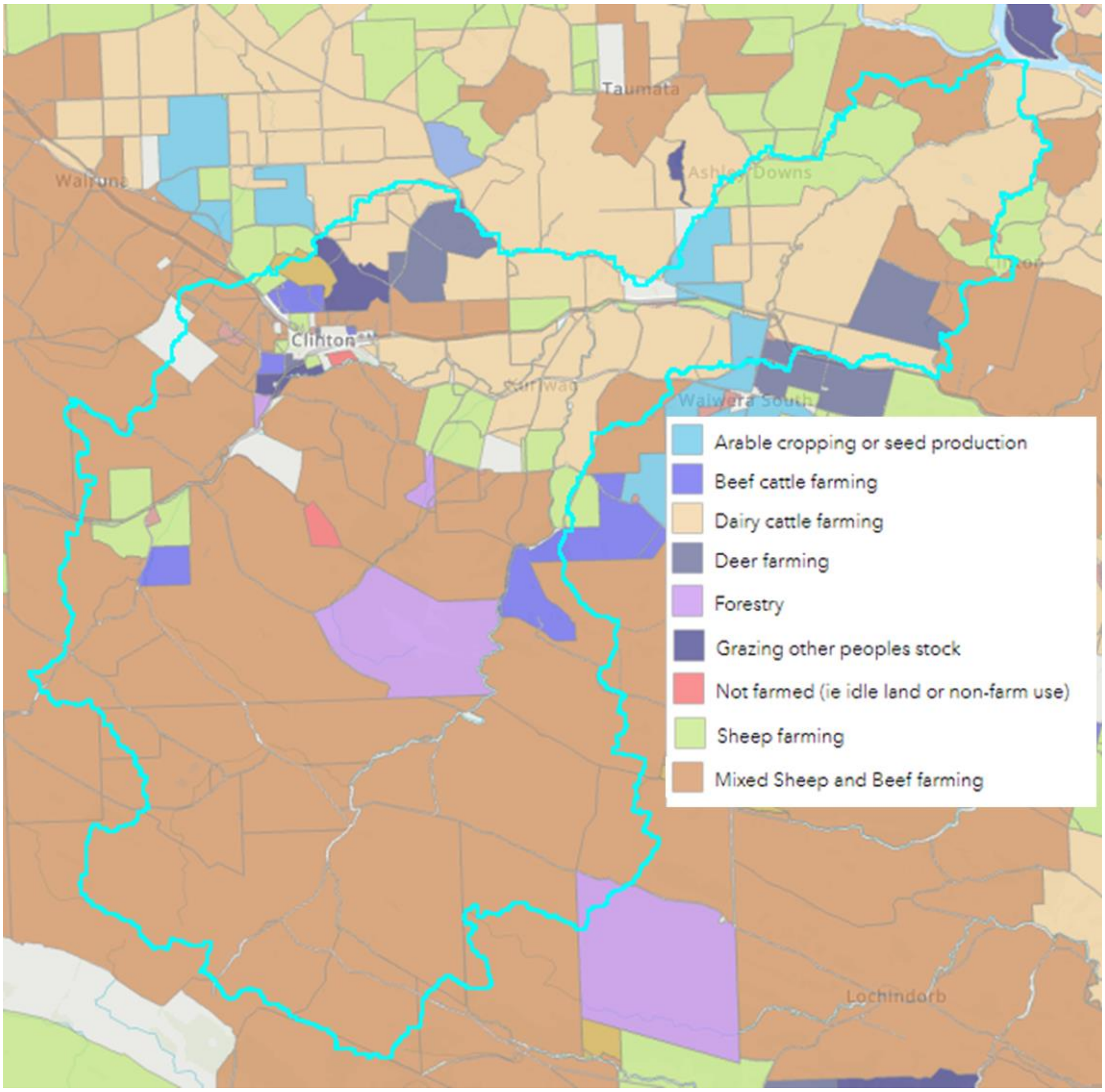

Figure 4 Farm types in the Waiwera River/Te Waiwhero catchment based on Agribase[1] (March 2023). Cyan outline is the Waiwera/Te Waiwhero catchment boundary.

[1] AgriBase, Spatially Maps Almost Every NZ Farm | AsureQuality

3 Regulatory setting

3.1 Regional Plan: Water (RPW)

The current minimum flow and allocation in the Waiwera River/Te Waiwhero catchment was added to the RPW by Plan Change 3C, which was notified on 13 December 2014 and became operative on 8 August 2015. Schedule 2A of the RPW specifies a minimum flow for primary allocation at the Waiwera at Maws Farm of 280 l/s (1 October to 30 April) or 400 l/s (1 May to 30 September). Schedule 2A specifies that if the 280 l/s minimum flow is breached by taking, flow must return to 310 l/s before taking can recommence.

The primary allocation limit specified for the Waiwera River/Te Waiwhero catchment in Schedule 2A is 150 l/s.

In addition, Schedule 2B of the RPW specifies a minimum flow for the first supplementary allocation block of 600 l/s at Maws Farm, with a supplementary allocation block size of 100 l/s. At the time of writing, the first supplementary allocation is 100 l/s (see Section 4.1.1).

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 Lower Clutha Rohe, which includes the Waiwera River/Te Waiwhero catchment. The baseline state and proposed attribute state targets, valid at the time of writing, are presented in **Error! Reference source not found.**.

Table 1 Baseline state and target attribute states for the state of the environment monitoring sites in the Waiwera catchment.

Attribute		Waiwera at Maws Farm		Waiwera at Clutha confluence u/s 1km	
		Baseline State	Target 2050	Baseline State	Target 2050
Periphyton Biomass (chlorophyll *a*)					
Periphyton TN		D	C		
Periphyton TP		D	C		
Ammonia - median		A	A		
Ammonia - 95th Percentile		A	A		
NNN - median		A (A - B)	A		
NNN - 95th percentile		B	A		
Suspended fine sediment		A	A		
E.Coli	% exceed 260 cfu/100 mL	D (C - D)	C		
	% exceed 540 cfu/100 mL	C (C - D)	C		
	Median	D	C		
	Q95	D	C		
Fish IBI					
MCI				D	C
ASPM				C (D - C)	C
DRP-median		D	A		
DRP Q95		C (C - D)	A		

4 Hydrology

4.1 Flow statistics

A continuous flow recorder has been installed in the Waiwera River/Te Waiwhero River at Maws Farm since 21 April 2010. This site is located approximately 2.4 km upstream of where it enters the Clutha River/Mata-Au.

Lu (2023) used available flow data for the Waiwera River/Te Waiwhero River at Maws Farm and water use data to produce a naturalised flow time-series for the period 1 July 2015 to 24 June 2023. The flow statistics based on the analysis of Lu (2023) are summarised in Table 2.

The naturalised 7-d MALF calculated for the Waiwera River/Te Waiwhero River at Maws Farm by Lu (2023) is considerably lower (-25%) than that estimated by ORC (2006). The estimates presented in ORC (2006) were based on a limited number of gaugings in the Waiwera at Clifton site and correlation with the nearby flow recorder at Waipahi at Waipahi.

Table 2 Flow statistics for the Waiwera River/Te Waiwhero River at Maws Farm from Lu (2023).

		Flow statistics (l/s)		
Site		**Mean**	**Median**	**7d MALF (Jul-Jun)**
Waiwera River at Maws Farm	Naturalised flows	2,285	1,126	231
	Observed flows	2,280	1,124	225
Waiwera at Clifton (gauging)	ORC 2006	3,100		310

The average number of events per year that exceed three times the median flow (FRE3) in the Waiwera River/Te Waiwhero River at Maws Farm is 7.1 events per year (Lu 2023).

4.1.1 Water allocation

Primary allocation

Five takes from the Waiwera River/Te Waiwhero catchment have a primary allocation of 148.7 l/s (Table 3). Two of these are from the Kuriwao Stream (4.2 l/s combined maximum rate of take), while the three other takes are from the mainstem of the Waiwera River/Te Waiwhero (combined maximum rate of take = 144.5 l/s). Thus, the current primary allocation in the Waiwera/Te Waiwhero catchment is 148.7 l/s.

Supplementary Block 1

There is one resource consent to take up to 100 l/s of supplementary water from the Waiwera River/Te Waiwhero when flows exceed 600 l/s (Table 3).

4.1.2 Seasonal water use

Water use in the Waiwera River/Te Waiwhero catchment is typically highest between December and February, with low water use between April and November (Figure 5). On average, water use is much lower than the consented allocation (Figure 5), with the maximum instantaneous rate of take recorded between 2010 and 2023 being less than 60 l/s (Lu 2023).

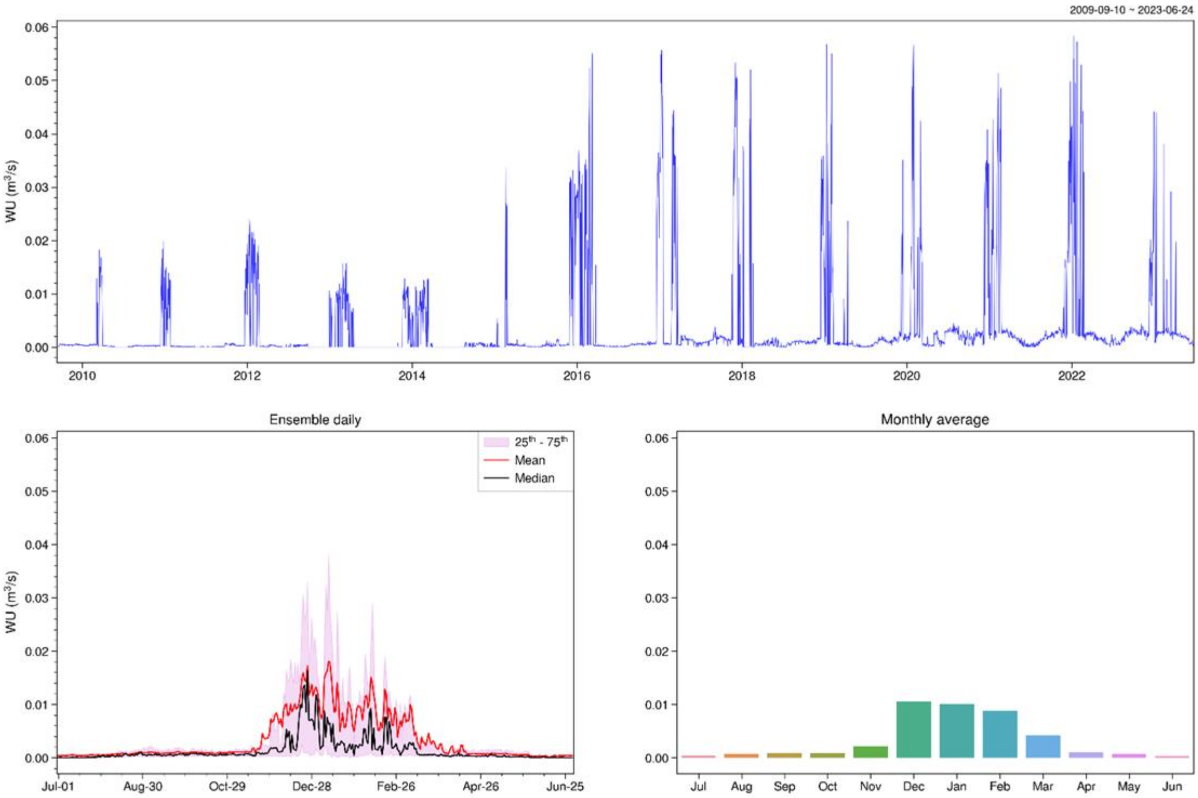

Figure 5 Water abstraction for the Waiwera River/Te Waiwhero River catchment. Top plot is a timeseries of water use. The lower, left plot presents the mean, median and inter-quartile range in daily water use across the hydrological year. Lower right plot presents the monthly mean water use. Reproduced from Lu (2023

Table 3 Active resource consents in the Waiwera River/Te Waiwhero catchment.

Consent Number	Consent Holder	Max rate (l/s)	Min flow (l/s)	Activity
Primary				
RM14.032.01.V1	Athelstane Ltd.	1.5	280	Stock water, dairy shed
RM13.079.01	Anderson Twin Rivers Ltd.	2.7	280	Stock water
RM13.480.V1	Westridge Farm Ltd.	20.5	280	Irrigation
RM13.278.01	PJ & AM Neame Limited	44	280	Irrigation, stock water and dairy shed
2003.818.V1	Dogterom Geddes Ltd.	80	280	Irrigation
Supplementary Block 1				
RM13.480.V1	Westridge Farm Ltd.	100	600	Irrigation

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 Waiwera River/Te Waiwhero 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 this 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 Waiwera River/Te Waiwhero at Maws Farm between April 2010 and April 2023 are presented in Figure 6 and Figure 7. Water temperatures in the Waiwera River/Te Waiwhero exceeded acute (73% of years) and chronic thermal criteria (53% of years) for brown trout (Table 4). Of the indigenous species present in the Waiwera River/Te Waiwhero catchment, temperatures exceeded acute criteria for the common mayfly *Deleatidium*, common bully, longfin and shortfin eels and the sand-cased caddis fly *Pycnocentria* (Table 4).

