Flow Management and Aquatic Ecosystems in the Waiwhakaata/Lake Hayes catchment

November 2023

Otago Regional Council

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Executive summary

Mill Creek is a small river that flows across the floor of the Whakatipu Basin into Waiwhakaata[1]/Lake Hayes and on into the Kawarau River. The Waiwhakaata/Lake Hayes catchment is within the Clutha Mata-Au Freshwater Management Unit (FMU) and the Dunstan Rohe. Schedule 2A of the Regional Plan: Water specifies a minimum flow for primary allocation in Mill Creek at Fish Trap of 180 l/s. The primary allocation limit set for the Waiwhakaata/Lake Hayes catchment (from the lake outlet to the headwaters) in Schedule 2A is 260 l/s.

Naturalised hydrological statistics for Mill Creek at Fish Trap used in this report are :

Type	Data range		Flow statistics (l/s)		
	Start	End	Mean	Median	7d MALF (Jul-Jun)
Naturalised flows	1 July 2013	24 April 2023	431	394	247
Observed flows	1 July 2013	24 April 2023	425	388	243
	1 April 1983	29 March 2023	431	378	248

There are six resource consents to take surface water from the Mill Creek catchment upstream of Waiwhakaata/Lake Hayes. Three are in tributaries of the upper catchment for snowmaking and a potable water supply for the Coronet Peak ski field and the other takes for irrigation and site development (total allocation: 85.7 l/s). In addition, there are three permits for a total take of 9.05 l/s from Waiwhakaata/Lake Hayes and a surface water depleting groundwater take near Rutherford Road Spring, with 40 l/s allocated against surface water. A further two surface water takes are located on Hayes Creek downstream of Lake Hayes (maximum rate of take = 8.2 l/s) along with two surface water depleting groundwater takes (maximum surface depletion = 17.5 l/s). However, currently takes from downstream of the Waiwhakaata/Lake Hayes outlet are not included in the water allocation for the Waiwhakaata/Lake Hayes catchment and are considered as allocation from unnamed tributaries of the Kawarau River.

Three indigenous freshwater fish species have been recorded from the Waiwhakaata/Lake Hayes catchment – longfin eel/tuna, common bully and kōaro. Brown trout are widespread in the Waiwhakaata/Lake Hayes/Mill Creek catchment, while perch are abundant in Waiwhakaata/Lake Hayes and Hayes Creek. Waiwhakaata/Lake Hayes is a regionally significant trout fishery and wildlife habitat. Mill Creek provides spawning habitat, at least as far upstream as a 43 m waterfall near Millbrook Resort.

Macroinvertebrate metrics (MCI & SQMCI scores) in Mill Creek do not meet the proposed target states for Ecosystem Health – Aquatic life and have declined since 2004, possibly reflecting the effects of sedimentation. Mill Creek does not meet proposed objectives for some water quality attributes, (ammoniacal nitrogen concentrations, water clarity and *E. coli*), although water abstraction is unlikely

[1] https://www.kahurumanu.co.nz/atlas

to account for these exceedances given the low water use in the catchment. Similarly, the degraded water quality in Waiwhakaata/Lake Hayes is not directly related to the effects of water abstraction/allocation. At present, flows in Mill Creek rarely reach the minimum flow of 180 l/s, furthermore this would be unlikely to occur even if the existing consents were fully exercised and/or the catchment was fully allocated.

Hydrological simulations suggest that higher minimum flows increase the duration of flows at the minimum flow, although the extent of this effect depends on the allocation limit. The current minimum flow/allocation limit has a high risk of ecological impact, although the current consented allocation (135 l/s) is associated with a low risk of impact. At higher minimum flows (195, 210, 230 l/s), an allocation limit of 135 l/s is expected to result in a moderate risk of impact. An allocation limit of 80 l/s (the sum of the maximum observed rate of take for each water take) was associated with a low risk of impact at all the minimum flows considered. In comparison, an allocation limit of 55 l/s (the maximum observed combined rate of take) is predicted to result in unimpacted hydrology relative to naturalised flows.

Given the long history of degraded water quality in the Waiwhakaata/Lake Hayes catchment and the exceedance and deterioration of proposed objectives for macroinvertebrate attributes in Mill Creek, there is a case for reducing the catchment primary allocation limit and/or raising the minimum flow from those in Schedule 2A. An allocation limit of 80 l/s would reflect the current peak rate of water use based on the sum of the maximum observed take by each consent. Thus, it would provide for existing users. With an allocation limit of 80 l/s, the various minimum flows (180, 195, 210, 230 l/s) would result in a degree of hydrological alteration that has a low risk of impact on ecological values.

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

1. Introduction

Mill Creek is a small river that flows across the floor of the Whakatipu Basin into Waiwhakaata[2]/Lake Hayes and on into the Kawarau River (Figure 1). It is located between the lower reaches of the Kimiākau[2]/Shotover River to the west and the Haehaenui[2]/Arrow River to the east (Figure 1). While the tributaries of the upper reaches of Mill Creek (Dan O'Connell Creek, Station Creek and McMullan Creek) flow steeply from tussock grasslands on the slopes of Coronet Peak near Queenstown, much of the mainstem flows at a gentle gradient before plunging off a 43 m high waterfall just below Millbrook resort approximately 2.5 km upstream of Waiwhakaata/Lake Hayes(Figure 1).

The Waiwhakaata/Lake Hayes catchment is within the Clutha Mata-Au Freshwater Management Unit (FMU) and the Dunstan Rohe. The current minimum flow and allocation in the Waiwhakaata/Lake Hayes catchment were introduced in the Regional Plan: Water, which became operative on 1 January 2004. Schedule 2A of the RPW specifies a minimum flow for primary allocation in Mill Creek at Fish Trap of 180 l/s. The primary allocation limit set for the Waiwhakaata/Lake Hayes catchment (from the lake outlet to the headwaters) in Schedule 2A is 260 l/s.

Arrow Irrigation operates a large weir in the Haehaenui/Arrow River gorge which takes water out of the Haehaenui/Arrow River catchment to irrigate land within the broader Whakatipu Basin, including the Mill Creek catchment. The Waiwhakaata/Lake Hayes catchment contains substantial residential development areas at the northern end of Waiwhakaata/Lake Hayes along with resorts (such as Millbrook and the under-development Waterfall Park). Such developments potentially affect the water balance of the Waiwhakaata/Lake Hayes catchment, with reduced infiltration to soil and groundwater resulting from an increase in impervious surfaces (concrete, asphalt, roofs) which, along with the stormwater network, decreases the length of time between the onset of precipitation and the flow peak in the receiving waterbody (or waterbodies) and can also result in reduced base flows (Shuster *et al*., 2005).

Water quality in Waiwhakaata/Lake Hayes has long been recognised as being degraded because of nutrient inputs from human activity, including historical fertiliser application, residential development, industrial development, historical septic tank effluent, and the removal of wetlands and riparian plantings. As a result, Lake Hayes now suffers from periodic algal blooms caused by the build-up of the nutrient phosphorous in lakebed sediments. The Friends of Lake Hayes group is leading a project with NIWA to identify options to improve water quality in the Waiwhataata/Lake Hayes catchment, including wetland restoration, riparian management (including stock exclusion and riparian planting), and the installation of sediment traps in Mill Creek. In addition, ORC is exploring options to address historical nutrients within the bed of Waiwhataata/Lake Hayes[3].

[2] https://www.kahurumanu.co.nz/atlas
[3] https://yoursay.orc.govt.nz/lakehayes

1.1. Purpose of the report

The purpose of this report is to present information to inform decision making on water allocation and flow management in the Waiwhakaata/Lake Hayes catchment. The report includes hydrological information (including flow naturalisation and flow statistics), and 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 Mill Creek compared to the proposed objectives for the Dunstan Rohe set out in the proposed Otago Land and Water Regional Plan are included.

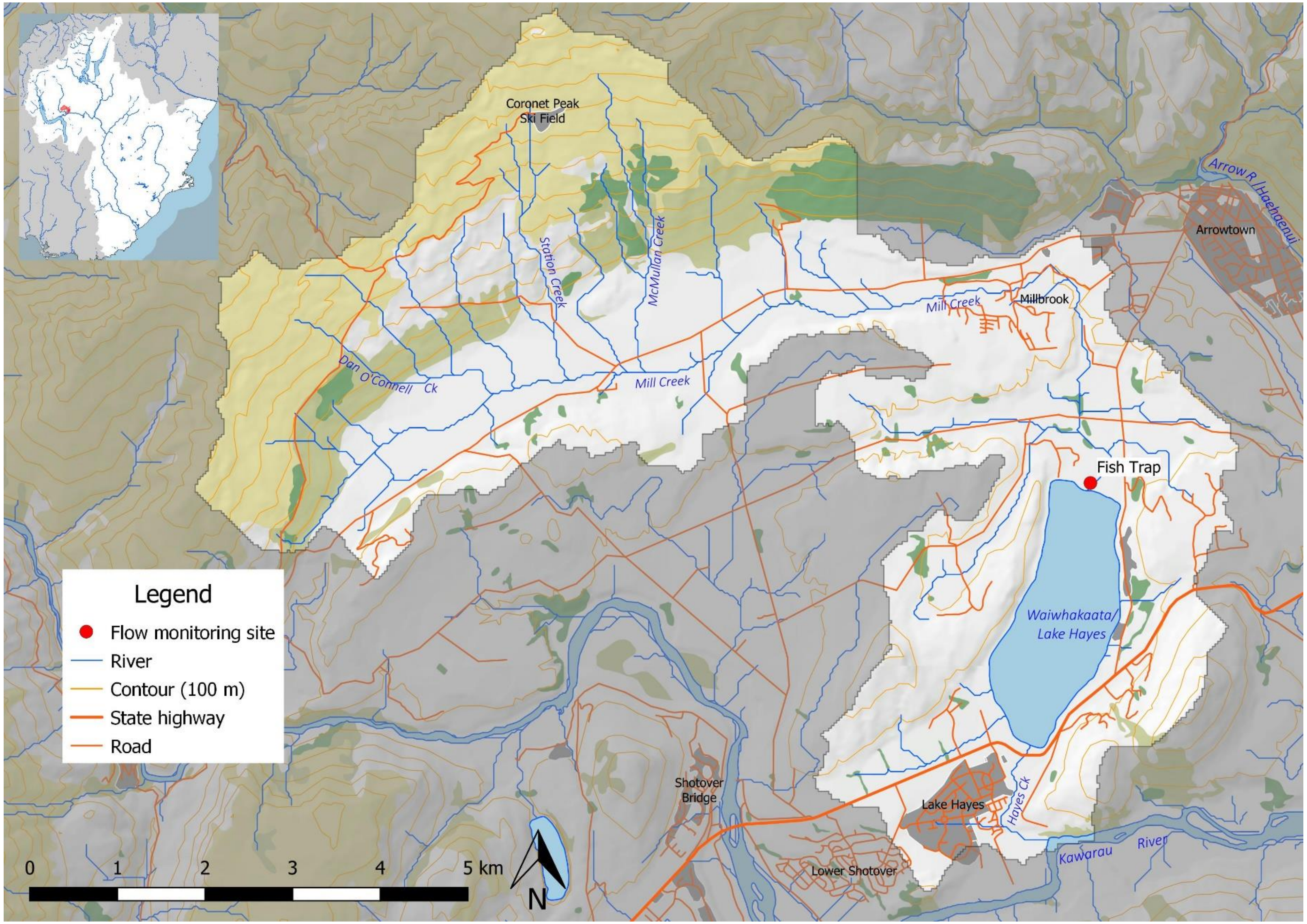

Figure 1 Map of the Waiwahataata/Lake Hayes catchment showing water races and flow recorder site.

2. Background information

2.1. Catchment description

Waiwhakaata/Lake Hayes is a medium-sized lake with a mean depth of 18 m and a maximum depth of 33 m. Monitoring has shown that it thermally stratifies at a depth of between 10 m and 15 m and that the hypolimnion can become anoxic through summer (Gibbs, 2018). During the anoxic phase, DRP is released from the sediments and accumulates in the hypolimnion, which can result in a late summer algal bloom (Gibbs, 2018). Waiwhakaata/Lake Hayes has a catchment area of 44 km^2, much of which is drained by Mill Creek (41.4 km^2). Much of the Mill Creek catchment is at elevations of between 330-440 m, although some tributaries of the upper catchment flow from the slopes of Coronet Peak near Queenstown.

2.1.1. Climate

The climate within the Mill Creek 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 1,200 mm of rain falling in the higher elevation areas. The mean annual rainfall in the lower catchment is as low as 750 mm (Figure 2). The mean annual rainfall at the nearby Queenstown (Airport) climate station is 757 mm (Macara, 2015).

The mean monthly air temperature at Queenstown is 12°C in summer (January-February), with an average of one day per year with a maximum temperature exceeding 30°C and 23 days exceeding 25°C (Macara, 2015). The highest air temperature recorded in Queenstown was 34.1°C (Macara, 2015). In contrast, Queenstown's mean monthly air temperature in winter is 7.8°C (June). The lowest temperature recorded is -12.2°C with an average of 47 days per year having a minimum temperature of less than 0°C (Macara, 2015).