These data suggest that at times the thermal environment of the Waiwera River/Te Waiwhero is unsuitable at times for several of the indigenous and introduced fish species found in the catchment.

Table 4 Number of exceedances of thermal criteria in the Waiwera River/Te Waiwhero at Maws Farm between April 2010 and April 2023. This analysis is based on hydrological years (July-June).

Thermal criteria	Number of exceedances (days/year)		Years with no exceedances	Years with exceedances (% of years)
	Mean	Max		
Brown trout acute (>24.6°C)	2.8	23	11	27%
Deleatidium acute (21°C)	15.1	58	2	87%
Common bully acute (22°C)	9.6	47	4	73%
Longfin eel, *Pycnocentria* acute (23°C)	5.9	35	7	53%
Aoteapsyche acute (24°C)	3.4	27	11	27%
Shortfin eel acute(26°C)	1.3	13	11	27%
Brown trout chronic (>19.6°C)	7.3	44	8	47%

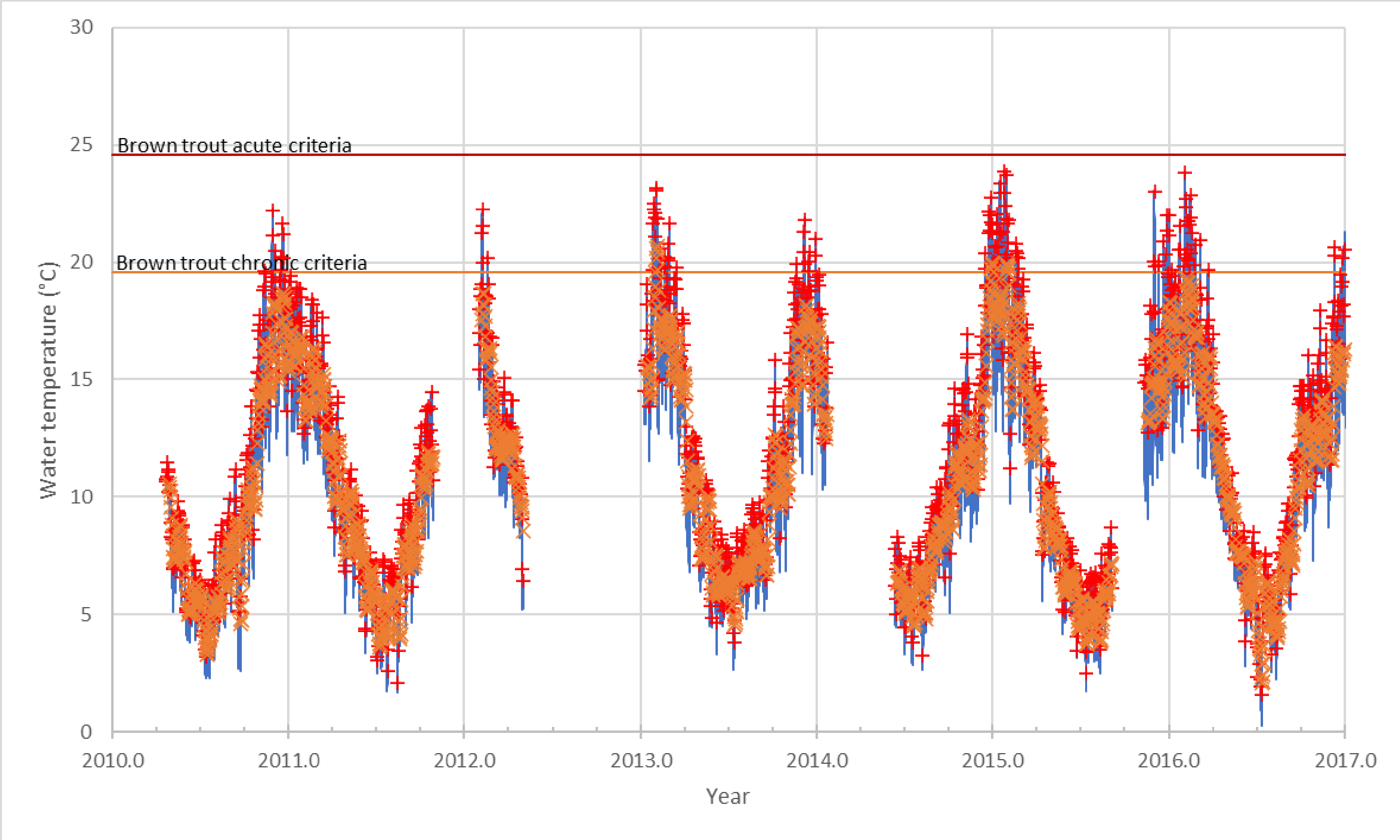

Figure 6 Water temperature in the Waiwera River/Te Waiwhero at Maws Farm between April 2010 and January 2017. Red crosses (+) are the maximum 2-h average water temperature for comparison with acute thermal criteria. Orange crosses (x) are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.

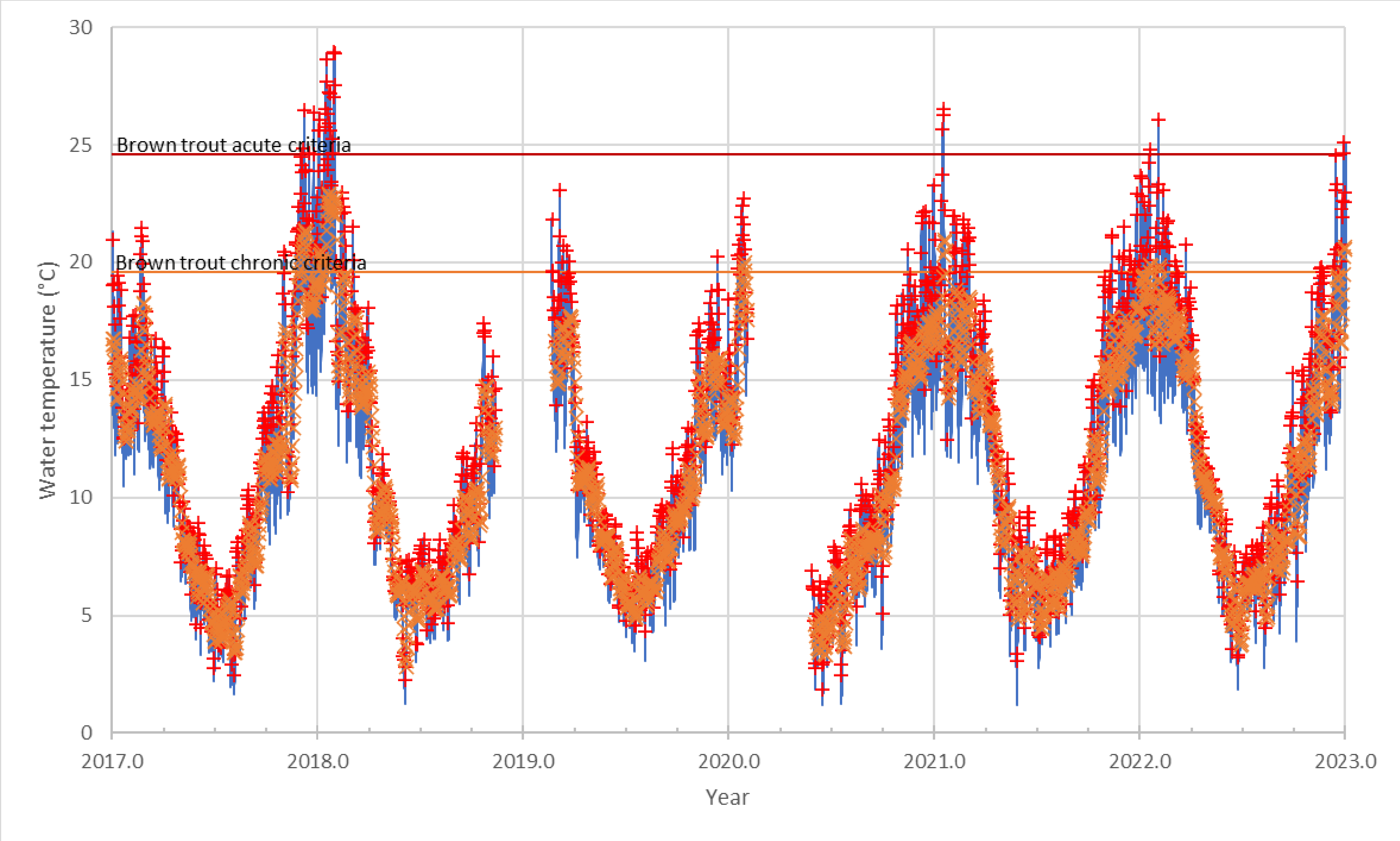

Figure 7 Water temperature in the Waiwera River/Te Waiwhero River at Maws Farm between January 2017 and April 2023. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red circles are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.

6 The aquatic ecosystem of the Waiwera River/Te Waiwhero 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).

Periphyton cover at twelve sites in the Waiwera catchment was undertaken in March 2017 (following the RAM-2 protocol of Biggs & Kilroy; Ozanne 2017). The composition of the periphyton community varied markedly between sites, although the periphyton at many sites was dominated by thin black-brown films, while long filamentous algae (>20 mm) exceeded 30% cover at three sites on the mainstem of the Waiwera River/Te Waiwhero (Owaka Valley Road, downstream of Robertson Road Bridge and Maws Farm), while cover by short filamentous algae (<20 mm) exceeded 30% at three sites on the mainstem (Waiwera Gorge Road, Hillfoot Road and Maws Farm).

Table 5 Periphyton cover in the Waiwera River/Te Waiwhero catchment in March 2017. From Ozanne (2017)

Site	Thin mat/film (<0.5 mm)			Medium mat (0.5-3 mm)			Thick mat (>3 mm)		Short filamentous (<20 mm)		Long filamentous (>20 mm)		Total periphyton cover
	Green	Light brown	Black/dark brown	Green	Light brown	Black/dark brown	Green/ light brown	Black/dark brown	Green	Brown/ reddish	Green	Brown/ reddish	
Awakia Stream at Hillfoot Road	0	0	6	0	0	2	0	0	2	1	0	1	10
Kuriwao Stream at Hillfoot Road	0	0	1	0	1	0	0	0	0	1	1	0	4
Kuriwao Stream at Old Coach Road	0	0	11	0	0	0	0	1	0	5	0	1	18
Kuriwao Stream upstream of Kuriwao Siding Rd	0	0	1	0	0	3	0	6	1	0	5	0	15
Tributary at Quarry Road	0	0	0	0	0	0	0	0	0	0	0	0	0
Waiwera River at Kuriwao Siding Road	0	0	75	0	1	7	0	0	1	0	0	0	84
Waiwera River at Maws Farm	0	0	1	0	0	0	0	0	0	51	0	35	87
Waiwera River at Owaka Valley Road	0	0	14	0	9	1	0	0	8	9	38	0	78
Waiwera River downstream of Robertson Rd Bridge	0	0	43	0	2	0	0	0	8	0	31	0	84
Waiwera River at Waiwera Gorge Rd	0	3	0	0	0	2	0	0	3	57	4	19	87
Waiwera River near Clifton	0	0	46	0	3	0	0	0	1	14	0	1	65
Waiwera River at Hillfoot Road	0	32	0	0	7	1	0	0	22	14	2	1	80
Waiwera River at SH1 bridge	0	0	47	0	2	10	0	2	11	0	5	0	76
Waiwera River tributary at Blaikie Road	0	0	0	0	0	0	0	0	0	0	0	0	0

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).

Prior to 2004, the common mayfly *Deleatidium* was the most abundant macroinvertebrate taxa collected at the monitoring site in the Waiwera River/Te Waiwhero catchment (Waiwera River 1km upstream Clutha confluence). The net-spinning caddis fly *Hydropsyche*, chironomid midges and various cased caddis flies (*Pycnocentrodes, Pycnocentria, Olinga*) were also among the most abundant taxa in the Waiwera River/Te Waiwhero at times. However, subsequent to 2004, the mudsnail *Potamopyrgyus* has consistently been the most abundant taxon at this site, along with the net-spinning caddis fly *Hydropsyche*, chironomid midges, segmented worms (Oligochaeta) and the cased caddis fly (*Pycnocentrodes*) were among the most abundant macroinvertebrate taxa present.

MCI scores for the Waiwera River 1km upstream of the Clutha confluence site (Range: 77-106, mean = 89.6, N=14), put this site in D-band of the NOF and below the national bottom line (Figure 8). SQMCI scores for this site have been highly variable over the last 15 years but have averaged D-band (Figure 8).

These results suggest that the macroinvertebrate community has deteriorated in the Waiwera since the early 2000's. Ozanne (2017) concluded that *"fine sediment accumulation seems to be the cause of dramatic losses in abundance and diversity of macroinvertebrate communities and fish populations in the Waiwera catchment, particularly the mainstem Waiwera*".

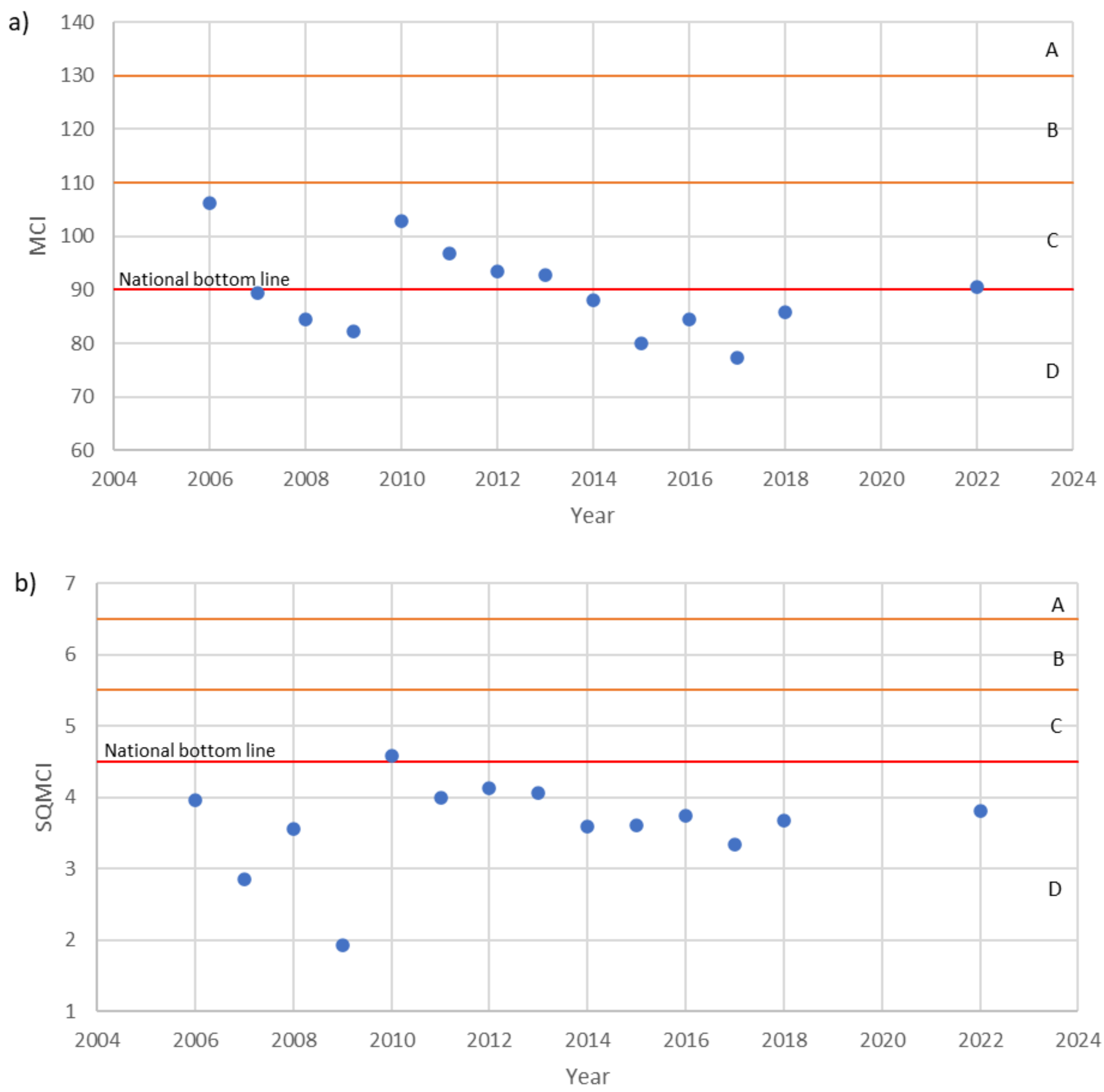

Figure 8 Macroinvertebrate indices for the Waiwera River/Te Waiwhero River at Maws Farm between 2007 and 2021. a) Macroinvertebrate community index (MCI), b) semi-quantitative MCI (SQMCI). Each plot includes thresholds for attribute states based on Table 14 of the National Objectives Framework.

6.3 Fish

6.3.1 Indigenous fish

Six species of indigenous freshwater fish have been recorded from the Waiwera River/Te Waiwhero catchment (Table 6). Of these species, longfin eels are defined as at risk, declining, and two of these species are classified as threatened, nationally vulnerable (lamprey, Pomahaka galaxias) Table 6).

There is some uncertainty around the galaxiid species that are present in the Waiwera/Te Waiwhero catchment, with records of Gollum galaxias, Clutha flathead galaxias and Pomahaka galaxias from the Waiwera/Te Waiwhero in the NZ Freshwater Fish Database. Genetic analyses by Campbell et al. (2022) from the upper reaches of the Waipahi and Kaihiku catchments classified these populations as being Pomahaka galaxias, and this is likely the case in the Waiwera/Te Waiwhero catchment as well.

6.3.2 Introduced fish

Brown trout are the only introduced fish collected from the Waiwera River/Te Waiwhero catchment (Table 6).

The Waiwera River/Te Waiwhero supports a locally important sport fishery (Otago Fish & Game Council 2015). Table 7 presents angler effort in the Waiwera River/Te Waiwhero recorded during National Angler Surveys conducted in 1994/95, 2007/08 and 2014/15. Overall angler usage is relatively low, with no effort recorded in the 2014/15 season (Table 7).

Table 6 Fish species recorded from the Waiwera River/Te Waiwhero catchment.

Family	Common name	Species	Threat classification
Anguillidae	Shortfin eel	*Anguilla australis*	Not threatened
	Longfin eel	*Anguilla dieffenbachii*	Declining
Eleotridae	Upland bully	*Gobiomorphus breviceps*	Not threatened
	Common bully	*Gobiomorphus cotidianus*	Not threatened
Geotriidae	Lamprey	*Geotria australis*	Nationally vulnerable
Galaxiidae	Pomahaka galaxias	*Galaxias* "Pomahaka"	Nationally vulnerable
Salmonidae	Brown trout	*Salmo trutta*	Introduced and naturalised

Table 7 Angler effort (angler days) on the Waiwera River/Te Waiwhero River based on the National Angler Survey (Unwin, 2016)

	National Angler Survey			
Catchment	**1994/95**	**2001/02**	**2007/08**	**2014/15**
Waiwera River/Te Waiwhero	110 ± 90	320 ± 250	60 ± 60	-

6.4 Current ecological state

The current minimum flow and allocation in the Waiwera River/Te Waiwhero catchment was added to the RPW by Plan Change 3C, which became operative on 8 August 2015. Thus, the current minimum flow and allocation limit have been in effect for several years and is reflected in the current state of the Waiwera River/Te Waiwhero River. Therefore, comparison of the current state of the Waiwera River/Te Waiwhero with objectives for the Lower Clutha 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 Lower Clutha FMU include the following narrative objectives: *"Freshwater bodies within the Lower Clutha 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 **Error! R eference source not found.** below.

6.4.1 Ecosystem health

In addition to the ecosystem health and human contact values identified in Table 1, 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 1. Attributes for natural form and character and threatened species within the Lower Clutha FMU are under development, so it is not possible to consider the current state of the Waiwera River/Te Waiwhero catchment relative to these attributes.

Table 8 presents the current attribute state for the Maws Farm monitoring site and compares the current state to the proposed target attribute state for the Lower Clutha FMU. Attributes for Ecosystem Health – Aquatic life did not meet the target state for macroinvertebrate attributes (Table 1). Periphyton was not able to be assessed, as periphyton is not monitored in the Waiwera/Te Waiwhero catchment. Fish communities were assessed as being in C-band, consistent with a fish community of low integrity (Table 13 of the NOF).

Both macroinvertebrate indices considered were below the national bottom line. The results of long-term sampling suggest that the macroinvertebrate community has deteriorated in the Waiwera/Te Waiwhero since the early 2000's, likely as a result of fine sediment deposition, as per the conclusions of Ozanne (2017). The adverse effects of sediment are well documented (Matthaei et al. 2006; Niyogi et al. 2007; Townsend et al. 2008) and it can interact with other stressors.

6.4.2 Water quality

Concentrations of ammoniacal nitrogen and nitrate-nitrite nitrogen in the Waiwera River/Te Waiwhero at Maws Farm were in B-band (Table 8). However, the attribute tables for ammoniacal nitrogen (Table 5 of the NOF) and nitrate nitrogen (Table 6 of the NOF) are focussed on the toxic effects of these substances, rather than their contribution to the risk of periphyton proliferation. The nitrate-nitrite nitrogen concentrations observed in the Waiwera River/Te Waiwhero at Maws Farm exceed levels that are expected to be associated with an elevated risk of periphyton reaching nuisance levels, even in systems with short accrual times (Ozanne 2017; Snelder 2023).

Dissolved reactive phosphorus and *E. coli* concentrations in the Waiwera River/Te Waiwhero were in D-band (Table 8). These results are consistent with the findings of a previous catchment water quality study that water quality in the Waiwera River/Te Waiwhero catchment is generally degraded (Ozanne 2017).

Water allocation is not expected to directly affect many of the water quality attributes in the Waiwera River/Te Waiwhero other than in its potential to support irrigated land uses that may support higher stocking rates. However, water abstraction may interact with water quality to increase the risk of adverse ecological outcomes in the Waiwera/Te Waiwhero (see Section 6.4.3).

Table 8 Comparison of the current attribute state at two sites in the Waiwera River/Te Waiwhero based on State of the Environment data collected between 1 July 2017 and 30 June 2022 (Ozanne, Borges & Levy, 2023).

Value	Attribute	Waiwera at Maws Farm			Waiwera at Clutha confluence u/s 1 km		
		Baseline attribute state	Target attribute state 2050	Current state	Baseline attribute state	Target attribute state 2050	Current state
EH - Aquatic life:	Periphyton (trophic state) (chlorophyll *a*)			Not able to be assessed			
	Fish index of biotic integrity						C Mean (5-y): 25.2
	Macroinvertebrate Community Index (MCI) score				D	C	D* 5-y median: 83.6
	Quantitative Macroinvertebrate Community Index (QMCI) score						D*† 5-y median: 3.64*
	Macroinvertebrate Average Score Per Metric (ASPM)				C (D – C)	C	
EH – Water quality	Ammonia (toxicity)	A	A	B Median: 0.008 Annual max: 0.116			
	Nitrate (toxicity)	A (A-B)	A	B Median: 0.980 95th %: 3.020			
	Dissolved oxygen						
	Suspended fine sediment - Visual clarity	A	A	A 1.73 m			
	Dissolved reactive phosphorus	C/D (C/D – C)	B	D Median: 0.022 95th %: 0.061			
EH - Habitat	Deposited fine sediment (% cover)		A	Not able to be determined			
EH – Ecological processes	Ecosystem metabolism (both gross primary production and ecosystem respiration)		C	Not able to be determined			
Human contact	*Escherichia coli*	D	C	D			
	Median	D (C - D)	C	248			
	95th percent	C (C - D)	C	1,634			
	% >260	D	C	46%			
	% >540	D	C	22%			
	Escherichia coli (E. coli) (primary contact sites) - 95th percentile	D	A	D 95th percent: 1,634			
	Suspended fine sediment - Visual clarity (metres)	A	A	A 1.73 m			

* Based on the 5 most recent annual values (2015-2018, 2022), as this site wasn't sampled in 2019-2021

† 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 Waiwera River/Te Waiwhero catchment with the target attribute state in the proposed LWRP indicates that the current state for many attributes is likely to not meet the target attribute state for the Lower Clutha FMU (Table 1).

Elevated nutrient concentrations are expected to enhance the risk of periphyton proliferation and the results of the catchment survey in 2017 suggests that periphyton cover exceeds guideline levels. Water abstraction may enhance the risk and magnitude of these exceedances. 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) and enhanced rates of cell division. However, such effects are expected to be minor in the Waiwera River/Te Waiwhero River due to the low abstraction pressure. Analysis by Lu (2023) shows that the maximum recorded water use was less than 60 l/s, despite primary allocation being close to the allocation limit of 150 l/s (see Figure 5). Thus, whilst the Schedule 2A allocation limit represents a relatively high proportion of the 7-d MALF (being approximately 65% of the naturalised 7-d MALF), the actual recorded water use in the Waiwera/Te Waiwhero catchment is substantially lower (25% of the naturalised 7-d MALF).