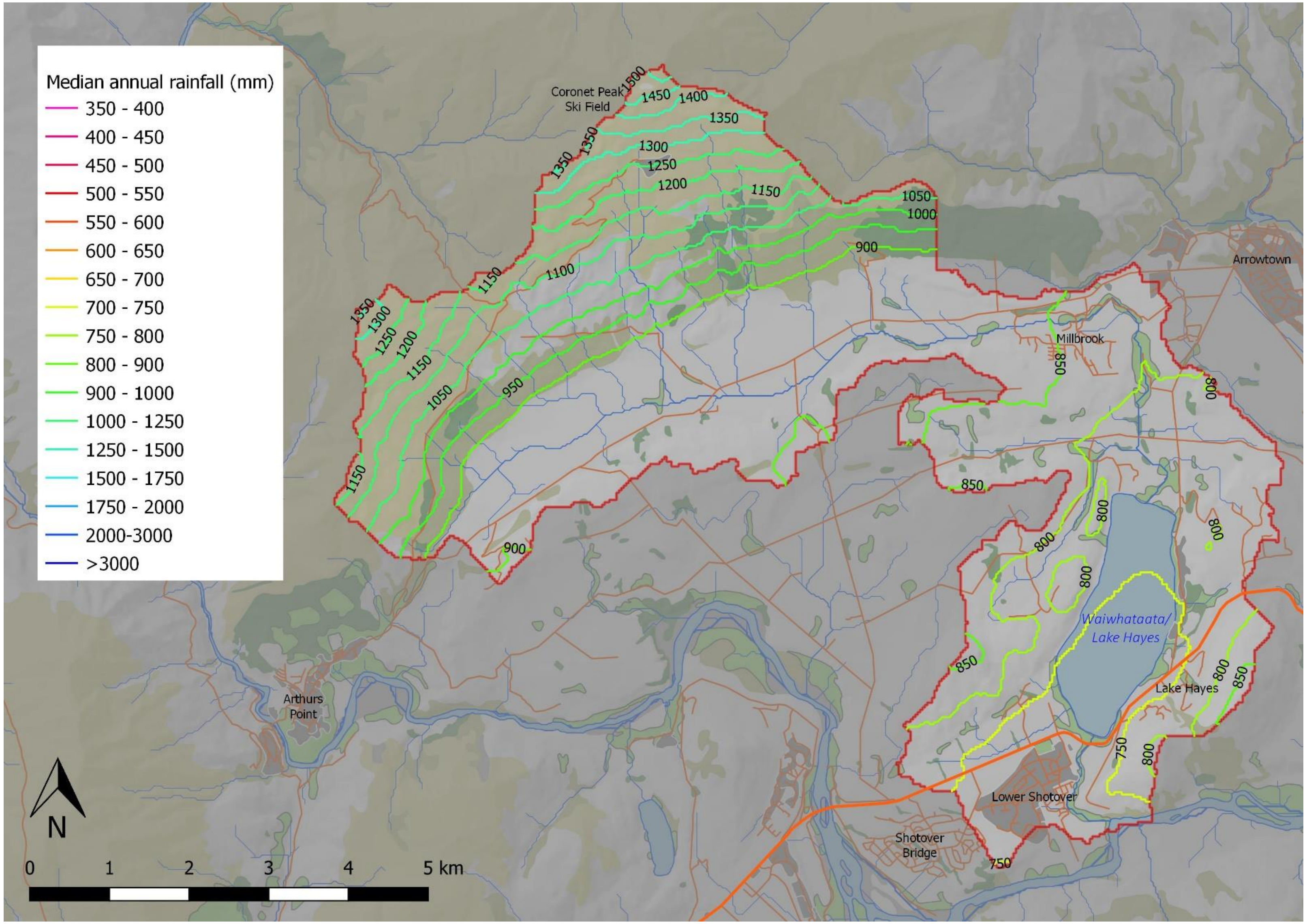

Figure 2 Distribution of rainfall (annual median rainfall) in the Waiwahataata/Lake Hayes catchment. From ORC (2004).

2.1.2. Geological setting

Much of the Mill Creek catchment is underlaid by schist (Rakaia terrane) with pockets of recent alluvial gravels (<24,000 years ago) and glacial till (71,000-59,000 years ago) (Turnbull, 2000). Recent lake deposits (<12,000 years ago) are found in the vicinity of Waiwhakaata/Lake Hayes (Turnbull, 2000).

Soils in the steep tributaries of Mill Creek are predominantly orthic brown soils, while the soils of the basin floor are immature, laminar and argillic pallic soils (Manaaki Whenua – Landcare Research, 2023).

2.1.3. Vegetation and land use

The vegetation of the upper Mill Creek catchment is mostly tussock grasslands at high altitudes, with areas of low producing pasture, scrublands and exotic forestry (Figure 3). Much of the exotic forestry in the catchment consists of wilding pines within the Arrowtown Municipal Reserve to the west of Arrowtown. The land cover of the lower portions of the Mill Creek catchment is dominated by high producing pastures (although much of this is likely to be lifestyle blocks) with areas of exotic trees and low producing pastures (Figure 3).

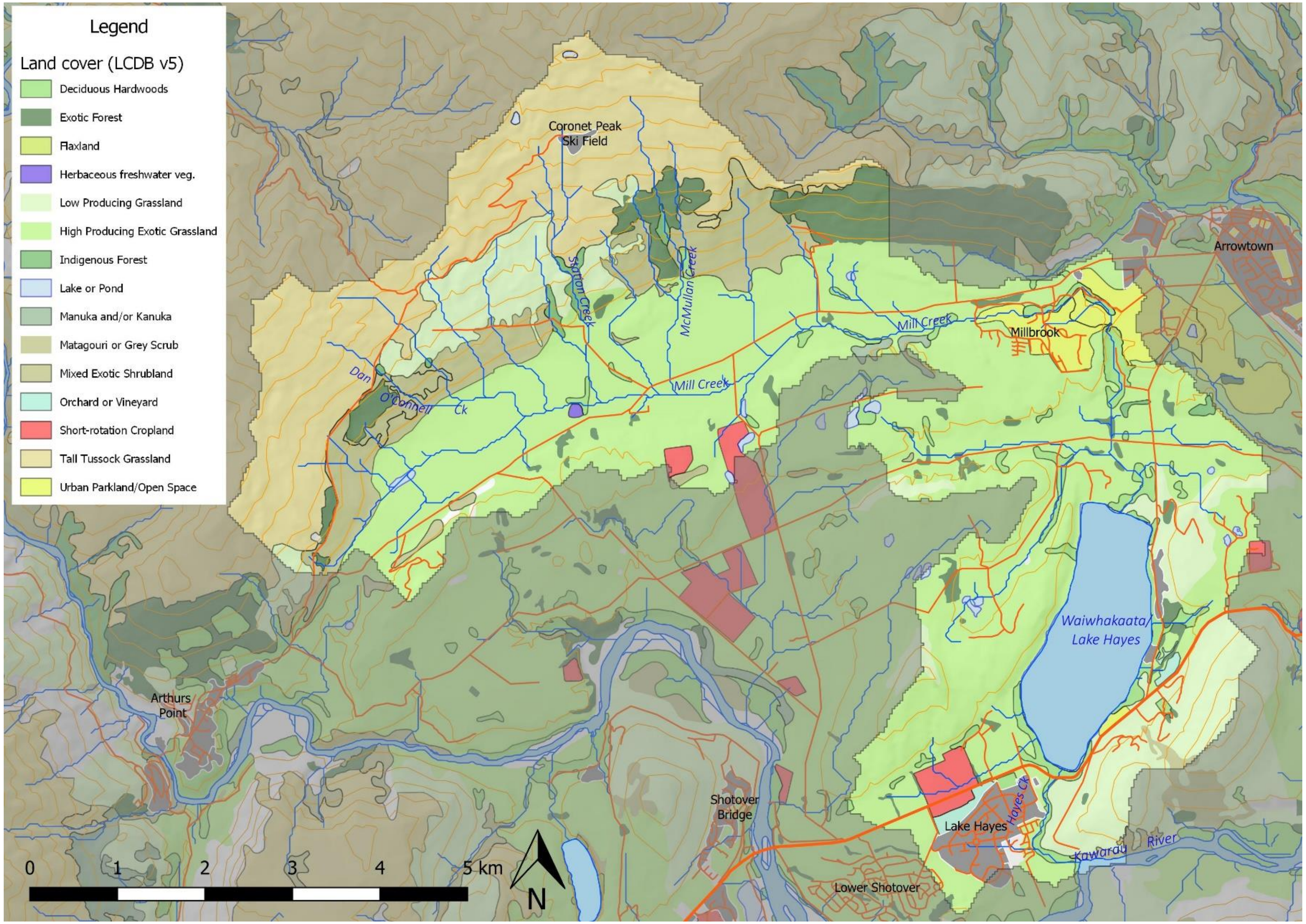

Figure 3 Land cover in the Waiwhakaata/Lake Hayes catchment based on the land cover database (version 5).

3. Regulatory setting

3.1. Regional Plan Water (RPW)

The current minimum flows and allocations in the Waiwhakaata/Lake Hayes catchment were included in the Regional Plan Water, which became operative on 1 January 2004. Schedule 2A of the RPW specifies a minimum flow for primary allocation at Mill Creek at Fish Trap of 180 l/s and a primary allocation limit of 260 l/s for the Mill Creek catchment. The total consented allocation in the Mill Creek catchment at the time of writing is 134.75 l/s (see Section 4.4).

3.2. Proposed Land and Water Plan

The ORC is undertaking 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 Clutha Mata-Au Freshwater Management Unit (FMU), which is further sub-divided into 5 Rohe: Upper Lakes, Dunstan, Manuherekia, Roxburgh and Lower Clutha. The Mill Creek is within the Dunstan Rohe. The proposed objectives for the Dunstan Rohe, valid at the time of writing, are presented in Table 1.

The objectives in Table 1 apply to waterbodies in the Waiwhakaata/Lake Hayes catchment.

Table 1 Possible environmental outcomes for the values identified in the Dunstan Rohe and their attributes and target attribute states (A, B, C, from corresponding tables in the National Objectives Framework of the National Policy Statement for Freshwater Management 2022).

Value	Narrative outcome statement	Attribute	Target attribute state
Ecosystem health – (all biophysical components)	Freshwater bodies within the Dunstan rohe 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/ m^3	B
		Periphyton - mg chl-a/m^2	B
		Submerged plants (Native Condition Index)	B
		Submerged plants (Invasive Impact Index)	B
		Fish - Fish index of biotic integrity	B
		Macroinvertebrates - Macroinvertebrate Community Index (MCI) score; Quantitative Macroinvertebrate Community Index (QMCI) score	B
		Macroinvertebrates - Macroinvertebrate Average Score Per Metric (ASPM)	B
EH – Water quality		Total nitrogen (mg/m^3	B
		Total phosphorus -mg/m^3	B
		Ammonia (toxicity) mg NH_4-N/L	A
		Nitrate (toxicity) - mg NO_3 – N/L	A
		Dissolved oxygen - mg/L	A
		Suspended fine sediment - Visual clarity (m)	A
		Dissolved oxygen - mg/L	A
		Lake-bottom dissolved oxygen mg/L	B
		Dissolved reactive phosphorus - DRP mg/L	A
		Mid-hypolimnetic dissolved oxygen - mg/L	B
EH - Habitat		Deposited fine sediment - % fine sediment cover	A
EH – Ecological processes		Ecosystem metabolism (both gross primary production and ecosystem respiration) - g O_2 m^{-2} d^{-1}	A
EH – Water quantity		Under development – awaiting national guidance	Not applicable

Table 1 Possible environmental outcomes for the values identified in the Dunstan Rohe and their attributes and target attribute states (A, B, C, from corresponding tables in the National Objectives Framework of the National Policy Statement for Freshwater Management 2022).

Human contact	Water bodies within the Dunstan rohe 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 Dunstan rohe 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 Dunstan rohe 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 Dunstan rohe 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 Dunstan rohe can still provide a suitable supply of water for commercial and industrial activities.		

Table 1 Possible environmental outcomes for the values identified in the Dunstan Rohe and their attributes and target attribute states (A, B, C, from corresponding tables in the National Objectives Framework of the National Policy Statement for Freshwater Management 2022).

Drinking water supply	Source water from waterbodies within the Dunstan rohe 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	
Natural form and character	Water bodies and riparian margins within the Dunstan rohe 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 Dunstan rohe 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 Dunstan rohe 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 Dunstan rohe can support low impact hydro-electric generation.		

4. Hydrology

4.1. General description

The tributaries of the upper reaches of Mill Creek arise as steep mountain streams at high altitudes (1,651 m a.s.l. at the summit of Coronet Peak) on the southern slopes of Coronet Peak before flowing onto across the gentle gradients of the Whakatipu Basin (Figure 1). Given the strong rainfall gradient in the catchment (Figure 2) and tussock vegetation cover (Figure 3), water yields in high altitude areas are expected to be much higher than low-altitude areas.

The combination of inflows from high-altitude tributaries (Dan O'Connell Creek, Station Creek and McMullan Creek) and inflows from springs at lower elevations result in the distinctive hydrology of Mill Creek, with with highest flows in September-November and lowest flows in February-May and the small magnitude of high flow events relative to nearby rainfall-driven catchments (for example, the highest flow recorded is 5,471 l/s on 17 November 1999). Consideration of the observed flow duration curve for Mill Creek shows that flows rarely drop below 230 l/s (exceeded 95% of the time with current abstraction and 97% of the time naturally) (Figure 5).

Arrow Irrigation Company's Hayes Basin Race has a by-wash to the tributary at Mooney Road, and this by-wash discharges excess water when irrigation demand drops. It is unlikely that this by-wash operates during low flow conditions (when water demand is expected to be high), and so for this report, this discharge is not considered.

4.2. Flow statistics

A continuous flow recorder in the Mill Creek at Fish Trap has been operating since 1 April 1983. The full measured hydrograph is shown in Figure 4. Flow naturalisation was conducted from 1 July 2013 – 29 March 2023, given the availability of water metering data. The flow statistics based on the analysis of Lu (2023)[4] are summarised in Table 2.

Table 2 Flow statistics for Mill Creek at Fish Trap.

Type	Data range		Flow statistics (l/s)		
	Start	End	Mean	Median	7d MALF (Jul-Jun)
Naturalised flows	1 July 2013	24 April 2023	431	394	247
Observed flows	1 July 2013	24 April 2023	425	388	243
	1 April 1983	29 March 2023	431	378	248

[4] Attached as Appendix A to this report

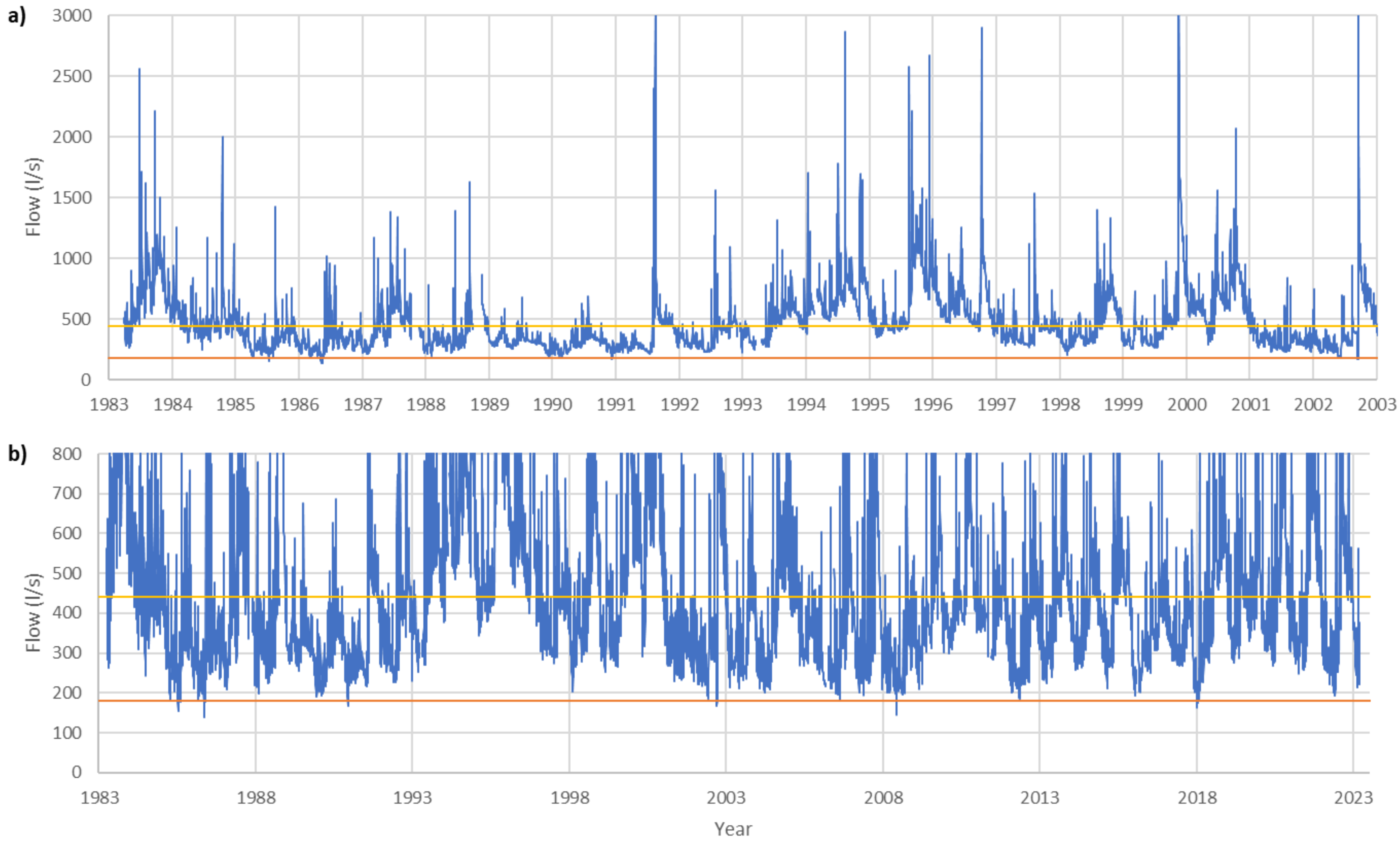

Figure 4 Hydrograph of Mill Creek at Fish Trap over the period 1 April 1983 – 30 June 2022. a) Full flow range, b) low-moderate flow range. Dark orange line = current minimum flow, light orange = current minimum flow + allocation limit.

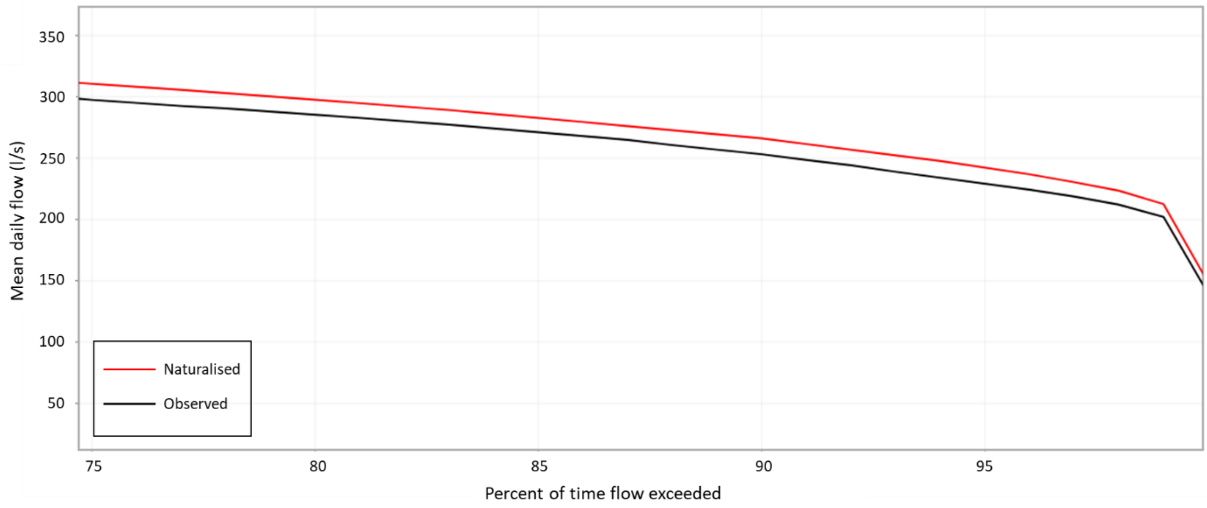

Figure 5 Low flow duration curve for Mill Creek based on observed flows (black line) and naturalised flows (red line) at the Mill Creek at Fish Trap hydrological site.

4.3. Flow variability

The average number of events per year that exceed three times the median flow (FRE3) in Mill Creek is estimated to be 1.7 events per year (Lu, 2023). Flow events of this magnitude are generally considered large enough to reduce periphyton biomass and cover and are referred to as flushing flows.

4.4. Water allocation & use

There are nine resource consents for primary surface water takes from the Waiwhakaata/Lake Hayes catchment for a total primary allocation of 134.75 l/s (

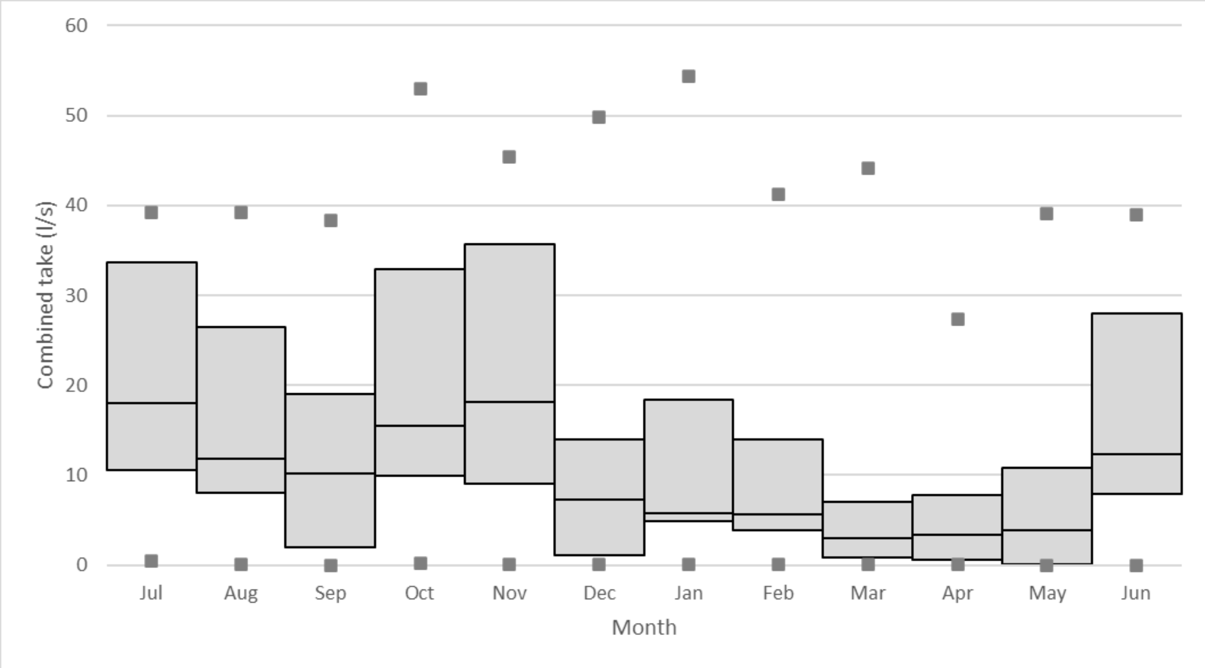

Figure 7 Monthly water abstraction (gap-filled) for Mill Creek upstream of Waiwhakaata/Lake Hayes. Boxes represent the monthly interquartile range (25th-75th percentile range), with the central line being the monthly median value. Smaller squares represent minimum/maximum values.

Table 3). The allocation and use based on these consents are considered by location within the catchment: Mill Creek (upstream Waiwhakaata/Lake Hayes), Waiwhakaata/Lake Hayes, and Hayes Creek (Waiwhakaata/Lake Hayes to Kawarau River).

At the time of writing, a consent is being processed (CONSENT NUMBER) for a water take (125.75 l/s) from the mid reaches of Mill Creek that will bring the total primary allocation up to 260 l/s. This resource consent is to divert water into a wetland area, with excess water being discharged back into Mill Creek approximately 500 m downstream. This consent is being processed as a consumptive take of water due to the distance between the point of take and downstream discharge point. However, the water taken will be returned to the source waterbody at a point downstream, where it will support instream values downstream of this discharge point, and it is available to downstream water users. Policy 6.4.2 specifies how primary allocation is to be calculated, which excludes takes where *"all of the water taken is immediately returned to the source water body"*.

4.4.1. Mill Creek

There are six resource consents to take surface water from the Mill Creek catchment upstream of Waiwhakaata/Lake Hayes, and one consent that is being processed at the time of writing. Three of these are in the upper reaches of tributaries of the upper catchment and are held by NZSki Ltd for snowmaking and potable water supply for the Coronet Peak ski field. Another take from McMullan Creek for irrigation and two other permits are held by Waterfall Park Developments Ltd for irrigation and site development. The total allocation of these takes is 85.7 l/s. The additional resource consent that is currently being processed (CONSENT NUMBER) is located in the middle reaches of Mill Creek. However, for the reasons stated above (Section 4.4), this permit is considered to be non-consumptive for the purpose of these analyses.

Consideration of water metering data for July 2015-February 2023[5] suggests that the cumulative take from Mill Creek or its tributaries usually represents less than 10% of the natural flows in Mill Creek, occasionally rising to almost 18% of the natural flows[6] (Figure 6). The annual average cumulative rate of take[7] from Mill Creek ranged from 8.43 l/s (2016-2017 hydrological year) to 13.2 l/s (2020-2021 hydrological year), while the maximum cumulative rate of take ranged from 39.2 l/s (2018-2019 and 2020-2021 hydrological years) to 54.4 l/s (2019-2020 hydrological year). Water use is greatest between June-November , likely associated with snow-making (Figure 7).

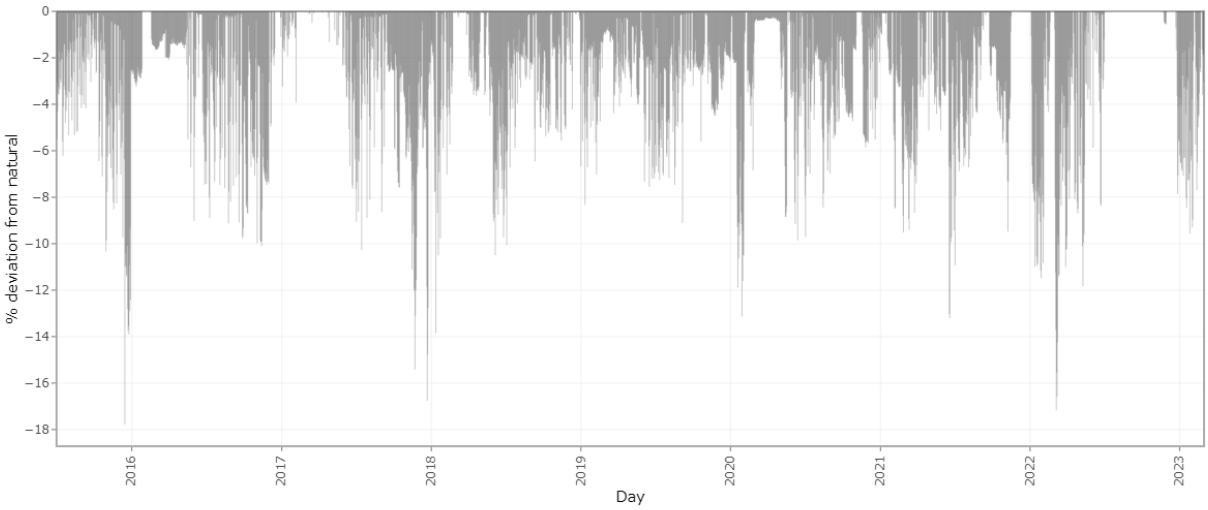

Figure 6 Water take as a proportion of natural flows Mill Creek between 2015 and 2023.

[5] Includes modelled water use where water metering data is not available for a water meter. Imputed data is based on seasonal water usage for that water meter.
[6] Estimated by adding metered water take back on to the measured flow at Mill Creek at Fish Trap.
[7] The average of the sum of all water takes at a point in time.

4.4.2. Waiwhakaata/Lake Hayes

There are three permits for a total take of 9.05 l/s from Waiwhakaata/Lake Hayes and a surface water depleting groundwater take near Rutherford Road Spring, with 40 l/s allocated against surface water allocation.

Water metering data for the Rutherford Road Spring take showed that the average take during December 2009 – 10 July 2022 was 10.2 l/s, with an upper quartile of 12.3 l/s and a maximum rate of take of 28.6 l/s on 27 January 2022.

4.4.3. Hayes Creek

A further two surface water takes are located on Hayes Creek downstream of Lake Hayes (maximum rate of take = 8.2 l/s) along with two surface water depleting groundwater takes (maximum surface depletion = 17.5 l/s). However, this allocation is not included in the water allocation for the Waiwhakaata/Lake Hayes catchment and is instead considered as allocation from unnamed tributaries of the Kawarau River.