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. However, 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 could be 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 Waiwera River/Te Waiwhero catchment.

7 Instream Habitat Assessment

7.1 Instream habitat modelling in Waiwera River/Te Waiwhero

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 NIWA in 2003-2004 (Jowett 2004) for a reach in the gorge in the lower reaches of the Waiwera River/Te Waiwhero. The survey site was surveyed at a flow of 290 l/s, with calibration surveys at 1,090 l/s and 3,600 l/s (Jowett 2004). Habitat mapping at the survey flow classified the reach as 15% pool, 41% run and 44% riffle habitats at the survey flow (Jowett 2004).

7.1.1 Habitat preferences and suitability curves

Habitat suitability curves (HSC) for a range of organisms present in the Waiwera River/Te Waiwhero catchment were modelled (Table 9) to consider a wide range of potential effects of flow regime changes in the Waiwera River/Te Waiwhero – from changes in the cover and type of periphyton, to changes in the availability of macroinvertebrate prey, to changes in the habitat for fish.

Table 9 Habitat suitability curves used in instream habitat modelling in the Waiwera River/Te Waiwhero River.

Group	HSC name	HSC source
Periphyton	Cyanobacteria (Phormidium[2])	Ex Heath et al. (2013)
	Diatoms	unpublished NIWA data
	Long filamentous	unpublished NIWA data
	Short filamentous	unpublished NIWA data
Macroinvertebrates	Food producing	Waters (1976)
	Benthic Invertebrate Density	
	Mayfly nymph (*Deleatidium*)	Jowett (1991)
	Net-spinning caddis fly (*Aoteapsyche*)[3]	Jowett (1991)
	Sand-cased caddis fly (*Pycnocentrodes*)	Jowett (1991)
Indigenous fish	Tuna/longfin eel (>300 mm)	Jellyman et al. (2003)
	Tuna/longfin eel (<300 mm)	Jellyman et al. (2003)
	Tuna/longfin eel (>300 mm)	Jowett & Richardson (2008)
	Tuna/longfin eel (<300 mm)	Jowett & Richardson (2008)
	Upland bully	Jowett & Richardson (2008)
	Common bully	Jowett & Richardson (2008)
	Flathead galaxias adult	Jowett & Richardson (2008)
	Flathead galaxias juvenile	Jowett & Richardson (2008)
	Roundhead galaxias adult	Jowett & Richardson (2008)
	Roundhead galaxias juvenile	Jowett & Richardson (2008)
	Juvenile Kanakana/lamprey	Jellyman & Glova (2002)
	Kanakana/lamprey	Jowett & Richardson (2008)
Sports fish	Brown trout adult	Hayes & Jowett (1994)
	Brown trout (< 100 mm)	Jowett & Richardson 2008
	Brown trout yearling	Raleigh *et al.* (1986)
	Brown trout fry to 15 cm	Raleigh *et al.* (1986)
	Brown trout yearling	Raleigh *et al.* (1986)
	Brown trout fry	Bovee (1978)
	Brown trout spawning*	Shirvell & Dungey (1983)

* Brown trout spawning considered, but not presented as the lack of suitable substrate meant that no spawning habitat was predicted within the modelled reach

[2] The benthic cyanobacterium formerly known as *Phormidium* is now classified as *Microcoleus*,. However, the HSC is referred to as Cyanobacteria (Phormidium) for consistency with the original source

[3] 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 Waiwera River/Te Waiwhero are presented in Figure 9.

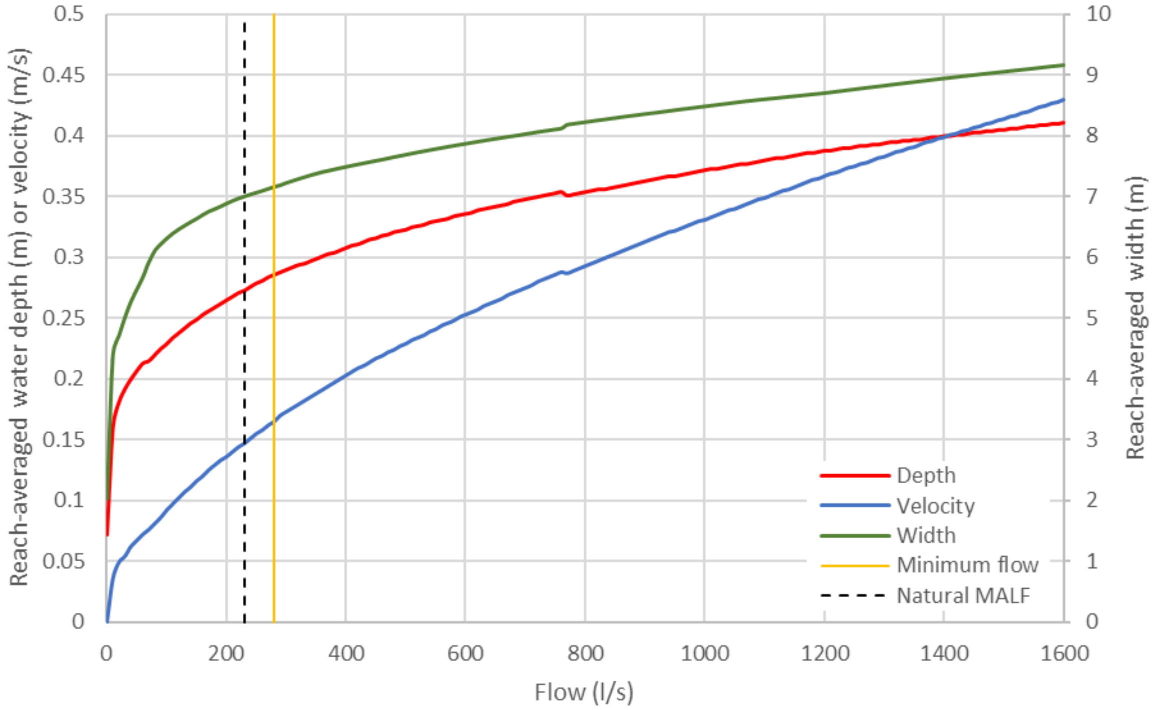

Figure 9 Changes in mean channel width, mean water depth and mean water velocity with changes in flow in the survey reach of the Waiwera River/Te Waiwhero River.

7.1.3 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 150 l/s (Figure 10). Habitat quality for native diatoms was predicted to be low but increase with increasing flow across the modelled flow range (Figure 10). Habitat quality for short filamentous algae was predicted to increase with increasing flows up to approximately 1,100 l/s before stabilising and dropping as flows increase above 1,200 l/s, while habitat quality for long filamentous algae was predicted to be highest at 10 l/s and to decline with increasing flows across the modelled flow range (Figure 10).

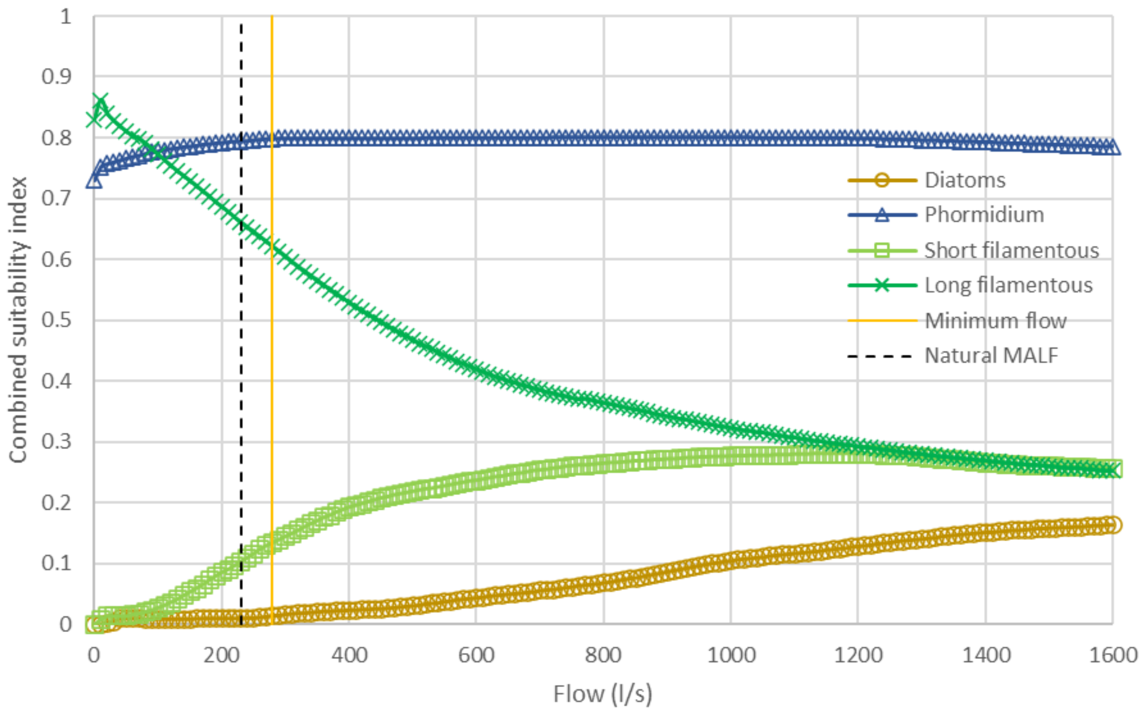

Figure 10 Variation in instream habitat quality (as measured by combined suitabilty index) for periphyton relative to flow in the survey reach of the Waiwera River/Te Waiwhero River.

Table 10 Flow requirements for periphyton habitat in the Waiwera River/Te Waiwhero 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 280 l/s
		120%	150%	200%	300%	
Cyanobacteria (*Phormidium*)	720-1,030	-	-	-	-	101%
Diatoms	>1,600	-	-	-	-	150%
Short filamentous	1,130-1,210	-	-	-	-	130%
Long filamentous	10	77	-	-	-	94%

7.1.4 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 was the most consistently abundant macroinvertebrates in the Waiwera River/Te Waiwhero prior to 2004, 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 among the most consistently abundant in the Waiwera River/Te Waiwhero. The stony-cased caddis *Pycnocentrodes* can be amongst the most common macroinvertebrate taxa in moderate to slow-moving streams and is abundant in the Waiwera River/Te Waiwhero at times. It is included in habitat modelling to represent taxa that prefer slower-flowing habitats.

Habitat for the common mayfly *Deleatidium* increased with increasing flow to 900 l/s, with habitat predicted to decline as flows increased above 960 l/s (Figure 11). Food producing habitat, benthic invertebrate density and habitat for all other macroinvertebrate taxa increased with flow across the modelled flow range (Figure 11). Flows required to achieve different levels of habitat retention for each of the macroinvertebrate taxa are presented in Table 11.

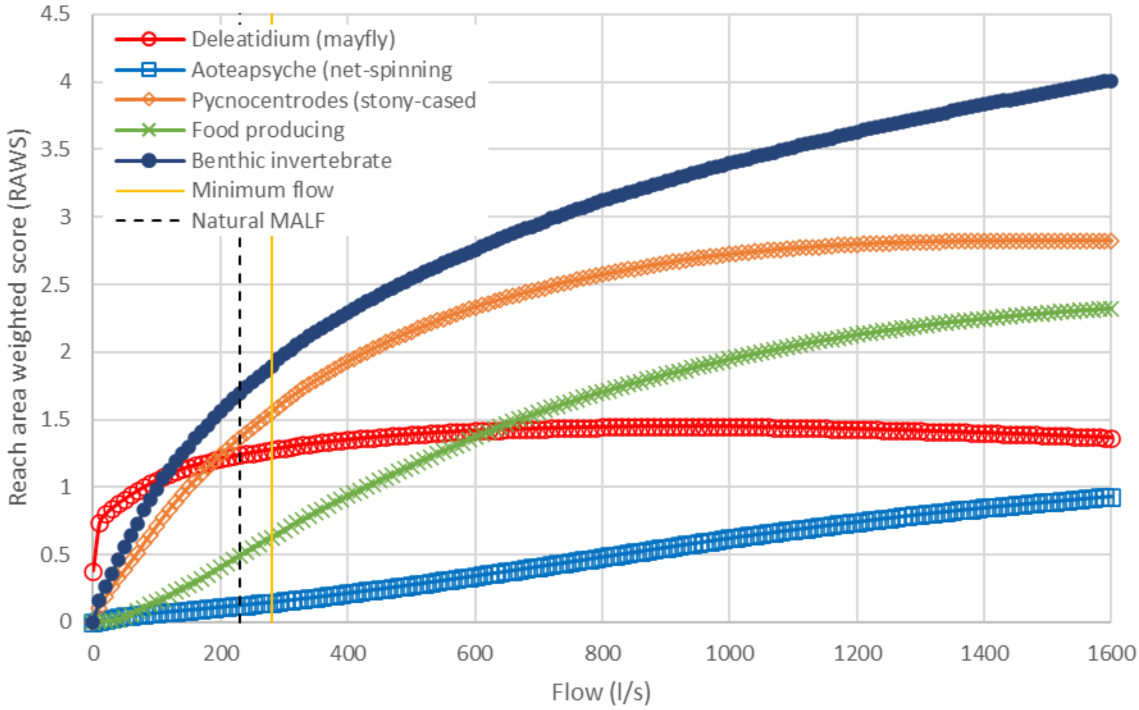

Figure 11 Variation in instream habitat for common macroinvertebrates relative to flow in the survey reach of the Waiwera River/Te Waiwhero River.