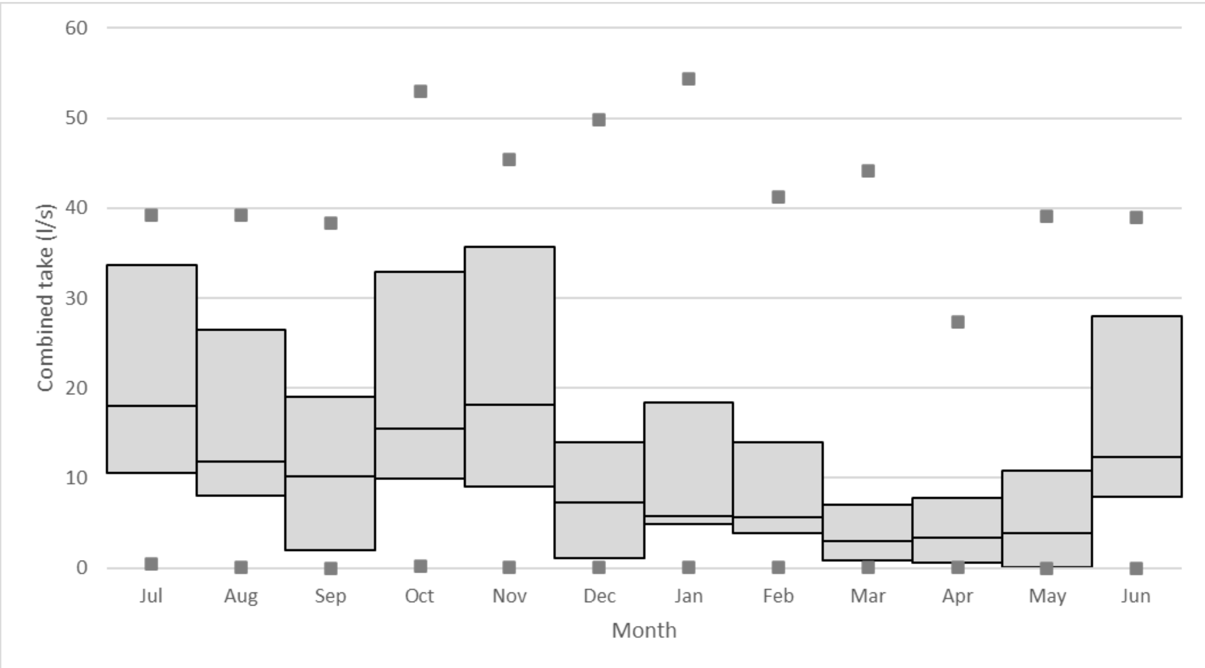

Figure 7 Monthly water abstraction (gap-filled) for Mill Creek upstream of Waiwhakaata/Lake Hayes. Boxes represent the monthly interquartile range (25th-75th percentile range), with the central line being the monthly median value. Smaller squares represent minimum/maximum values.

Table 3 Active resource consents for surface water takes (or flow-depleting groundwater takes) in the Mill Creek catchment.

Consent Number	Consent Expiry Date	Source	Purpose	Max rate (l/s)	Max monthly volume (m³)	Max annual volume (m³)
2004.011.V1	1/06/2025	Unnamed tributary of Station Creek	Potable water	4.3	-	57,350
2004.013	1/06/2025	Unnamed tributary of McMullan Creek	Potable water	1.5	-	14,000
RM21.284.01	21/07/2028	Four small streams on Coronet Peak ski field	Snow making	13.7	-	184,421
RM12.113.01	24/08/2042	Mill Creek	Irrigation	16.2	7,200	51,503
RM14.124.01	1/03/2042	McMullan Creek	Irrigation	50	74,300	282,150
RM20.296.02*	1/03/2027	Mill Creek	Site development	25*	-	-
CONSENT‡	TBC	Mill Creek	Wetland	125.75 ‡	-	-
CONSENT #	TBC	Mill Creek	Wetland	TBC	-	-
2000.592	1/02/2025	Waiwhakaata/Lake Hayes	Domestic supply and irrigation	3	3,750	-
RM16.278.01	1/10/2051	Waiwhakaata/Lake Hayes	Irrigation	2.55	1,500	6,012
2004.289.V1	12/07/2025	Waiwhakaata/Lake Hayes	Irrigation	3.5	-	9,600
2001.822†	20/5/2027	Groundwater – Lake Hayes	Community water supply	40	-	805.200
RM17.160.01	11/08/2042	Hayes Creek	Irrigation	2.2	5,892.5	69,379.2
RM17.073.01	15/06/2037	Hayes Creek	Irrigation and domestic use	6	16,163	76,330
RM18.188.01*†		Groundwater – Hayes Creek		5.3	1,720	17,640
RM14.077.01*†		Groundwater – Hayes Creek		12.2	21,390	251,850
RM17.160.01	11/08/2042	Hayes Creek	Irrigation	2.2	5,892.5	69,379.20

* Supplementary allocation when flows are above mean flow – this take is not considered in these assessments

† Groundwater take with surface water depletion

‡ This take is considered to be non-consumptive in these assessments

Supplementary allocation when flows are above 550 l/s– this take is considered to be non-consumptive in these assessments

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 Waiwhakaata/Lake Hayes catchment, brown trout (*Salmo trutta*) are likely 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 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 temperature data is available for Mill Creek at Fish Trap (Figure 8, Figure 9). These data are based on temperature data recorded by flow monitoring equipment at this site. In addition, water temperature is measured using a hand-held meter during monthly water quality monitoring. These handheld measurements verify the accuracy of the continuous data (linear regression: a = 0.0164, b = 0.9975, R^2=0.993, N=106).

Water temperatures in Mill Creek were below acute and chronic thermal criteria for brown trout (Figure 8, Figure 9). 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 in the Mill Creek catchment, the common mayfly *Deleatidium* is probably the most sensitive taxon, with an interim acute criterion of 21°C (Olsen *et al*. 2012). However, water temperatures in the lower Mill Creek were well within these criteria (Figure 8, Figure 9).

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

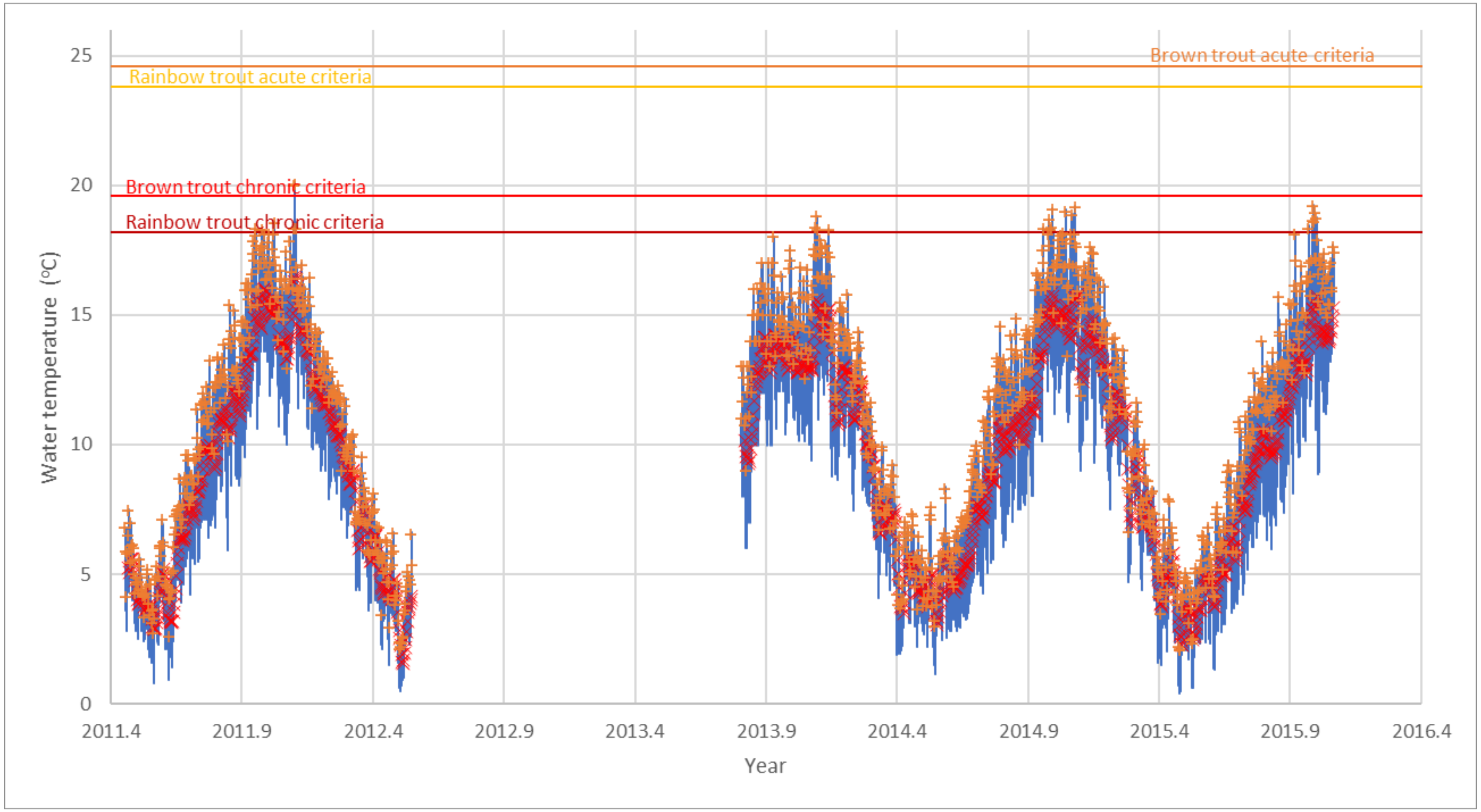

Figure 8 **Water temperature in Mill Creek at Fish Trap between June 2011 and January 2016. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red Xs are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.**

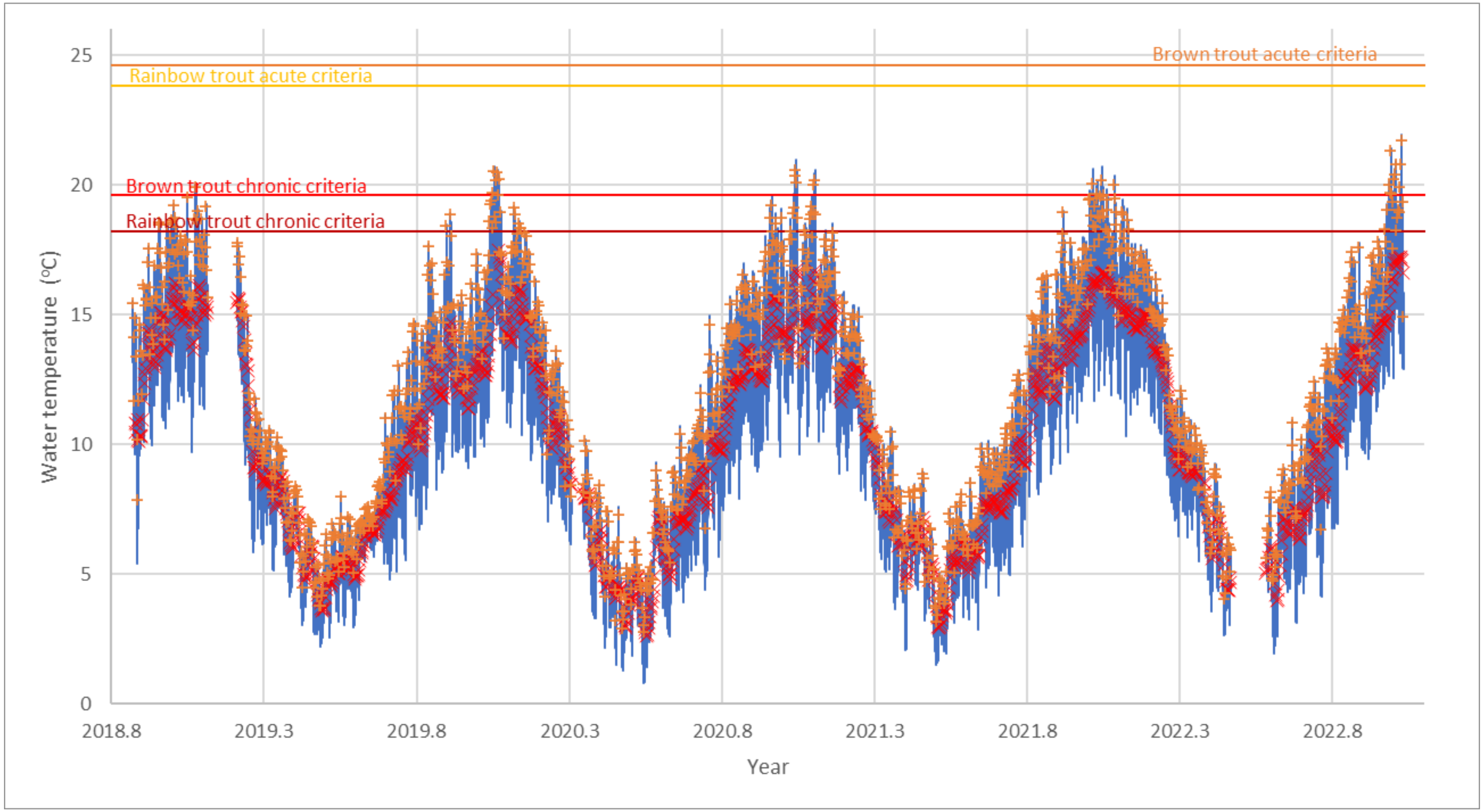

Figure 9 Water temperature in Mill Creek at Fish Trap between November 2018 and January 2023. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red Xs are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.

6. The aquatic ecosystem of the Waiwhakaata/Lake Hayes catchment

6.1. Periphyton

The periphyton community forms the slimy coating on the surface of stones and other substrates in freshwaters and can include various 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, fish, and some birds. 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 (e.g. Hamill, 2001; Wood *et al*., 2007). These include toxins that affect the nervous system (neurotoxins), liver (hepatotoxins), and dermatotoxins that can cause severe skin irritation.

No information is currently available on periphyton communities in Mill Creek.

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 (MCI; Stark, 1985) and its variants (e.g., semi-quantitative MCI (SQMCI); Stark, 1998) have been widely used in New Zealand to assess the effects of nutrients and sediment (Wagenhoff *et al*., 2016).

Macroinvertebrate samples were collected from Mill Creek at Fish Trap between 2006 and 2018. Between 2014 and 2018, MCI scores for this site (Range: 81-95, mean = 87, N=5), were indicative of 'poor' habitat/water quality based on the criteria of Stark & Maxted (2004) (Figure 10a). Similarly, SQMCI scores (Range: 3.53-5.80, mean = 4.51, N=5), ranged from 'poor' to 'good' habitat/water quality based on the criteria of Stark & Maxted (2004), although the mean score was indicative of 'fair' habitat/water quality (Figure 10b). Average Score Per Metric (ASPM) scores (Range: 0.25 -0.41, mean = 0.30, N=5), ranged from 'mild to moderate loss of ecological integrity' to 'moderate to severe loss of ecological integrity'. However, the mean score indicated 'mild to moderate loss of ecological integrity' (based on Table 15 of the NPSFM 2020) (Figure 10c). Trend analyses on these metrics indicate that MCI and SQMCI scores declined between 2001 and 2022, while no trend was evident for ASPM (Table 4).

Between 2001 and 2004, the common mayfly *Deleatidium*, riffle beetles (Elmidae), and the sand-cased caddis fly *Pycnocentria* were consistently the most abundant macroinvertebrate taxa in Mill Creek. However, the abundance of *Deleatidium* and riffle beetles have declined since 2005, along with the net-spinning caddis fly *Hydropsyche (Aoteapsyche)*. From 2005, the mudsnail *Potamopyrgus* and segmented worms (Oligochaeta) became more consistently abundant. These changes indicate a deterioration in water quality in Mill Creek, probably an increase in sedimentation.

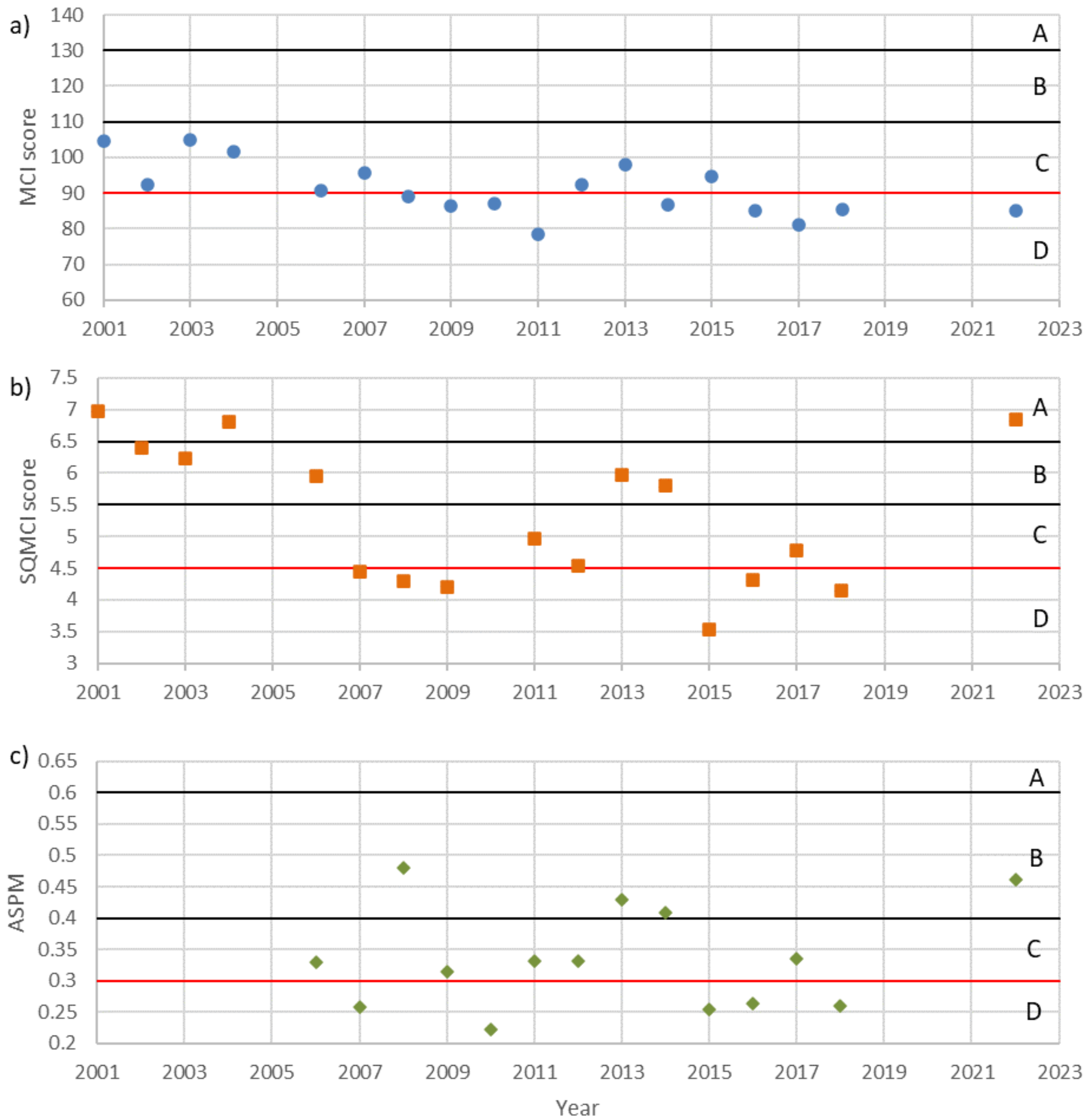

Figure 10 Macroinvertebrate indices for Mill Creek at Fish Trap between 2007 and 2018. a) Macroinvertebrate community index (MCI), b) semi-quantitative MCI (SQMCI) and c) average score per metric (ASPM). Each plot includes thresholds for attribute states based on Tables 14 and 15 of the National Objectives Framework.

Table 4 Trends in macroinvertebrate metrics in Mill Creek at Fish Trap state of the environment monitoring site between 2001 and 2023. Analysis conducted in Time Trends version 9.0. 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	-2.919	0.004	Decreasing trend virtually certain
SQMCI	-1.742	0.081	Decreasing trend likely
ASPM	0.438	0.661	-

6.3. Fish

6.3.1. Indigenous fish

Three indigenous freshwater fish species have been recorded from the Waiwhakaata/Lake Hayes catchment – longfin eel/tuna, common bully and kōaro (Table 5; Figure 11). Longfin eel/tuna have been recorded from Waiwhakaata/Lake Hayes, although given that the Roxburgh and Clyde Dams are barriers to migration by longfin eel to the upper Clutha/Mata-Au and Kawarau catchments, populations of longfin eel/tuna in the Waiwhakaata/Lake Hayes catchment have likely declined relative to historical levels. Common bully have been recorded from Waiwhakaata/Lake Hayes, Hayes Creek and the lower reaches of Mill Creek. The common bully upstream extent is likely limited to downstream of the 43 m-high waterfall at Millbrook. Kōaro are strong upstream migrants found in much of the Waiwhakaata/Lake Hayes catchment. They are the only indigenous species found upstream of the waterfall at Millbrook Resort. Longfin eels and kōaro are classified as at risk – declining, while common bully are classified as not threatened (Dunn *et al*., 2017).

The lack of non-migratory indigenous fish, such as Clutha flathead galaxias and upland bully, from much of the Kawarau catchment (with some exceptions) is considered a legacy of Pleistocene glaciation (McDowall, 2010).

6.3.2. Introduced fish

Brown trout are widespread in the Waiwhakaata/Lake Hayes/Mill Creek catchment, while perch are abundant in Waiwhakaata/Lake Hayes and Hayes Creek (Table 5; Figure 11).

No angler effort has been recorded in Mill Creek in the National Angler Survey (Unwin, 2016). However, Waiwhakaata/Lake Hayes has historically received more than 1,400 angler days and is considered to be a regionally significant trout fishery and wildlife habitat (Otago Fish & Game Council, 2015), although angler usage has been markedly lower in recent surveys (Table 6). Mill Creek provides spawning habitat for the Waiwhakaata/Lake Hayes fishery, at least as far upstream as a 43 m waterfall near Millbrook Resort.

Table 5 Fish species recorded from the Mill Creek catchment.

Family	Common name	Species	Threat classification	Subcatchments
Anguillidae	Longfin eel, tuna	*Anguilla dieffenbachii*	Declining	Waiwhakaata/Lake Hayes
Eleotridae	Common bully	*Gobiomorphus cotidianus*	Declining	Mill Creek, Waiwhakaata/Lake Hayes, Hayes Creek
Galaxidae	Kōaro	*Galaxias brevipinnis*	Declining	Mill Creek, Dan O'Donnell Creek
Salmonidae	Brown trout	*Salmo trutta*	Introduced and naturalised	Mill Creek, Waiwhakaata/Lake Hayes, Dan O'Donnell Creek, Hayes Creek
Percidae	Perch	*Perca fluviatilis*	Introduced and naturalised	Waiwhakaata/Lake Hayes, Hayes Creek

Table 6 Angler effort on Waiwhakaata/Lake Hayes based on the National Angler Survey (Unwin, 2016)

	NAS (angler days)			
Waterway	2014/15	2007/08	2001/02	1994/95
Waiwhakaata/Lake Hayes	180 ± 90	500 ± 160	1,540 ± 830	1,430 ± 480

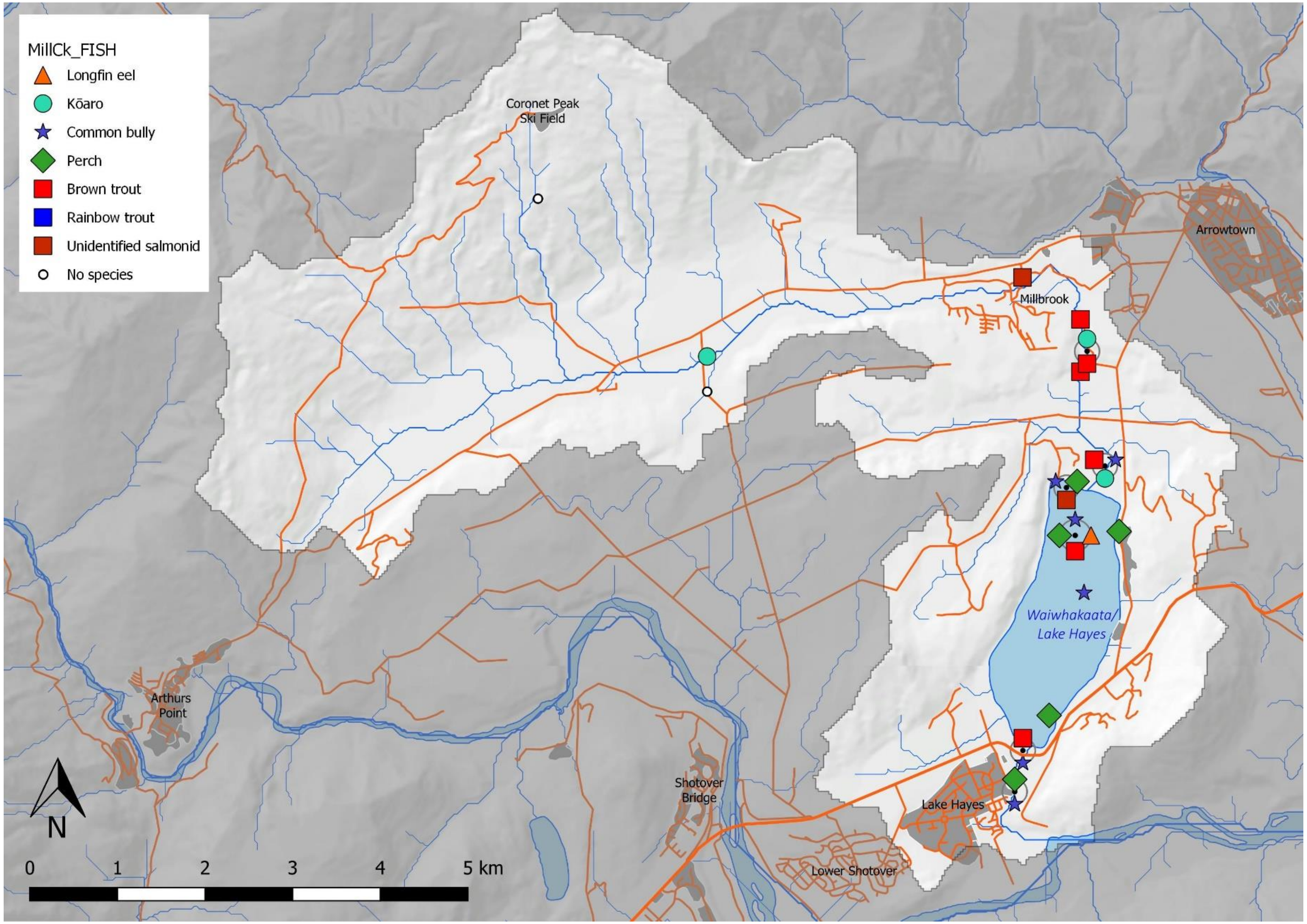

Figure 11 Fish distribution in the Waiwhakaata/Lake Hayes catchment

6.4. Current ecological state

The current ecological state of Mill Creek and Waiwhakaata/Lake Hayes reflects the cumulative effects of all development and activities occurring in the upstream catchment as well as the presence of introduced sports fish. Comparison of the current state of Mill Creek and Waiwhakaata/Lake Hayes with objectives for the Dunstan Rohe provides insight into whether current conditions are consistent with the objectives proposed in the Land & Water Regional Plan, although this data does not identify the relative contribution of the different catchment factors to these environmental outcomes.

At the time of writing, the proposed objectives for the Dunstan Rohe include the following narrative objectives: *"Freshwater bodies within the Dunstan Rohe 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 7 below.

6.4.1. Ecosystem health

In addition to the ecosystem health and human contact values identified in Table 7, the proposed objectives for fishing, animal drinking water, cultivation and production of food, beverages and fibre, commercial and industrial use, and drinking water supply are measured by the target attribute states for ecosystem health and human contact presented in Table 7 and Table 8. Attributes for natural form and character and threatened species within the Dunstan Rohe are under development at the time of writing, so it was not possible to consider the current state of the Mill Creek catchment relative to these attributes.

Mill Creek

Table 7 presents the available information on the current attribute state for the Mill Creek at Fish Trap and compares the current state to the proposed target attribute states for the Dunstan Rohe. Attributes for Ecosystem Health – Aquatic life do not meet the target states for MCI & QMCI scores (Table 7). Macroinvertebrate community composition is affected by a range of factors including flow., periphyton composition and biomass, predation by salmonids, water physicochemistry (e.g. water temperature, dissolved oxygen) and habitat characteristics (e.g. substrate composition, fine sediment cover). The MCI/QMCI scores observed in Mill Creek likely reflect the effects of sedimentation from land use and development within the catchment. This is consistent with the trend for increased turbidity in Mill Creek (20-y trend, Annual SenSlope = 0.12275, improving trend exceptionally unlikely; Ozanne et al., 2023).