Table 11 Flow requirements for macroinvertebrate habitat in the Waiwera River/Te Waiwhero 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 280 l/s
		60%	70%	80%	90%	
Food producing habitat	>1,600	159	177	195	213	128%
Benthic invertebrate density	>1,600	104	130	159	193	112%
Common mayfly *Deleatidium*	900-960	11	36	76	128	103%
Net-spinning caddis fly (*Aoteapsyche*)	>1,600	117	145	176	203	119%
Cased caddis fly (*Pycnocentrodes*)	>1,600	117	142	168	197	114%

7.1.5 Indigenous fish

Habitat for tuna/longfin eel (<300 mm) is predicted by the Jellyman *et al.* (2003) HSC to increase across the modelled flow range while the Jowett & Richardson (2008) HSC predicted that habitat for small tuna would increase to 920 l/s before declining, and habitat for large tuna would increase to 1,120-1,140 l/s before declining at higher flows (Figure 11). Habitat for juvenile lamprey and adult lamprey increase across the modelled flow range (Figure 11).

Habitat preferences for two groups of non-migratory galaxias (flathead and roundhead) were used to consider the habitat requirement of the non-migratory galaxias present in the Waiwera/Te Waiwhero. Whilst the HSC used in these analyses are not for the exact species present in the Waiwera/Te Waiwhero, they provide an idea of a likely range in which the habitat requirements of Pomahaka galaxias fall within. Habitat for adult flathead galaxias is predicted to increase with increasing flows to 350 l/s before declining at flows above 370 l/s, while habitat for juvenile flathead galaxias is predicted to decline with increasing flows above 150 l/s (Figure 11). For roundhead galaxias, adult habitat is predicted to increase with increasing flows to around MALF (220-250 l/s) before declining at higher flows, while juvenile habitat is predicted to peak at 200 l/s with habitat dropping at higher flows (Figure 11).

Flows required to achieve different levels of habitat retention for indigenous fish species are presented in Table 12.

Table 12 Flow requirements for indigenous fish habitat in the Waiwera River/Te Waiwhero 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 280 l/s
		60%	70%	80%	90%	
Tuna/longfin eel <300 mm (Jellyman et al. 2003)	>1,600	12	43	78	118	104%
Tuna/longfin eel >300 mm (Jellyman et al. 2003)	>1,600	37	68	104	153	105%
Tuna/longfin eel <300 mm (Jowett & Richardson 2008)	920	80	109	139	175	106%
Tuna/longfin eel >300 mm (Jowett & Richardson 2008)	1,120-1,140	67	95	130	173	107%
Juvenile lamprey	>1,600	33	57	87	157	107%
Lamprey	>1,600	86	77	68	59	89%
Flathead galaxias adult	350-370	50	71	94	123	102%
Flathead galaxias juvenile	30	2	3	5	6	92%
Roundhead galaxias adult	220-250	7	12	30	82	100%
Roundhead galaxias juvenile	200	44	68	95	118	99%

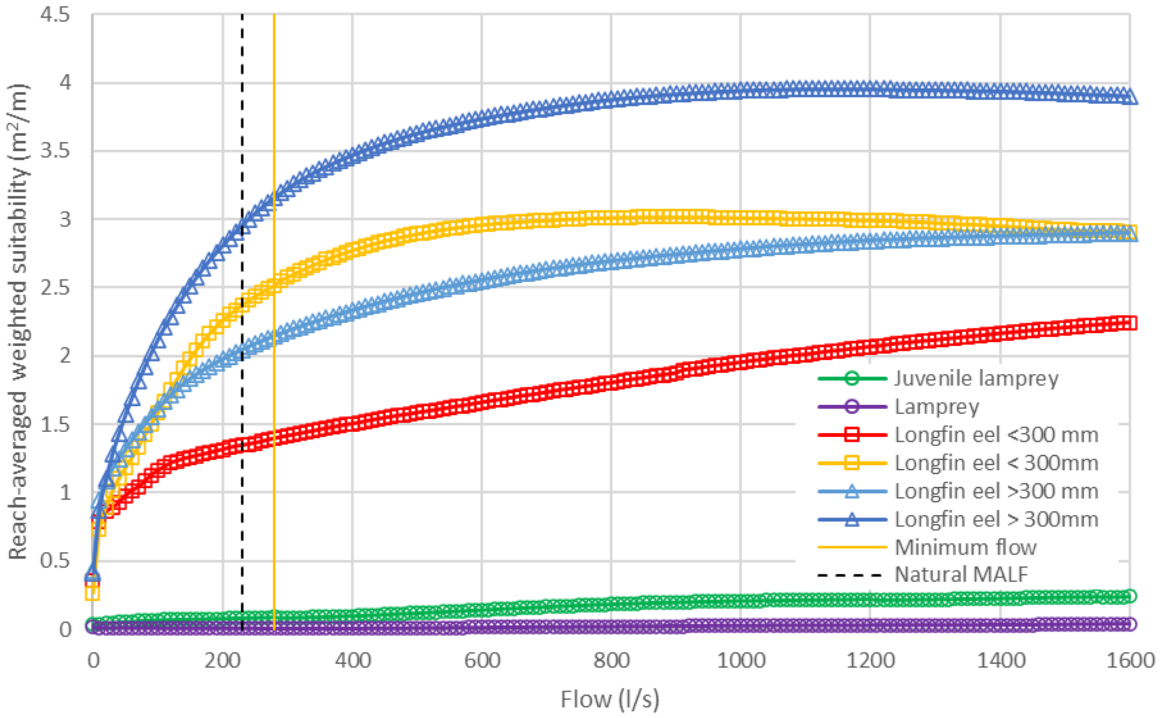

Figure 12 Variation in instream habitat for longfin eel and upland bully relative to flow in the survey reach of the Waiwera River/Te Waiwhero River.

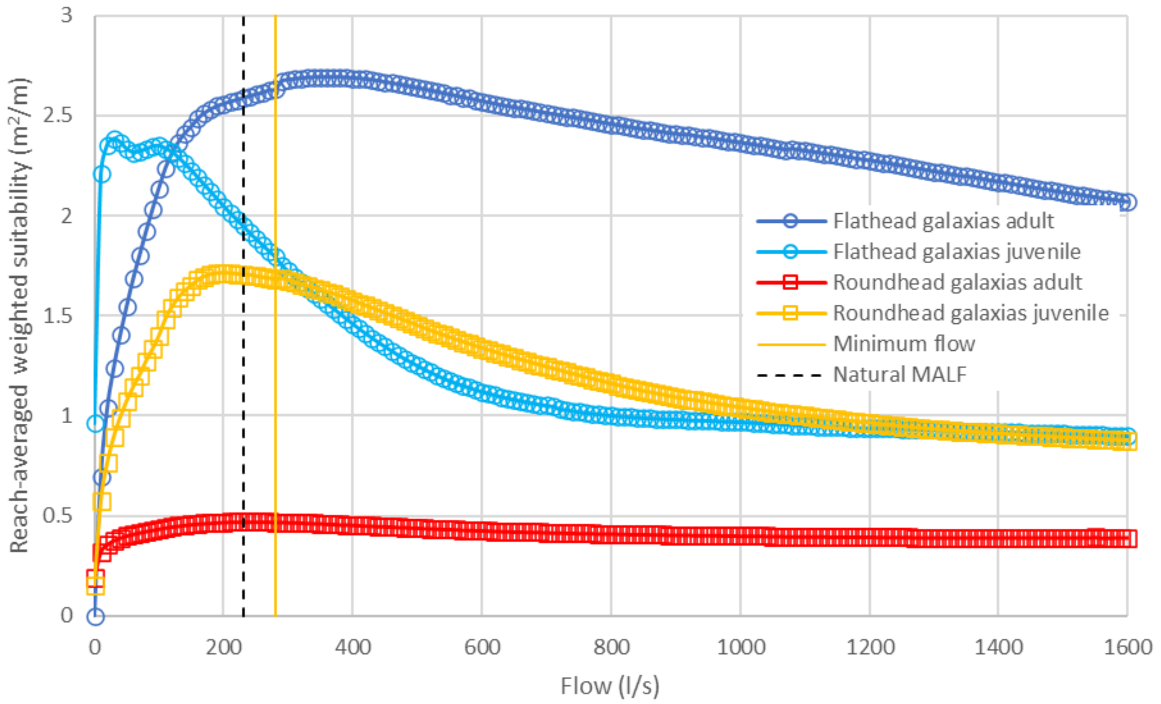

Figure 13 Variation in instream habitat for galaxiids relative to flow in the survey reach of the Waiwera River/Te Waiwhero River.

7.1.6 Sports fish

Habitat for brown trout adult, yearlings and fry up to 15 cm is predicted to increase with flow across the modelled range (Figure 11). Flows required to achieve different levels of habitat retention for each of these species/life-stages are presented in Table 13.

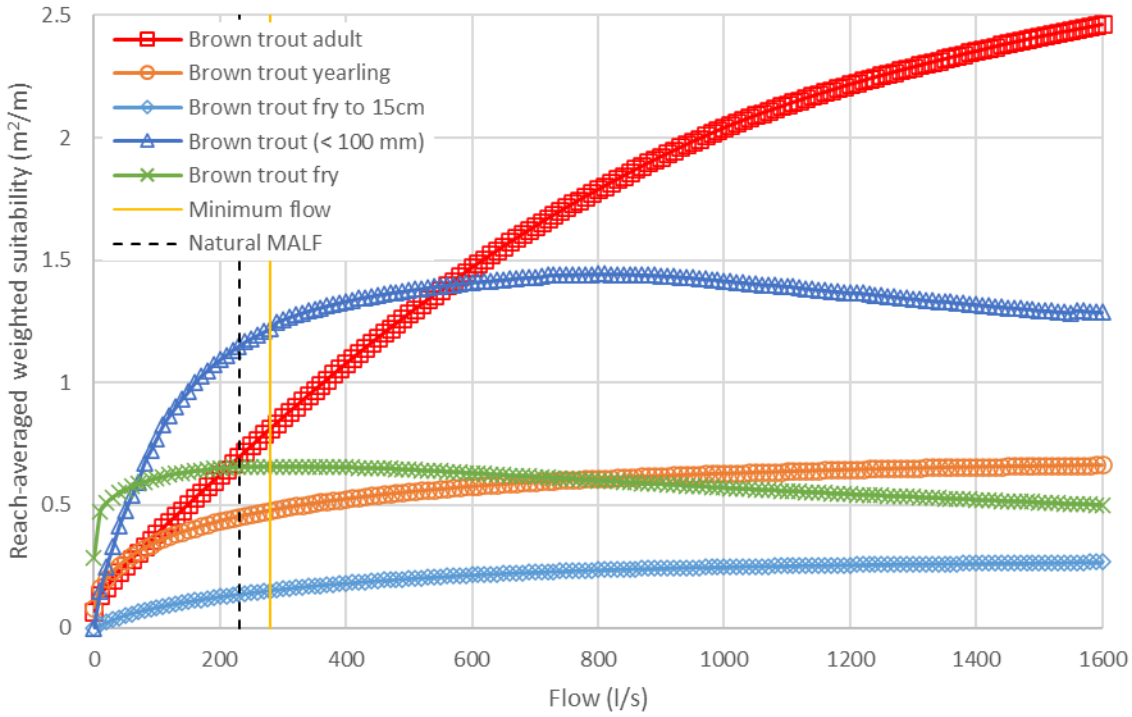

Figure 14 Variation in instream habitat for sportsfish relative to flow in the survey reach of the Waiwera River/Te Waiwhero River.

Table 13 Flow requirements for sportsfish habitat in the Waiwera River/Te Waiwhero 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 280 l/s
		60%	70%	80%	90%	
Brown trout adult	>1,600	114	143	172	201	117%
Brown trout yearling	>1,600	48	75	112	162	105%
Brown trout fry to 15 cm	>1,600	99	126	157	191	111%
Brown trout (<100 mm)	800-810	83	106	136	174	106%
Brown trout fry	290-300	6	9	26	74	100%

7.2 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 Lower Clutha Rohe outlined in Table 1.