Waiwhakaata/Lake Hayes

Table 8 presents available information on the current attribute state for Waiwhakaata/Lake Hayes and compares the current state to the proposed target attribute state for lakes within the Dunstan Rohe. Attributes for Ecosystem Health – Aquatic life does not meet the target states for phytoplankton biomass and the Submerged Plant Index (SPI) attributes for native condition and invasive species (Table 7). The high phytoplankton biomass reflects the high nutrient concentrations in the lake, while the SPI attributes are due to degraded water quality (such as sedimentation, shading by suspended sediment and phytoplankton, and growth of epiphytic algae) and the invasive macrophyte *Elodea*[8].

6.4.2. Water quality

Mill Creek

Water quality in Mill Creek does not meet the proposed objectives in the LWRP for ammoniacal nitrogen (toxicity), visual clarity, and the faecal indicator bacterium *Escherichia coli* (Table 7).

Ammoniacal nitrogen concentrations exceeded the proposed objective based on the annual 95th percentile value. The most likely source of elevated ammoniacal nitrogen is from livestock or human waste, although it can be released from the decomposition of plant material under nutrient-poor conditions. It is unclear whether water allocation would contribute to the elevated concentrations observed in Mill Creek. The concentrations of ammoniacal nitrogen observed in Mill Creek are at levels that are expected to *"starts impacting occasionally on the 5% most sensitive species"*[9] at the Fish Trap flow site.

Water clarity in Mill Creek at Fish Trap is poor (<1 m) and is below the national bottom line (Table 7). Water clarity is negatively correlated with flow, with reduced clarity at higher flows. Increased flow results in higher water velocities that can mobilise larger sediment particles and carry suspended particles further before they settle out. Therefore, water allocation is unlikely to account for the low water clarity observed in Mill Creek.

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. The greater water depths and reduced water clarity during such events reduce microbial die-off from exposure to the UV in sunlight (Wilkinson *et al*., 2011). In contrast, during periods of low flows, there is little transport of microbes and shallow water depths, and clear water and low water velocities favour microbe die-off (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 Mill Creek.

[8] https://lakespi.niwa.co.nz/lake/54190

[9] Description for B-band of Table 5 – Ammonia (toxicity) of the National Objectives Framework, NPS-FM (2020), amended December 2022.

Waiwhakaata/Lake Hayes

Water quality in Waiwhakaata/Lake Hayes does not meet the proposed objectives in the LWRP for total phosphorus and phytoplankton biomass. Both outcomes reflect the long-term eutrophication of the Waiwhakaata/Lake Hayes (Schallenberg & O'Connell-Milne 2023), rather than being a direct effect of water abstraction within the Mill Creek catchment, especially given the low level of water abstraction observed (Section 4.4).

6.4.3. Human contact

Mill Creek

Water quality in Mill Creek does not meet the proposed objectives for human contact in the LWRP for the faecal indicator bacterium *Escherichia coli* or visual clarity (Table 7). However, as discussed in Section 6.4.2 above, water allocation is unlikely to account for the low water clarity or elevated *E. coli* observed in Mill Creek.

Waiwhakaata/Lake Hayes

Water quality in Waiwhakaata/Lake Hayes does not meet the proposed objectives for human contact in the LWRP for *E. coli* and phytoplankton biomass. The high phytoplankton biomass observed in Waiwhakaata/Lake Hayes reflect the long-term eutrophication of the Waiwhakaata/Lake Hayes (Schallenberg & O'Connell-Milne 2023), rather than being a direct effect of water abstraction within the Mill Creek catchment. The most likely impact of flow management on *E. coli* concentrations in Waiwhakaata/Lake Hayes is via the delivery of *E. coli* from Mill Creek into Waiwhakaata/Lake Hayes. However, as discussed at Section 6.4.2, the relationship between flows and *E. coli* concentrations in Mill Creek is complicated.

Table 7 Comparison of the current attribute state in the Mill Creek at Fish Trap with proposed objectives for the Dunstan Rohe based on available information.

Value	Attribute	Target attribute state	Current attribute state Mill Creek at Fish Trap
Ecosystem health – (all biophysical components)			
	Periphyton (trophic state) (chlorophyll *a*) (mg/m²)	B	Not able to be determined
	Fish index of biotic integrity	B	A Mean (5-y): 37.2
	Macroinvertebrate Community Index (MCI) score	B	D 2014-2018: 87
	Quantitative Macroinvertebrate Community Index (QMCI) score	B	C 2014-2018: 4.51
	Macroinvertebrate Average Score Per Metric (ASPM)	B	B 2014-2018: 0.30
EH – Water quality	Ammonia (toxicity) (mg/L)	A	B Median: <0.005 95th percent: 0.024
	Nitrate (toxicity) (mg/L)	A	A Median: 0.35 95th percent: 0.50
	Suspended fine sediment - Visual clarity (m)	A	D 0.96 m
	Dissolved oxygen (mg/L)	A	Not able to be determined
	Dissolved reactive phosphorus (mg/L)	A	A Median: 0.0038
EH - Habitat	Deposited fine sediment (% cover)	A	Not able to be determined
EH – Ecological processes	Ecosystem metabolism (both gross primary production and ecosystem respiration)	A	Not able to be determined
Human contact	*Escherichia coli* (cfu/100 mL)	A	C Median: 100 95th percent: 548 % >260: 26% % >540: 14%
	E. coli (primary contact sites) – 95th percentile (cfu/100 mL)	A	D 95th percent: 548
	Visual clarity (m)	A	D 0.96 m

Table 8 Comparison of the current attribute state in the Waiwhakaata/Lake Hayes with proposed objectives for the Dunstan Rohe based on available information.

Value	Attribute	Target attribute state	Current attribute state Waiwhakaata/Lake Hayes
Ecosystem health – (all biophysical components)			
	Phytoplankton mg chl-a/ m^3	B	D
	Submerged plants - Lake Submerged Plant (Native Condition Index)	B	C[10]
	Submerged plants - Lake Submerged Plant (Invasive Impact Index)	B	C[10]
EH – Water quality	Total nitrogen (mg/m^3)	B	B
	Total phosphorus (mg/m^3)	B	C
	Lake-bottom dissolved oxygen (mg/L)	B	Not able to be determined
	Mid-hypolimnetic dissolved oxygen (mg/L)	B	Not able to be determined
	Ammonia (toxicity) (mg/L)	A	B
	Dissolved oxygen (mg/L)	A	Not able to be determined
Human contact	*Escherichia coli* (cfu/100 mL)	A	B
	E. coli (primary contact sites) – 95^{th} percentile (cfu/100 mL)	A	A
	Cyanobacteria (planktonic) - Biovolume mm^3/L	A	A
	Phytoplankton mg chl-a/ m^3	B	D

[10] https://www.lawa.org.nz/explore-data/otago-region/lakes/lake-hayes/

7. Consideration of current minimum flows and allocation limit

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 is 180 l/s in Mill Creek at the Fish Trap hydrological site and the current allocation limit is 260 l/s, although the current consented maximum rate of take is 134.75 l/s. For this analysis, the resource consent CONSENT NUM was not considered, as for the purposes of this analysis, this take is non-consumptive.

The current combination of minimum flow/allocation limit in the Waiwhakaata/Lake Hayes catchment means that when natural flows are above 440 l/s, all resource consents in the catchment could be exercised at their maximum rate of take. Theoretically this means that flows could be drawn down to 180 l/s. When natural flows are between 181 l/s and 440 l/s, all consent holders would not be able to fully exercise their consents and would need to ration[11] water to ensure the minimum flow is maintained, although in practice in the Mill Creek water users probably don't have to ration because the actual water use is low. Minimum flows are often the focus of concerns by interested parties, however, the river will be above the minimum flow much of the time. The allocation limit restricts the potential ecological effects of abstraction at all flows and affects water users' ability to abstract water at their consented rate (i.e., reliability of supply). Therefore, particular consideration is required when setting the allocation limit.

Inspection of the observed flow duration curve for Mill Creek shows that flows have rarely dropped below 230 l/s (exceeded 95% of the time), with flows dropping to below 200 l/s less than 1% of the time (Section 9). These results suggest that the current minimum flow is inconsequential to water users at current levels of water take which generally represents less than 10% of the natural flows, with occasional periods when up to 18% of the naturalised flows are abstracted (Figure 6). This represents a small degree of hydrological alteration. However, should current water use change (such as current users fully exercising their consents, or development of storage, or other changes that mean that allocation is more fully utilised), there is the potential for the water allocation pressure within the Waiwhakaata/Lake Hayes catchment to increase significantly compared to the present situation. The potential consequences of the current minimum flow and allocation limit are considered further in Section 8.

The composition of the macroinvertebrate community of Mill Creek (as measured by MCI and QMCI scores) does not meet the proposed objectives for the Dunstan Rohe and these metrics have declined since 2001. Macroinvertebrate community composition has changed over this time with a decline in the abundance of *Deleatidium* and riffle beetles (Elmidae) since 2005, along with the net-spinning caddis fly *Hydropsyche (Aoteapsyche),* while the mudsnail *Potamopyrgus* and segmented worms (Oligochaeta) became more consistently abundant. These changes are consistent with a deterioration in water quality in Mill Creek, most probably an increase in sedimentation. It is considered that water allocation does not account for the low water clarity or elevated *E. coli* observed in Mill Creek (Section 6.4.2).

[11] Water rationing is when consent holders work together to either take water at a lower rate (for practical reasons this usually done in quarters, i.e. 75%, 50% or 25% of consented maximum rate of take), or roster when they take water to maintain flows above the minimum flow.

The degraded water quality in Waiwhakaata/Lake Hayes is not directly related to the effects of water abstraction/allocation, although irrigation may contribute to increased nutrient inputs to the lake by supporting more intensive land use activities. Water inflows from Mill Creek may affect hydrodynamics in Waiwhakaata/Lake Hayes (depending on the temperature of inflows and conditions in Waiwhakaata/Lake Hayes) and will contribute to increased outflows from Waiwhakaata/Lake Hayes. However, such effects are expected to vary through time and full consideration of the effects of water abstraction on hydrodynamics and water quality in Waiwhakaata/Lake Hayes would require specific investigations (e.g., such as those of McBride *et al*., 2019) that are beyond the scope of this report.

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 9). Minimum flows considered ranged from the default approach of Hayes et al. (2021; minimum flow of 90% of 7-d MALF) to the current minimum flow (~70% of the 7-d MALF). Allocation limits considered ranged from the default allocation of 20% of the 7-d MALF (equivalent to the observed maximum cumulative rate of take) to the current allocation limit (260 l/s, ~100% of the 7-d MALF).

To consider the hydrological effects of the various combinations of minimum flow/allocation, simulations were run for the period 1 July 2012 – 30 June 2021 using naturalised flows estimated by adding water take (based on water metering data for water users in the upstream of the Fish Trap flow monitoring site) back onto the observed flows at Mill Creek at Fish Trap. Water takes were simulated to be restricted by pro-rata partial restrictions to maintain the simulated minimum flow and seasonal water usage was based on historical patterns of seasonal water usage.

Table 9 Minimum flow and allocation limits considered in this analysis.

Minimum flow		Allocation limit		
Option	% 7-d MALF	Option	% 7-d MALF	Description
180 l/s	69%	260 l/s	100%	Current minimum flow and allocation limit.
		135 l/s	52%	Current minimum flow and current consented allocation.
		80 l/s	30%	Current minimum flow and current combined maximum observed rates of take[12].
		55 l/s	20%	Current minimum flow and maximum observed cumulative rate of take[13].
195 l/s	75%	135 l/s	52%	Minimum flow of 195 l/s and current consented allocation.
		80 l/s	30%	Minimum flow of 195 l/s and current combined maximum observed rates of take.
		55 l/s	20%	Minimum flow of 195 l/s and maximum observed cumulative rate of take.
210 l/s	80%	135 l/s	52%	Minimum flow of 210 l/s and current consented allocation.
		80 l/s	30%	Minimum flow of 210 l/s and current combined maximum observed rates of take.
		55 l/s	20%	Minimum flow of 210 l/s and maximum observed cumulative rate of take.
230 l/s	90%	135 l/s	52%	Minimum flow of 230 l/s and current consented allocation.
		80 l/s	30%	Minimum flow of 230 l/s and current combined maximum observed rates of take.
		55 l/s	20%	Minimum flow of 230 l/s and maximum observed cumulative rate of take.

[12] The sum of the maximum observed rate of take for each consent
[13] The maximum of the observed combined rate of take at any point in time

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[14] are calculated. These indices are used to calculate an overall score, which is categorised based on the risk of ecological impact (**Error! Reference source not found.**). The results of these simulations are presented in Table 11.

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

Table 10 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

As expected, for any given minimum flow, the higher the allocation limit, the higher the degree of hydrological alteration – as reflected in the time spent at minimum flow and deviation from the naturalised flow (as evident in Table 11). Similarly, for any given allocation limit, an increased minimum flow typically results in reduced deviation from the naturalised flow, and reduced reliability for water users, and may increase the duration of flows at the minimum flow (Table 11).

These simulations confirm that the current minimum flow (180 l/s) and allocation limit (260 l/s), if fully allocated, would result in a high risk of ecological impact, with long periods at the minimum flow and a significant deviation from natural flows (Figure 12a). Given that macroinvertebrate communities do not meet the proposed objectives in LWRP despite the current consented allocation (134.75 l/s) being considerably lower than the allocation limit in Schedule 2A, the full implementation of the Schedule 2A allocation limit is not consistent with the proposed instream ecology objectives for the Dunstan Rohe.

The current minimum flow (180 l/s) and an allocation limit reflecting the current consented allocation (134.75 l/s) results in a low risk of impact, although it is expected that macroinvertebrate communities would continue not to meet the proposed objectives in LWRP. This scenario may result in the minimum

[14] 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.

flow being reached more frequently and for longer periods than at present if the current water allocation is utilised more fully (Figure 12b; Table 11).

The current minimum flow (180 l/s) and an allocation limit reflecting the current consented allocation (80 l/s) results in a low risk of impact (Figure 12c), while the current minimum flow (180 l/s) with an allocation limit of 55 l/s results in a unimpacted degree of hydrological alteration (Figure 12d).

Comparison of the plots with equivalent allocation values in Figure 12, Figure 13, Figure 14 and Figure 15 show that the minimum flow has little effect on the hydrological outcome compared to the effects of the different levels of allocation. The main effects of higher minimum flows are to increase the time spent at the minimum flow (sometimes referred to as flat-lining) (Figure 12, Figure 13, Figure 14 and Figure 15).

Table 11 Comparison of the hydrological effects of different minimum flow/allocation limit combinations in Mill Creek. CV = coefficient of variation.

Minimum flow (l/s)	Allocation limit (l/s)	Monthly		Min/max means		Date/timing		Pulse count/duration		Rate of change		DHRAM	Description
		CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean		
Observed[15]		0	0	0	0	0	0	0	0	0	0	0	Un-impacted
180	260	1	2	0	0	0	0	3	1	3	1	11	High risk of impact
180	135	0	1	0	0	0	0	0	0	3	0	4	Low risk of impact
180	80	0	0	0	0	0	0	0	0	1	0	1	Low risk of impact
180	55	0	0	0	0	0	0	0	0	0	0	0	Un-impacted
195	135	0	1	0	0	0	0	3	1	3	0	8	Moderate risk of impact
195	80	0	0	0	0	0	0	0	0	1	0	1	Low risk of impact
195	55	0	0	0	0	0	0	0	0	0	0	0	Un-impacted
210	135	0	1	0	0	0	0	3	1	3	0	8	Moderate risk of impact
210	80	0	0	0	0	0	0	0	0	1	0	1	Low risk of impact
210	55	0	0	0	0	0	0	0	0	0	0	0	Un-impacted
230	135	0	1	0	0	0	0	3	1	3	0	8	Moderate risk of impact
230	80	0	0	0	0	0	0	0	0	1	0	1	Low risk of impact
230	55	0	0	0	0	0	0	0	0	0	0	0	Un-impacted

[15] Observed flows are the flows measured at the Mill Creek at Fish Trap flow monitoring site, which reflects actual take and use of water upstream of this location

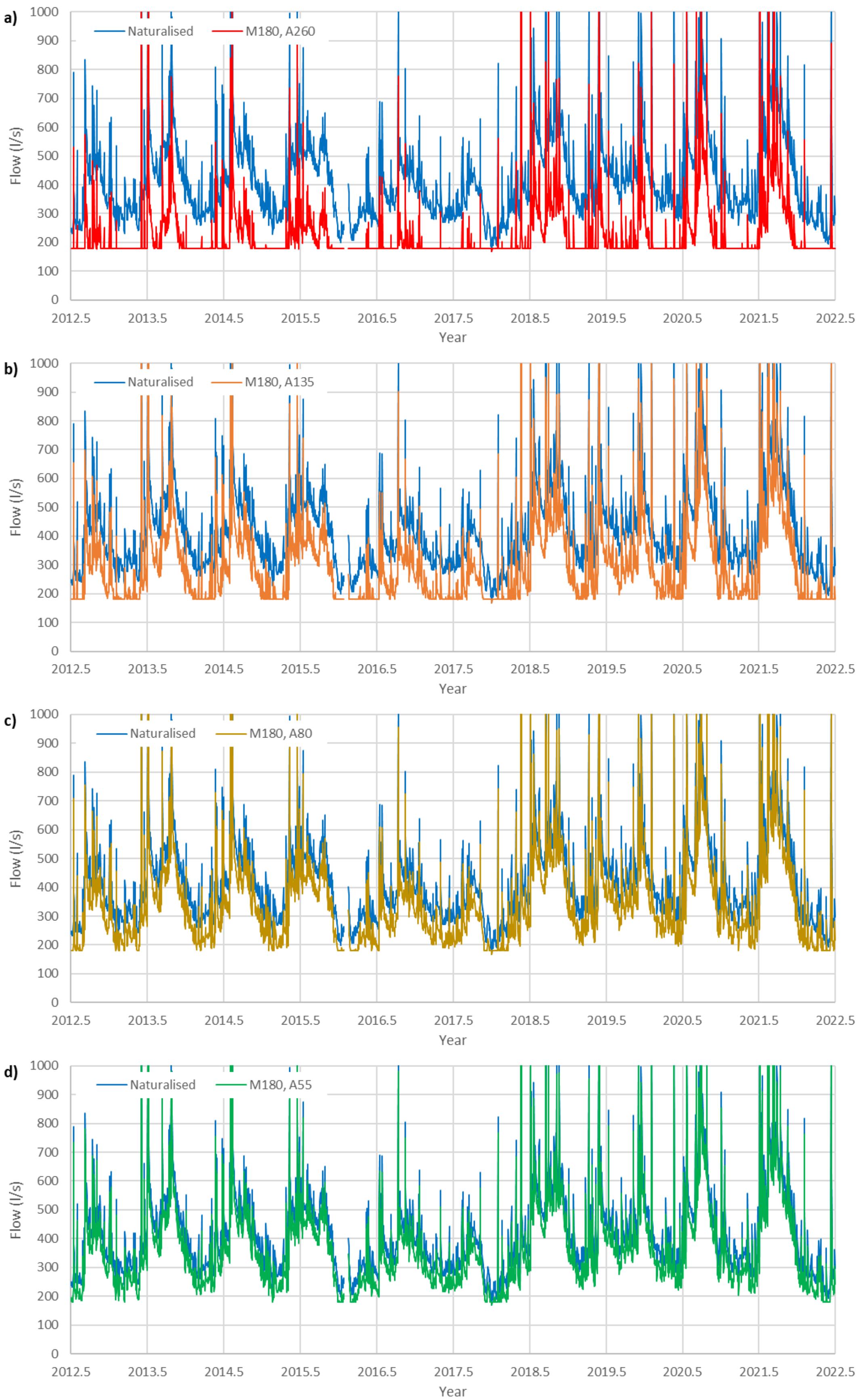

Figure 12 Hydrographs of allocation scenarios with a minimum flow of 180 l/s. a) Current allocation limit 260 l/s, b) allocation limit of 135 l/s, c) allocation limit of 80 l/s, d) allocation limit of 55 l/s.

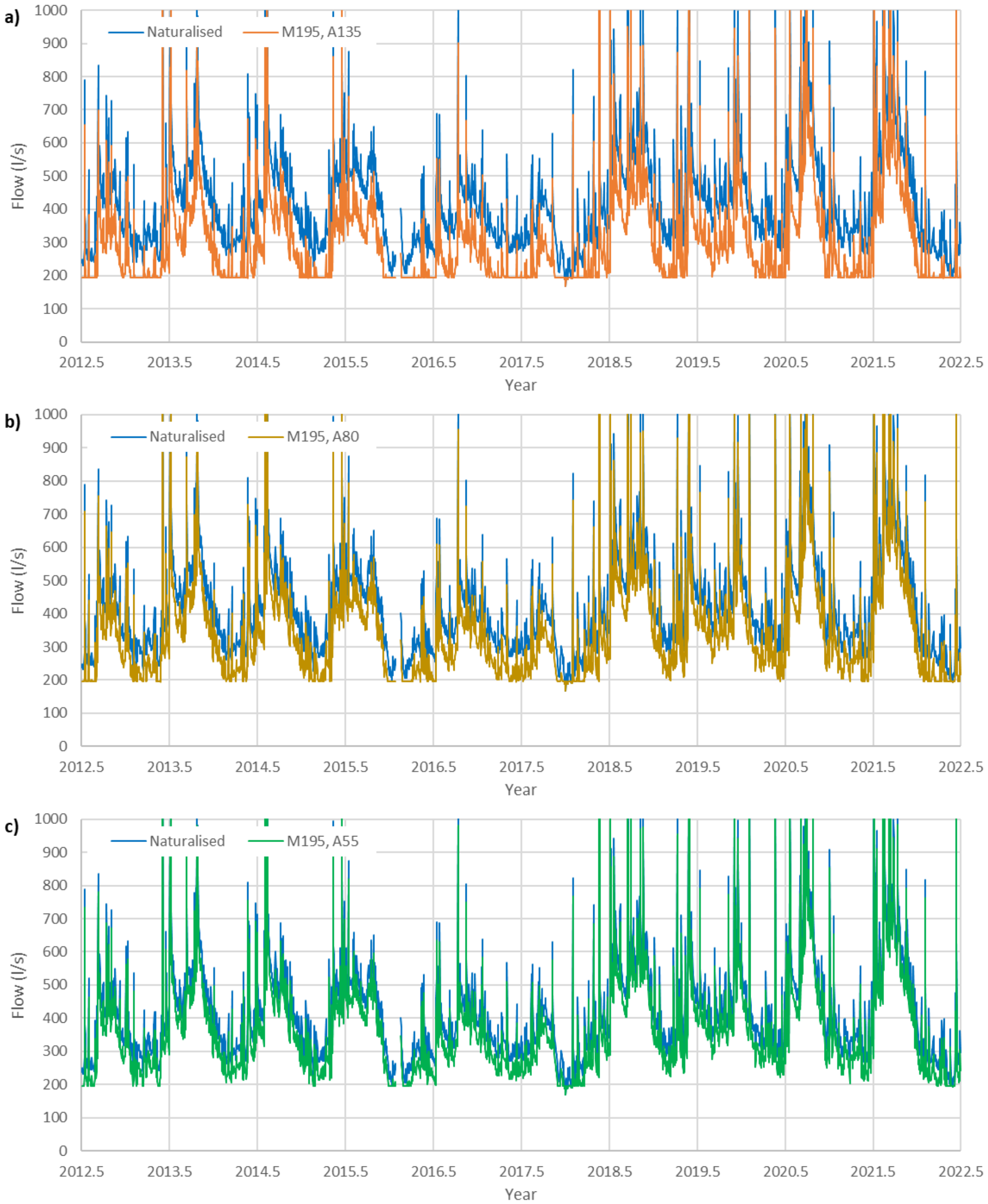

Figure 13 Hydrographs of allocation scenarios with a minimum flow of 195 l/s. a) allocation limit of 135 l/s, b) allocation limit of 80 l/s, c) allocation limit of 55 l/s.

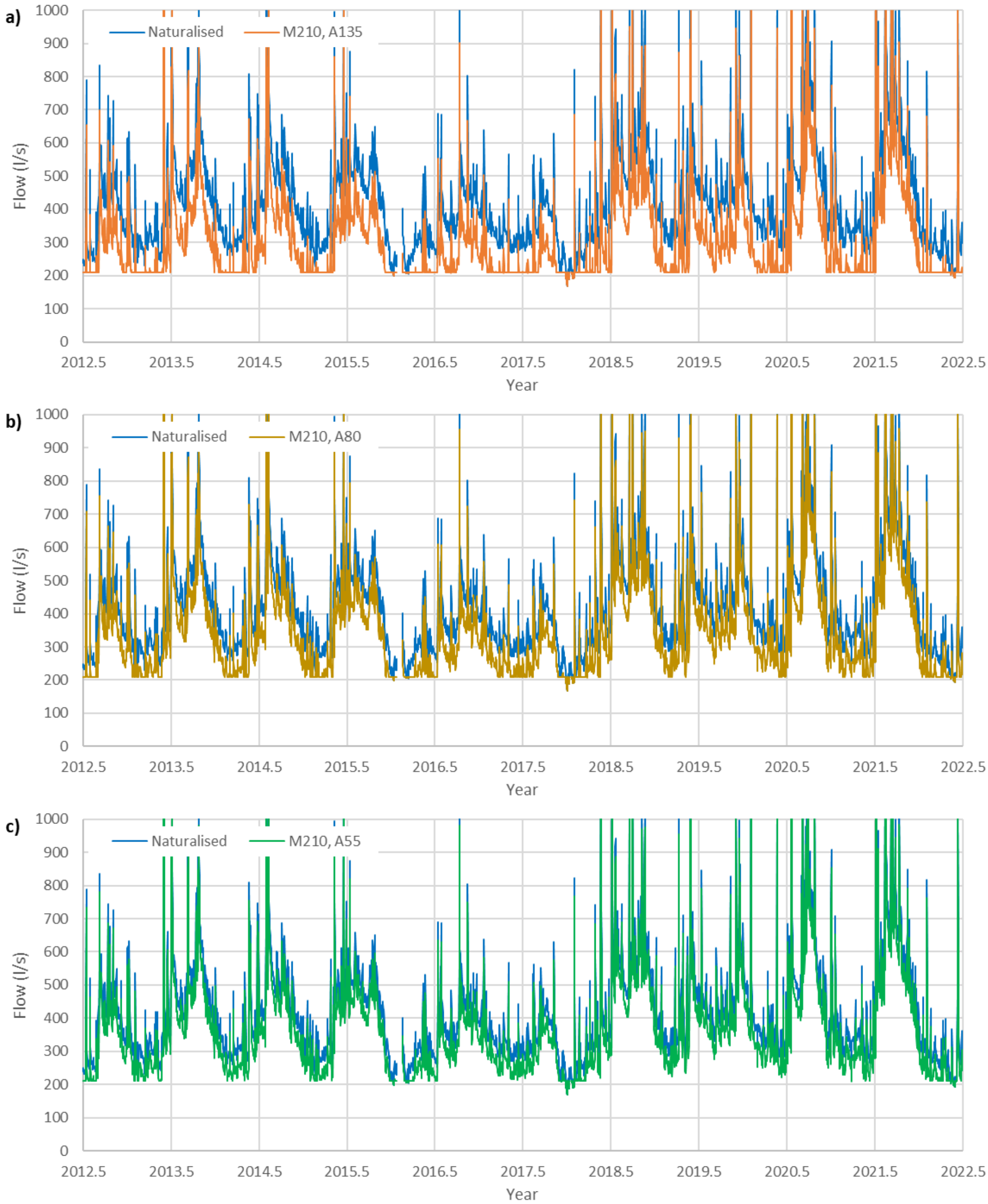

Figure 14 Hydrographs of allocation scenarios with a minimum flow of 210 l/s. a) allocation limit of 135 l/s, b) allocation limit of 80 l/s, c) allocation limit of 55 l/s.