Flows of 168-194 l/s would provide 80% habitat retention (relative to naturalised flows) for most macroinvertebrate taxa considered, although the mayfly *Deleatdium* which has historically been abundant in the Waiwera River/Te Waiwhero is predicted to have 80% habitat retention at just 76 l/s (Table 14).

Flows of between 118 and 175 l/s are predicted to retain 90% of the habitat available at the naturalised MALF for tuna/longfin eel life-stages while flows of 157 l/s are predicted to retain 90% of the habitat available at the naturalised MALF for Kanakana/lamprey (Table 14). Flows of approximately 120 l/s are predicted to provide 90% habitat retention for adult non-migratory galaxias in the Waiwera River/Te Waiwhero (Table 14).

Given that the Waiwera River/Te Waiwhero supports a local significant fishery (Otago Fish & Game 2015), an appropriate management objective for trout may be to maintain 70% of the habitat for the various life-stages of trout relative to naturalised flows (Table 14). A flow of 143 l/s would retain 70% of adult trout habitat at the 7-d MALF, while a flow of 172 l/s would maintain 80%. For juvenile trout, flows of between 75 and 126 l/s would retain 70% of the habitat at the 7-d MALF, while flows of 112-157 l/s would maintain 80% of juvenile habitat at the 7-d MALF.

Table 14 Flow requirements for habitat objectives in the Waiwera River/Te Waiwhero 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 280 l/s
Food producing habitat	All year	Life-supporting capacity	80% relative to naturalised	194	128%
Common mayfly *Deleatidium*	All year	Life-supporting capacity	80% relative to naturalised	76	103%
Net-spinning caddisfly *Aoteapsyche*	All year	Life-supporting capacity	80% relative to naturalised	176	119%
Stony-cased caddisfly *Pycnocentrodes*	All year	Life-supporting capacity	80% relative to naturalised	168	114%
Tuna/longfin eel	All year	Life-supporting capacity, indigenous biodiversity, mahika kai	90% relative to naturalised	118-175	104-107%
Kanakana/lamprey	All year	Life-supporting capacity, indigenous biodiversity, conservation concern, mahika kai	90% relative to naturalised	59-157	89-107%
Roundhead galaxias	All year	Life-supporting capacity, indigenous biodiversity, conservation concern	90% relative to naturalised	82-118	99-100
Flathead galaxias	All year	Life-supporting capacity, indigenous biodiversity, conservation concern,	90% relative to naturalised	6-123	92-123%
Brown trout adult	All year	Sports fish – locally significant fishery	70% relative to naturalised	143	117%
			80% relative to naturalised	172	
Juvenile trout	All year	Sports fish – locally significant fishery	70% relative to naturalised	75-126	105-111%
			80% relative to naturalised	112-157	
Brown trout spawning	Winter	Sports fish	Current winter minimum	400	-

8 Assessment of alternative minimum flows and allocation limits

Three minimum flows were considered representing different proportions of the 7-day MALF along with four allocation limits (Table 15). To consider the hydrological effects of the various combinations of minimum flow/allocation, simulations were run for the period 1 July 2016 – 29 June 2023 using naturalised flows estimated by adding measured water take (based on water metering data for water users in the upstream of the Maws Farm flow monitoring site) back onto the observed flows in the Waiwera River/Te Waiwhero at Maws Farm. For each simulation, a supplementary allocation block of 100 l/s was included, with a minimum flow of 600 l/s.

Table 15 Minimum flow and allocation limits considered in this analysis.

Minimum flow		Allocation limit		
Option	% 7-d MALF	Option	% 7-d MALF	Description
280 l/s	121%	150 l/s	65%	Current minimum flow and current allocation limit (65% of MALF).
		90 l/s	39%	Current minimum flow and current combined maximum observed rates of take[4] (39% of MALF).
		60 l/s	26%	Current minimum flow and current maximum observed cumulative rate of take[5] (26% of MALF).
		46 l/s	20%	Current minimum flow and allocation at 20% of MALF.
230 l/s	100%	150 l/s	65%	Minimum flow at 100% MALF and current allocation limit (65% of MALF).
		90 l/s	39%	Minimum flow at 100% MALF and current combined maximum observed rates of take[4] (39% of MALF).
		60 l/s	26%	Minimum flow at 100% MALF and current maximum observed cumulative rate of take[5] (26% of MALF).
		46 l/s	20%	Minimum flow at 100% MALF and allocation at 20% of MALF.
185 l/s	80%	150 l/s	65%	Minimum flow at 80% MALF and current allocation limit (65% of MALF).
		90 l/s	39%	Minimum flow at 80% MALF and current combined maximum observed rates of take[4] (39% of MALF).
		60 l/s	26%	Minimum flow at 80% MALF and current maximum wobserved cumulative rate of take[5] (26% of MALF).
		46 l/s	20%	Minimum flow at 80% MALF and allocation at 20% of MALF.

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

[4] The sum of the maximum observed rate of take or the consented maximum rate of take for each consent, whatever is higher.

[5] The maximum of the observed combined rate of take at any point in time.

each parameter, the mean and co-efficient of variation[6] is calculated. The results of these simulations are presented in Table 17.

Table 16 DHRAM classes used in the assessment of alternative minimum flow/allocation

Class	Points range	Description
1	0	Unimpacted 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 17; Figure 15, Figure 16, Figure 17 and **Error! Reference source not found.**).

Table 17 Comparison of the hydrological effects of different minimum flow/allocation limit combinations in the Waiwera River/Te Waiwhero.

Minimum flow	Allocation limit	Monthly		Min/max means		Date/timing		Pulse count/ duration		Rate of change		Risk grade
		CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	
280 l/s	150 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted
	115 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted
	90 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted
	60 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted
	46 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted
230 l/s	150 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted
	115 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted
	90 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted
	60 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted
	46 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted
185 l/s	150 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted
	115 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted
	90 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted
	60 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted
	46 l/s	0	0	0	0	0	0	0	0	0	0	Unimpacted

[6] 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.

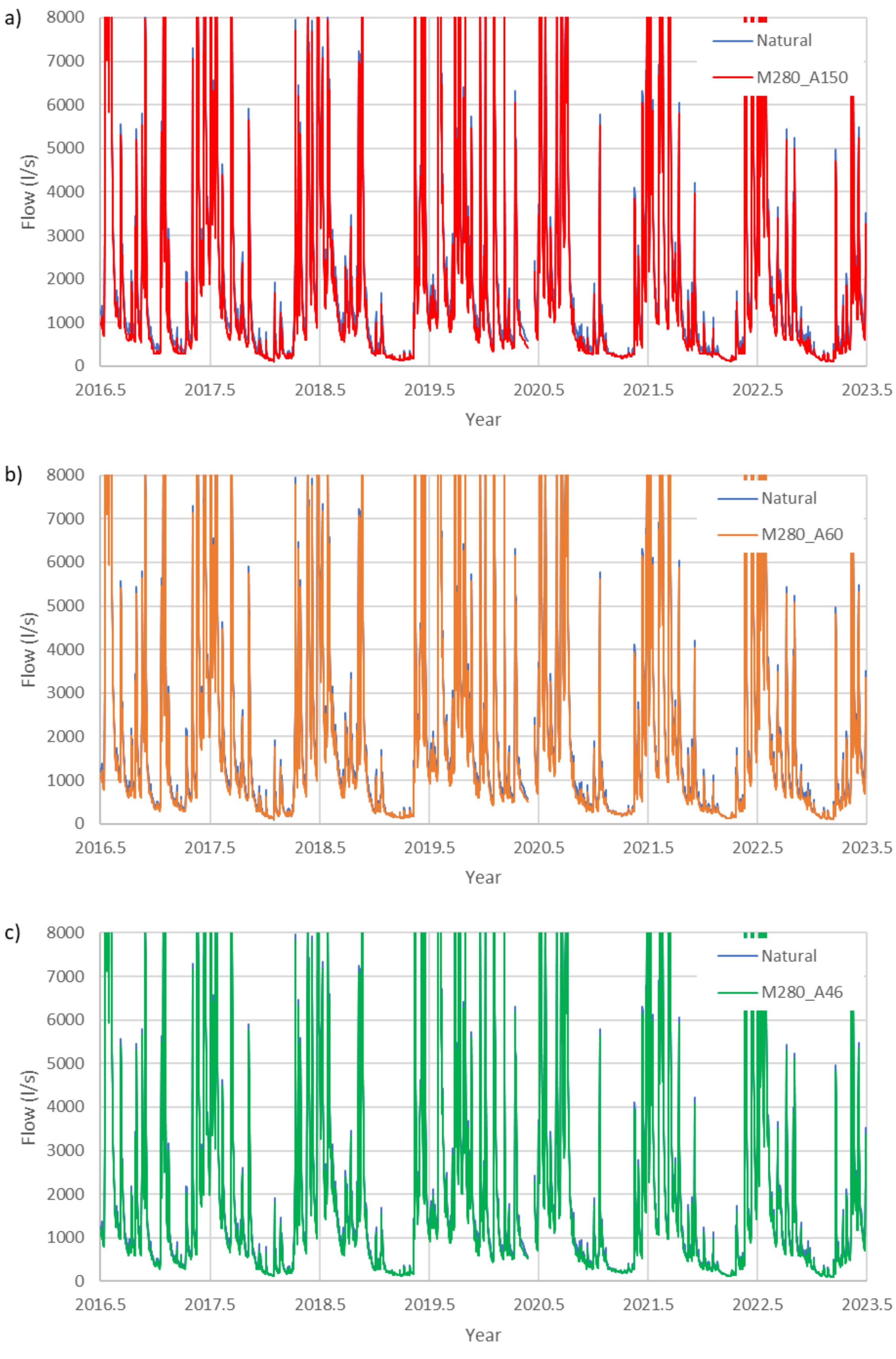

Figure 15 Hydrographs of allocation scenarios with a minimum flow of 280 l/s. a) Current allocation limit 150 l/s, b) allocation limit of 60 l/s, c) allocation limit of 46 l/s.

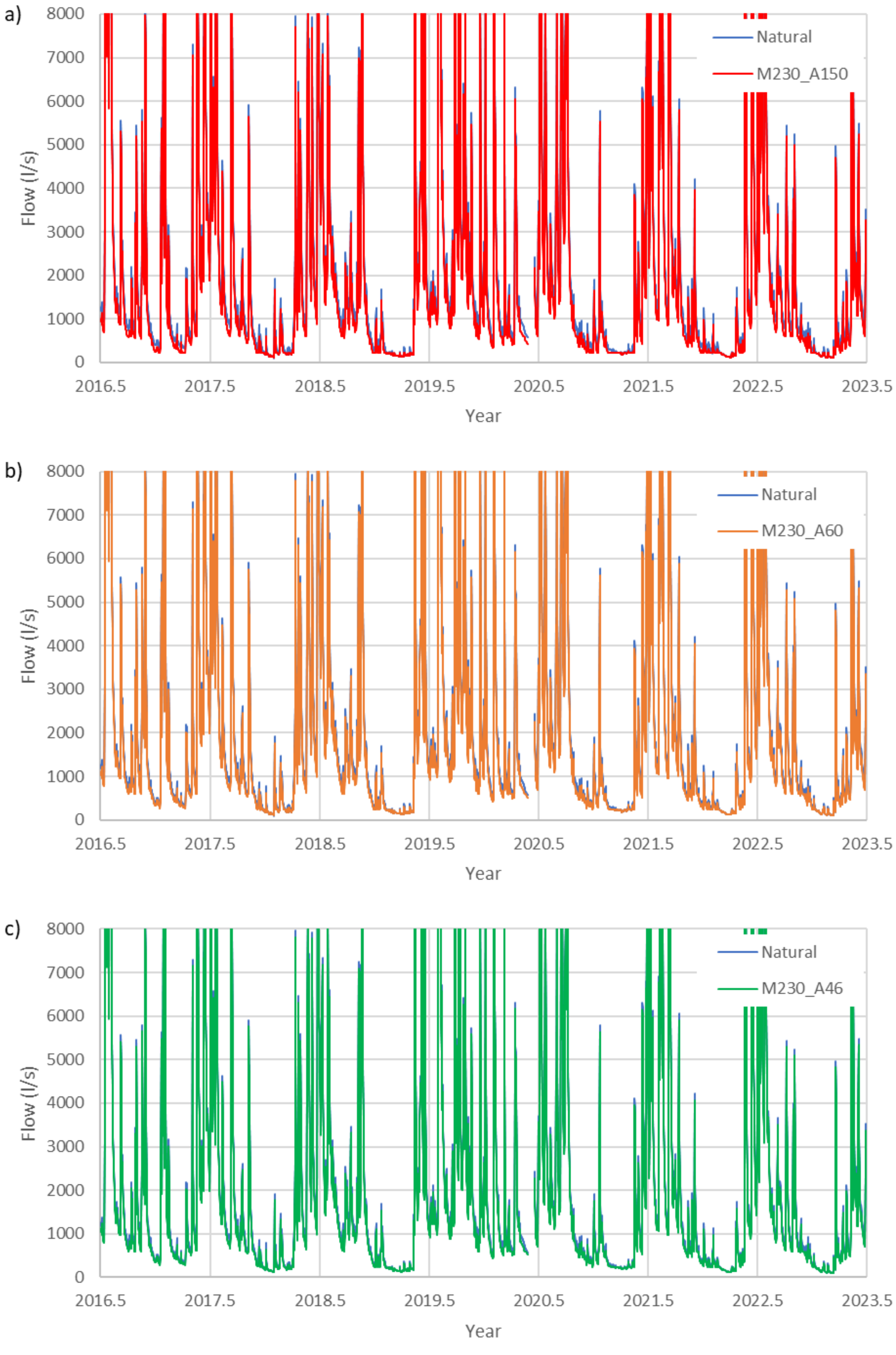

Figure 16 Hydrographs of allocation scenarios with a minimum flow of 230 l/s. a) Current allocation limit 150 l/s, b) allocation limit of 60 l/s, c) allocation limit of 46 l/s..

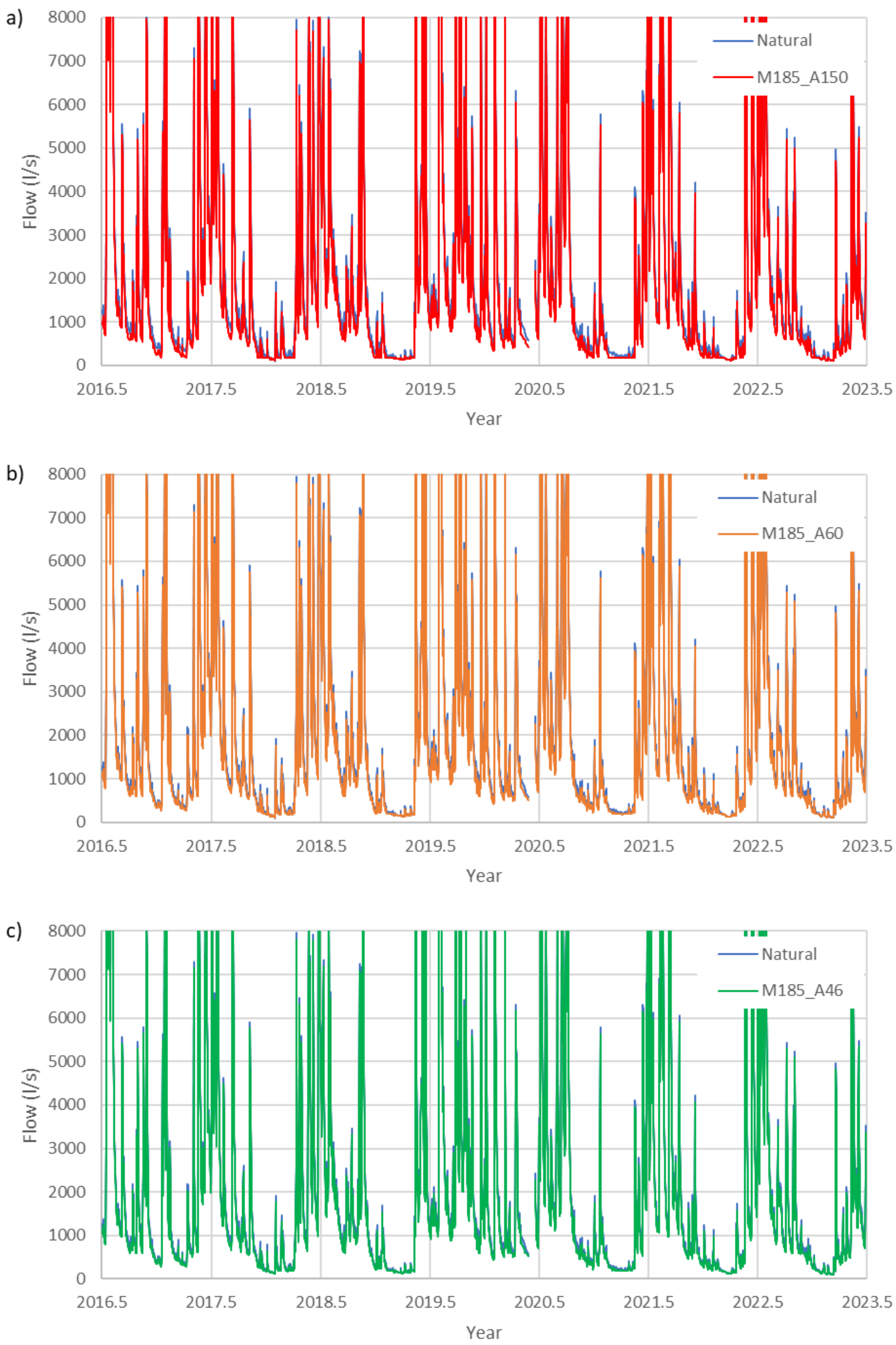

Figure 17 Hydrographs of allocation scenarios with a minimum flow of 185 l/s. a) Current allocation limit 150 l/s, b) allocation limit of 60 l/s, c) allocation limit of 46 l/s..

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. The current minimum flow and allocation in the Waiwera River/Te Waiwhero catchment was added to the RPW by Plan Change 3C, which was notified on 13 December 2014 and became operative on 8 August 2015.

Schedule 2A of the RPW specifies a minimum flow for primary allocation at the Waiwera at Maws Farm of 280 l/s (1 October to 30 April) or 400 l/s (1 May to 30 September). Schedule 2A specifies that if the 280 l/s minimum flow is breached by taking, flow must return to 310 l/s before taking can recommence. The primary allocation limit specified for the Waiwera River/Te Waiwhero catchment in Schedule 2A is 150 l/s. Primary allocation at the time of writing is 148.7 l/s (see Section 4.1.1).

The current minimum flow of 280 l/s was 90% of the 7-d MALF based on the ORC (2006) report. However, the updated hydrological analysis of Lu (2023) suggests that the 7-d MALF is 231 l/s, suggesting that the current minimum flow is set at 121% of the 7-d MALF. This has been reflected in the flows in the Waiwera River/Te Waiwhero at Maws Farm being at or below the summer minimum flow 20% of the time (8 August 2015-23 August 2023). Flows have been at or below the winter minimum flow 4% of the time during winter months over the same period.

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).

8.2 Potential effects of climate change in the Waiwera River/Te Waiwhero 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 (from Macara et al. 2019) are not expected to significantly increase the probability, magnitude and duration of low flow events in the Waiwera River/Te Waiwhero catchment (Table 18) and are not expected to affect the achievability of in-stream objectives in the Waiwera River/Te Waiwhero catchment.

Table 18 Potential effects of climate change on the Waiwera River/Te Waiwhero 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 Waiwera River/Te Waiwhero	Potential ecological consequences
Temperature	• Increased mean temperatures (0.5-1°C) • Increased annual mean maximum temperature (0.5-1.5°C) • No increase in number of hot days (>30°C) (increase of <1 days per annum) • Reduced frost days (5-10 fewer frost days per annum)	• Increased evapotranspiration • Faster flow recession • Slightly increased irrigation demand	• Higher water temperatures, reduced suitability for sensitive species • Faster accrual of periphyton biomass
Rainfall	• Little change in annual mean rainfall (0-5%) • Increased summer mean rainfall (-5% -+5%) • Slight increase in risk of low rainfall events • Small increase in heavy rain days	• Little change in likelihood and/or magnitude of low flow events • Little change in likelihood of high rainfall events	
Snow	• No change in snow days		
Hydrology	• No change to slight increase in Q95 flow (-5 - +10%) • Little change to slight increase in reliability for irrigators	• Little change in low flows	• Little change in habitat availability

9 Conclusions

The Waiwera River/Te Waiwhero is a small river, which rises between the Wisp and Kaihiku Ranges in South Otago. Landcover in Te Waiwhero catchment predominantly consists of high-producing grasslands, with areas of exotic forestry and low-producing grasslands in the middle reach, and small remnants of the historical tussock grasslands. Landuse in the upper catchment is dominated by sheep and beef farming, while dairy farming dominates much of the lower catchment. There are also several sheep farms and deer farms in the Waiwera River/Te Waiwhero catchment.

Minimum flows of 280 l/s (1 October to 30 April) or 400 l/s (1 May to 30 September) apply at the Maws Farm flow monitoring site to primary allocation in the Waiwera River/Te Waiwhero catchment. The primary allocation limit specified for the Waiwera River/Te Waiwhero catchment in Schedule 2A is 150 l/s. These restrictions have been in place since 2015.

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

Site		Flow statistics (l/s)		
		Mean	Median	7d MALF (Jul-Jun)
Waiwera River at Maws Farm	Naturalised flows	2,285	1,126	231
	Observed flows	2,280	1,124	225
	ORC 2006	3,100		310

There are five resource consents for primary water takes from the Waiwera River/Te Waiwhero catchment. Two of these are from the Kuriwao Stream (4.2 l/s combined maximum rate of take), while the three other takes are from the mainstem of the Waiwera River/Te Waiwhero (combined maximum rate of take = 144.5 l/s). Thus, the current primary allocation in the Waiwera/Te Waiwhero catchment is 148.7 l/s. In addition to these primary permits, there is one resource consent to take up to 100 l/s of supplementary water from the Waiwera River/Te Waiwhero when flows exceed 600 l/s.

The composition of the periphyton community varied markedly between twelve sites in the Waiwera catchment surveyed in March 2017, although the periphyton at many sites was dominated by thin black-brown films, while long filamentous algae (>20 mm) exceeded 30% cover at three sites on the mainstem of the Waiwera River/Te Waiwhero and cover by short filamentous algae (<20 mm) exceeded 30% at three sites on the mainstem.

Prior to 2004, the common mayfly *Deleatidium* was the most abundant macroinvertebrate taxa collected at the monitoring site in the Waiwera River/Te Waiwhero catchment. However, since 2004, the mudsnail *Potamopyrgyus* has consistently been the most abundant taxon at this site, with *Deleatidium* being far less abundant than historically. The net-spinning caddis fly *Hydropsyche* and the cased caddis fly (*Pycnocentrodes*) have consistently been among the most abundant macroinvertebrate taxa present, while chironomid midges and segmented worms (Oligochaeta) have been among the most abundant taxa since 2007. MCI and SQMCI scores for this site place it in D-band. Macroinvertebrate community metrics have deteriorated in the Waiwera since the early 2000's. Ozanne (2017) concluded that *"fine sediment accumulation seems to be the cause of dramatic losses* *in abundance and diversity of macroinvertebrate communities and fish populations in the Waiwera catchment, particularly the mainstem Waiwera*". This decline appears to be on-going.

Six species of indigenous freshwater fish have been recorded from the Waiwera River/Te Waiwhero catchment, longfin eels are defined as at risk, declining, and two of these species are classified as threatened, nationally vulnerable (lamprey, Pomahaka galaxias) and brown trout have been collected from the Waiwera River/Te Waiwhero catchment. The Waiwera River/Te Waiwhero supports a locally important sport fishery, with low levels of angler usage recorded.

The current minimum flow of 280 l/s was 90% of the 7-d MALF based on the ORC (2006) report. However, the updated hydrological analysis of Lu (2023) suggests that the 7-d MALF is 231 l/s, suggesting that the current minimum flow is set at 121% of the 7-d MALF. This has been reflected in the flows in the Waiwera River/Te Waiwhero at Maws Farm being at or below the summer minimum flow 20% of the time (8 August 2015-23 August 2023). Flows have been at or below the winter minimum flow 4% of the time during winter months over the same period.

An instream habitat model developed for the mainstem of the Waiwera River/Te Waiwhero was applied to consider the effects of different flows on the physical characteristics of the Waiwera River/Te Waiwhero and habitat for periphyton, macroinvertebrates and fish. The existing minimum flow is predicted to retain 103-119% of macroinvertebrate habitat, 89-107% of habitat of indigenous fish species, and 100-117% of brown trout habitat, relative to the 7-d MALF.

Flows of 168-194 l/s would provide 80% habitat retention (relative to naturalised flows) for most macroinvertebrate taxa considered, although the mayfly *Deleatdium* which has historically been abundant in the Waiwera River/Te Waiwhero is predicted to have 80% habitat retention at just 76 l/s. Flows of between 118 and 175 l/s are predicted to retain 90% of the habitat available at the naturalised MALF for tuna/longfin eel life-stages while flows of 157 l/s are predicted to retain 90% of the habitat available at the naturalised MALF for Kanakana/lamprey. Flows of approximately 120 l/s are predicted to provide 90% habitat retention for adult non-migratory galaxias.

A flow of 143 l/s would retain 70% of adult trout habitat at the 7-d MALF, while a flow of 172 l/s would maintain 80%. For juvenile trout, flows of between 75 and 126 l/s would retain 70% of the habitat at the 7-d MALF, while flows of 112-157 l/s would maintain 80% of juvenile habitat at the 7-d MALF.

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).

Macroinvertebrate indices in the Waiwera River/Te Waiwhero at Maws Farm exceed both the LWRP objectives for the Lower Clutha FMU and the national bottom line (based on Table 14 of the NOF; NPSFM 2022). The results of long-term sampling suggest that the macroinvertebrate community has deteriorated in the Waiwera/Te Waiwhero since the early 2000's, likely as a result of fine sediment deposition, as per the conclusions of Ozanne (2017).

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Appendix A

Flow naturalisation of the Waiwera River/Te Waiwhero River

Flow naturalisation of Waiwera River

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Document Review

Name	Role	Date Completed
Xiaofeng Lu	Author	27/06/2023
Helen Manly	Reviewer	27/06/2023
Dave Stewart	Technical Reviewer	30/06/2023

This document describes how naturalised flow statistics at the flow recorder on Waiwera at Maws Farm were derived.

A1 Daily flow time series data for Waiwera River

The daily flow time series data available for analysis are shown in **Table 1**. The locations of the site and current consents are shown in **Figure 1**. The current consents used for flow naturalisation are listed in **Table A1** in the **Appendix**.

Table 1: The daily flow time series data available for analysis above Mill Creek at Fish Trap.

Sites	Start	End	Length (year)
Waiwera at Maws Farm	21/04/2010	24/06/2023	13.2

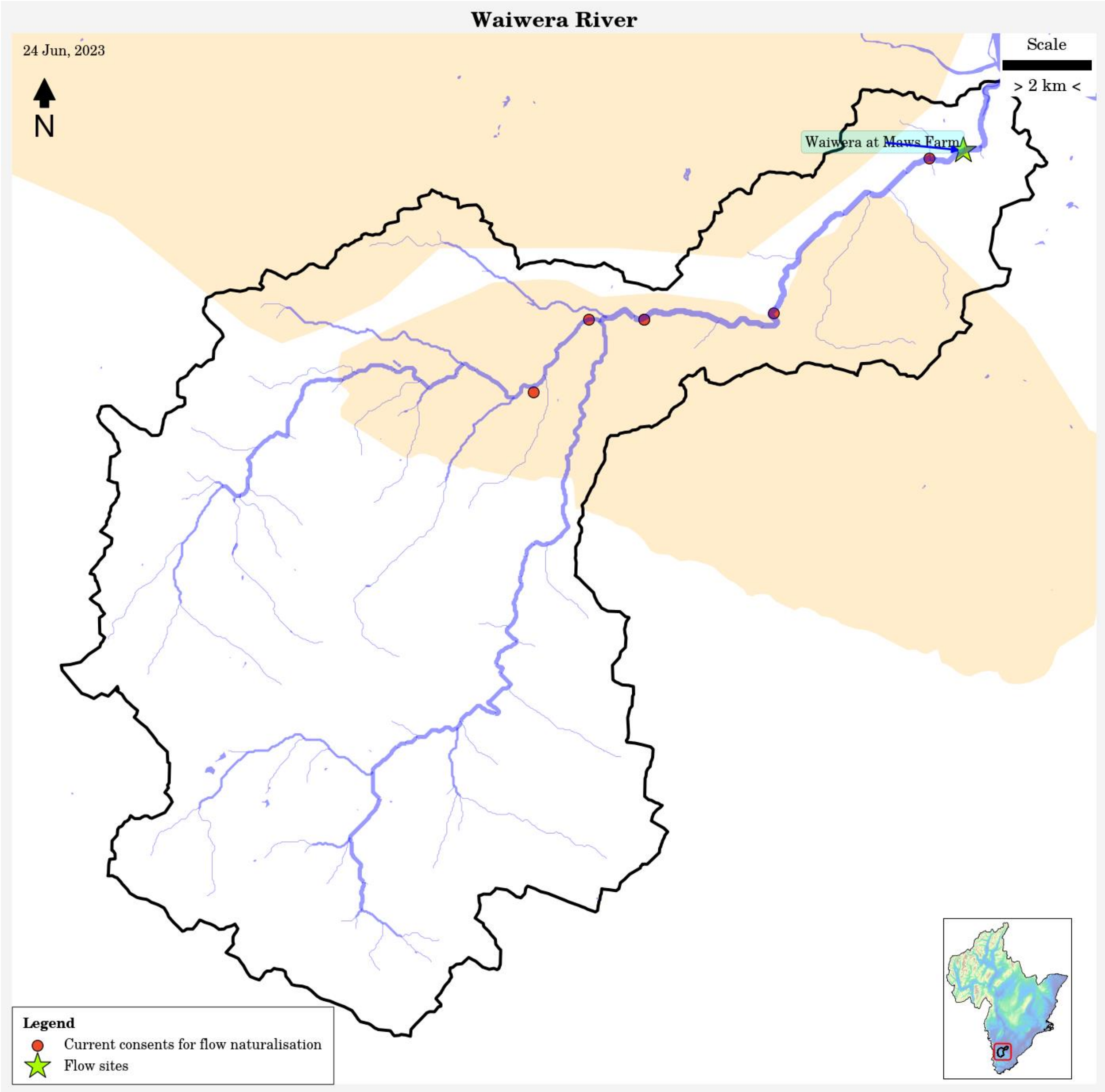

Figure 1: The location of flow recorders and current consents used in this study on Waiwera River in South Otago.

A2 Daily water use time series

Time series data of water use (WU) is used to naturalise the flow of the Waiwera River at the Maws Farm flow recorder. All consents above the flow recorder must first be identified.

A2.1 Total water use above Waiwera at Maws Farm flow recorder

Altogether 13 consents have been issued above the Maws Farm flow recorder on the Waiwera River. However, after removing consents which do not affect flow, 11[7] are used for estimating the natural flow (See **Table A1** in the Appendix), and six consents are currently active. **Figure 2** shows the total water use (WU) regime above the Waiwera at Maws Farm flow site.

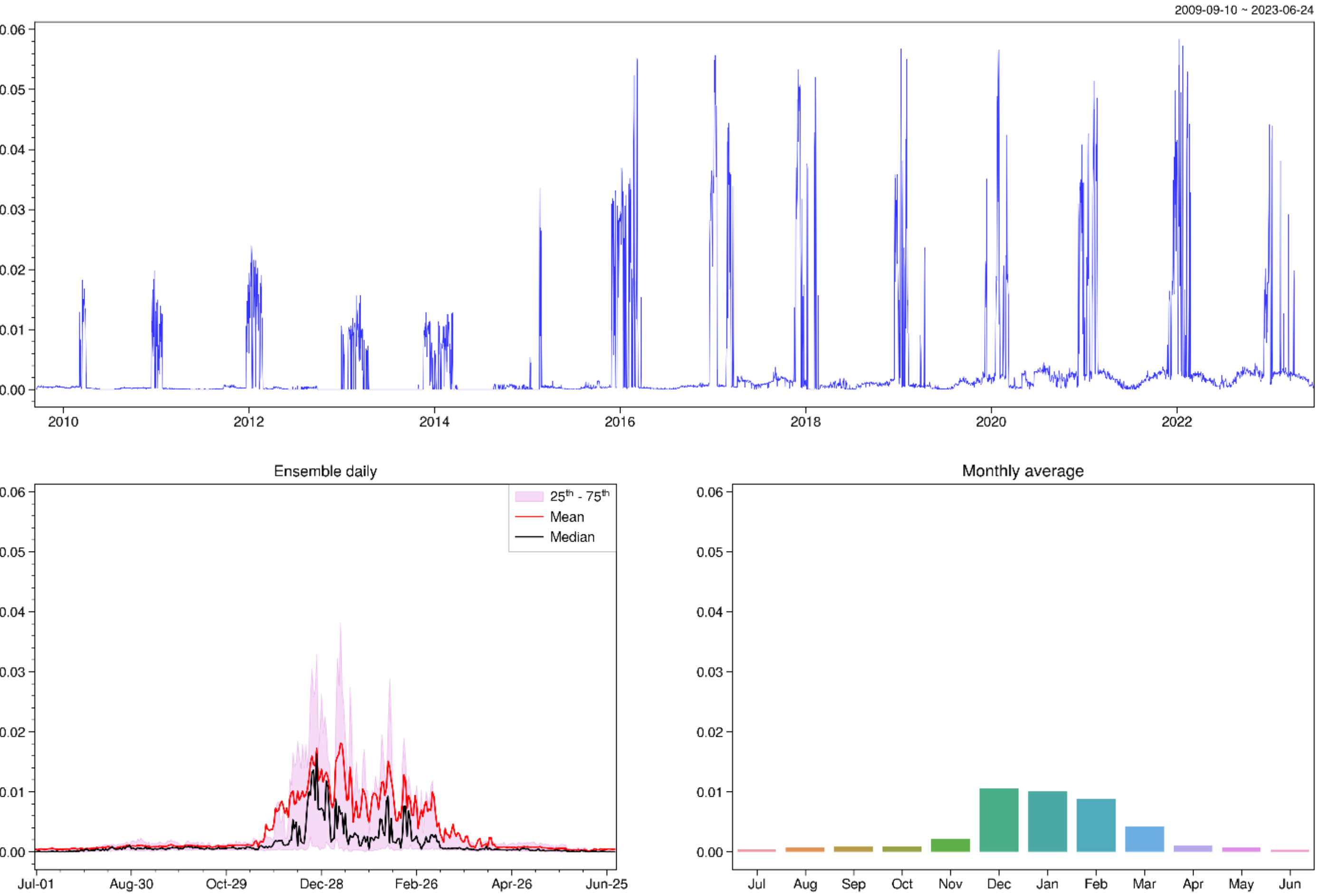

Figure 2: The total water use upstream of the recorder at Waiwera at Maws Farm.

As shown in **Figure 2**, the patterns before and after the water year 2015/16 are different due to water meter abstraction data availability. In this study, only the water use data after 2015/16 is used. The average total WU during the water year (July - June) is 10 L/s after 2015/16 during the irrigation season between November and March.

[7] 11 consents used in this study are listed in **Table A1** in the **Appendix**. They are the consents left by filtering out:

- Groundwater takes with no effect on the nearby water body (refer to the attribute of *Stream depletion rate*)
- Non-consumptive takes
- Retakes

A3 Flow naturalisation

This section describes how the naturalised flow statistics are estimated for the flow recorder at Waiwera at Maws Farm.

A3.1 Method

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

Producing long-term flow statistics is this study's key goal, including the naturalised seven-day mean annual flow (7dMALF) and long-term median and mean flows for the flow recorder on the Waiwera river at Maws Farm.

A3.2 Naturalised flow Statistics

A3.2.1 Basic flow statistics (Table 2).

Table 2: Statistics of the observed and naturalised flows for the recorder at Waiwera at Maws Farm (01/07/2015 ~ present).

Site	Mean (m^3/s)	Median (m^3/s)	FRE3[8] ($year^{-1}$)	7dMALF (m^3/s) (Jul - Jun)
Waiwera at Maws Farm (observed)	2.280	1.124	7.1	0.225
Waiwera at Maws Farm (naturalised)	2.285	1.126	7.1	0.231

[8] The frequency of events exceeding three times the median flow value. In this study, an independent event is defined by a minimal event interval of 7 days.

4 Appendix

Table A1. The consents used for flow naturalisation at site Waiwera at Maws Farm

Consent	Status	Water meter	Allocation type	Category	Consented rate
2003.818.V1	Current	WM0363	Primary	Surface Take	80
RM13.079.01	Current	WM0646		Surface Take	2.7
RM13.278.01	Current	WM0895, WM1135		Surface Take	44
RM13.480.01.V1	Current	WM1270	Primary	Surface Take	
RM13.480.02.V1	Current	WM1270	Supplementary Block 1	Surface Take	120.5
RM14.032.01.V1	Current	WM1346, WM1481		Surface Take	1.5
RM10.456.02	Declined		Primary	Surface Take	1.3
RM12.541.04	Lapsed		Supplementary Block 1	Surface Take	80
2007.669.V1	Surrendered	WM0895	Primary	Surface Take	2
2150	Surrendered			Surface Take	
2003.366	Withdrawn			Surface Take	