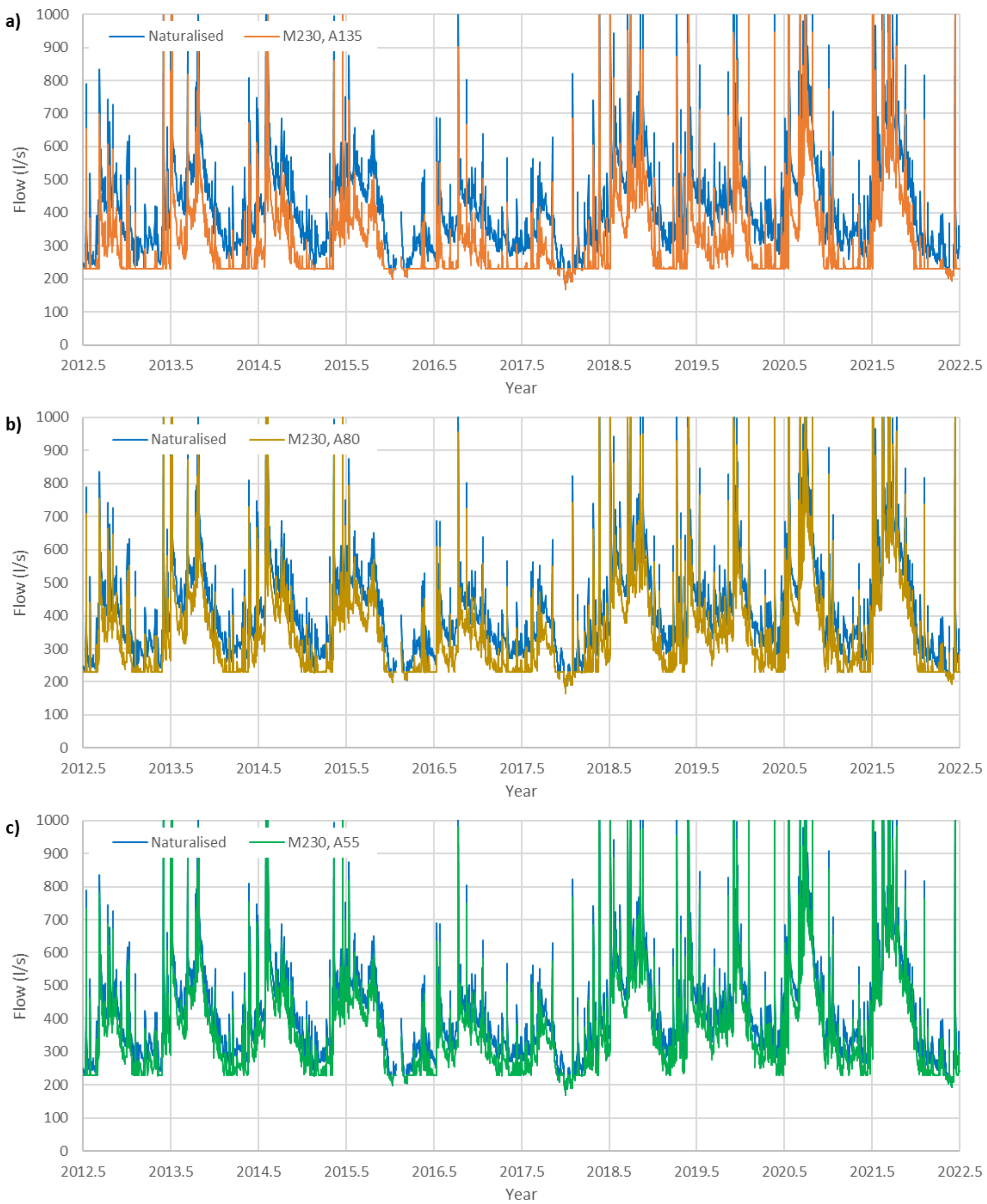

Figure 15 Hydrographs of allocation scenarios with a minimum flow of 230 l/s. a) allocation limit of 135 l/s, b) allocation limit of 80 l/s, c) allocation limit of 55 l/s.

8.1. Potential effects of climate change in the Waiwhakaata/Lake Hayes 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[16]) for the period 2031-2050.

The probability, magnitude and duration of low flow events in the Waiwhakaata/Lake Hayes catchment is expected to be similar to, or slightly less than what is currently experienced (Table 12). Climate change is not expected to reduce habitat suitability for sensitive species (via increased water temperatures) in the Waiwhakaata/Lake Hayes catchment by 2040 given that current temperatures are well within the tolerances of the most sensitive species present in the catchment (see Section 0).

The predicted changes in the hydrology of Mill Creek resulting from climate change include slightly higher mean annual flow and higher flood magnitudes, which may enhance flushing of fine sediments and periphyton (Table 12), which is expected to be a positive ecological effect, particularly on the macroinvertebrate community of Mill Creek.

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

Table 12 Potential effects of climate change on the Waiwhakaata/Lake Hayes 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 Mill Creek	Potential ecological consequences
Temperature	• Increased mean temperatures (0.6-1.2°C) • Increased annual mean maximum temperature (0.7-1.7°C) • Small increase in number of hot days (>30°C) (increase by 2.3-2.6 days per annum) • Reduced frost days (-10.5--11.9 days per year) 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	• Increase in annual mean rainfall (5-6%) • Small increase in summer mean rainfall (1 - 4%) • Increased winter rainfall (11-14%) • Similar or slightly reduced risk of low rainfall events • Small increase in heavy rain days (>25 mm; +0.7-+0.9 days per annum) • Increase in peak rainfall intensity	• Similar or slightly reduced likelihood and/or magnitude of low flow events • Potential increase in magnitude of high flow events	• Enhanced flushing of sediment and periphyton
Snow	• Small reduction in snow days	• Reduced snowpack • Earlier and/or shorter spring snowmelt • Larger winter floods	• Enhanced flushing of sediment and periphyton
Hydrology	• Little change in Q95 flow • Slight increase in mean flow • Increased mean annual flood	• Low flows similar magnitude to existing • Irrigation demand may slightly decrease • Increased frequency and/or magnitude of flushing flows • Reliability for irrigators similar or slightly higher than present	• Enhanced flushing of sediment and periphyton

9. Conclusions

Available information on the hydrology, aquatic values, and the current state of the Mill Creek were compared to the proposed objectives for the Dunstan Rohe set out in the proposed Otago Land and Water Regional Plan with the objective of informing decision making on water allocation and flow management in the Waiwhakaata/Lake Hayes catchment.

The current minimum flow of 180 l/s and allocation limit of 260 l/s have been in place since 2004. Thus, the current state of Mill Creek provides an indication of whether the current minimum flow/allocation limit are likely to contribute to the achievement of proposed environmental objectives for the Dunstan Rohe. However, it should be kept in mind that the Waiwhakaata/Lake Hayes catchment is not fully allocated (at least for consumptive takes), so the current state reflects existing water allocation and use and that the current allocation limit would allow for further allocation and water use in the catchment. Further water take in the catchment would increase the probability of the minimum flow being reached (which has occurred rarely to date) and would reduce the reliability of existing takes in the Mill Creek catchment.

Macroinvertebrate metrics (MCI & QMCI scores) in the lower reaches of Mill Creek do not meet the proposed target states for Ecosystem Health – Aquatic life (Table 7). Macroinvertebrate community composition is affected by a range of factors including flow, periphyton composition and biomass, predation by salmonids, water quality, water physicochemistry (e.g., water temperature, dissolved oxygen) and habitat characteristics (e.g., substrate composition, fine sediment cover). In this case, the MCI/QMCI scores observed in Mill Creek have declined since 2004 and are likely to reflect the effects of sedimentation resulting from land use and development within the catchment. Water abstraction may contribute to the effects of sedimentation, by reducing the sediment transport capacity of Mill Creek and enhancing rates of sedimentation. However, it should be kept in mind that increased rates of sediment transport may contribute to enhanced phosphorus transport to Waiwhakaata/Lake Hayes, unless mitigation measures (such as sediment traps) are employed.

While the current water quality does not meet proposed objectives for some water quality attributes, (ammoniacal nitrogen concentrations, water clarity and *E. coli* concentrations – see Section 6.4.2), water allocation is unlikely to account for these exceedances in Mill Creek. Similarly, the degraded water quality in Waiwhakaata/Lake Hayes is not directly related to the effects of water abstraction/allocation.

At present, flows in Mill Creek rarely reach the minimum flow of 180 l/s. Hydrological simulations indicate that the main hydrological effect of higher minimum flows is to increase the duration of flows at the minimum flow, although the extent of this effect depends on the allocation limit. The DHRAM hydrological index suggests that the current minimum flow/allocation limit would have a high risk of ecological impact, although the current consented consumptive allocation (135 l/s) is associated with a low risk of impact. At higher minimum flows (195, 210, 230 l/s), an allocation limit of 135 l/s is expected to result in a moderate risk of impact. An allocation limit of 80 l/s (the sum of the maximum observed rate of take for each of the water takes) was associated with a low risk of impact at all of the minimum flows considered, while an allocation limit of 55 l/s (the maximum observed combined rate of take) is predicted to result in an unimpacted hydrology relative to naturalised flows.

Given the long history of degraded water quality in the Waiwhakaata/Lake Hayes catchment and the exceedance and deterioration of proposed objectives for macroinvertebrate attributes in Mill Creek, there is a case for reducing the catchment primary allocation limit and/or raising the minimum flow from those in Schedule 2A. An allocation limit of 80 l/s would reflect the current peak rate of water use based on the sum of the maximum observed take by each consent. Thus, it would provide for existing users. With an allocation limit of 80 l/s, the various minimum flows (180, 195, 210, 230 l/s) would result in a degree of hydrological alteration that has a low risk of impact on ecological values.

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Appendix A

Flow naturalisation of Mill Creek

Flow naturalisation of Mill Creek

Contents

10.1. Document Review

Name	Role	Date Completed
Lu Xiaofeng	Author	17th April 2023
Helen Manly	Readability Review	18th April 2023
Dave Stewart	Technical Review	5th May 2023
Lu Xiaofeng	Final Version completion	9th May 2023

This document describes how naturalised flow statistics at the flow recorder on Mill Creek at Fish Trap were derived.

10.2. Daily flow time series data for Mill Creek

The daily flow time series data available for analysis are listed in **Table 1**. The locations of the sites are shown in **Figure 1**. The current consents used in this study (shown in **Figure 1**) are listed in **Table A1** in the **Appendix**.

Table 13: The daily flow time series data available for analysis above Mill Creek at Fish Trap.

Sites	Start	End	Length (year)
Mill Creek at Fish Trap	31/03/1983	24/04/2023	40.1
Mill Creek at Hunter Road	18/09/2018	14/10/2020	2.1

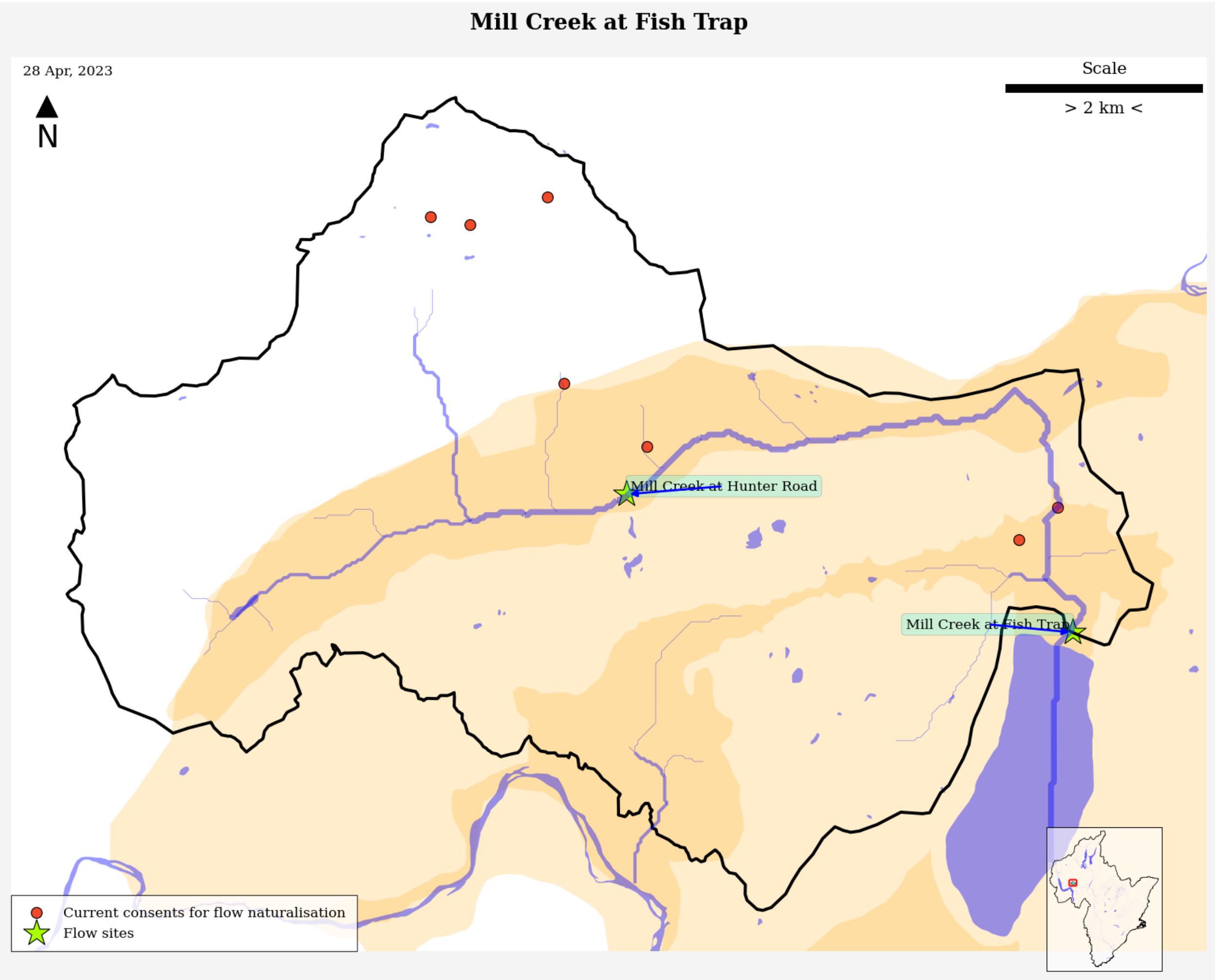

Figure 16: The location of flow recorders and current consents used in this study on Mill Creek in Central Otago.

The flow recorder at Mill Creek at Hunter Road is not considered in this study as it is not the location of interest.

10.3. Daily water use time series

Time series data of water use (WU) is used to naturalise the flow at Mill Creek at Fish Trap flow recorder. All consents above the flow recorder must first be identified.

10.3.1. Total water use above Mill Creek at Fish Trap flow recorder

Altogether 96 consents have been issued in history above the Mill Creek at Fish Trap flow recorder. However, 41[17] consents are used in the flow naturalisation process

[17] 41 consents used in this study are listed in **Table A1** in the **Appendix**. They are the consents left by filtering out:

(See **Table A1** in the Appendix). As shown in the table, 7 are currently active. **Figure 2** shows the total water use (WU) regime above Mill Creek at Fish Trap.

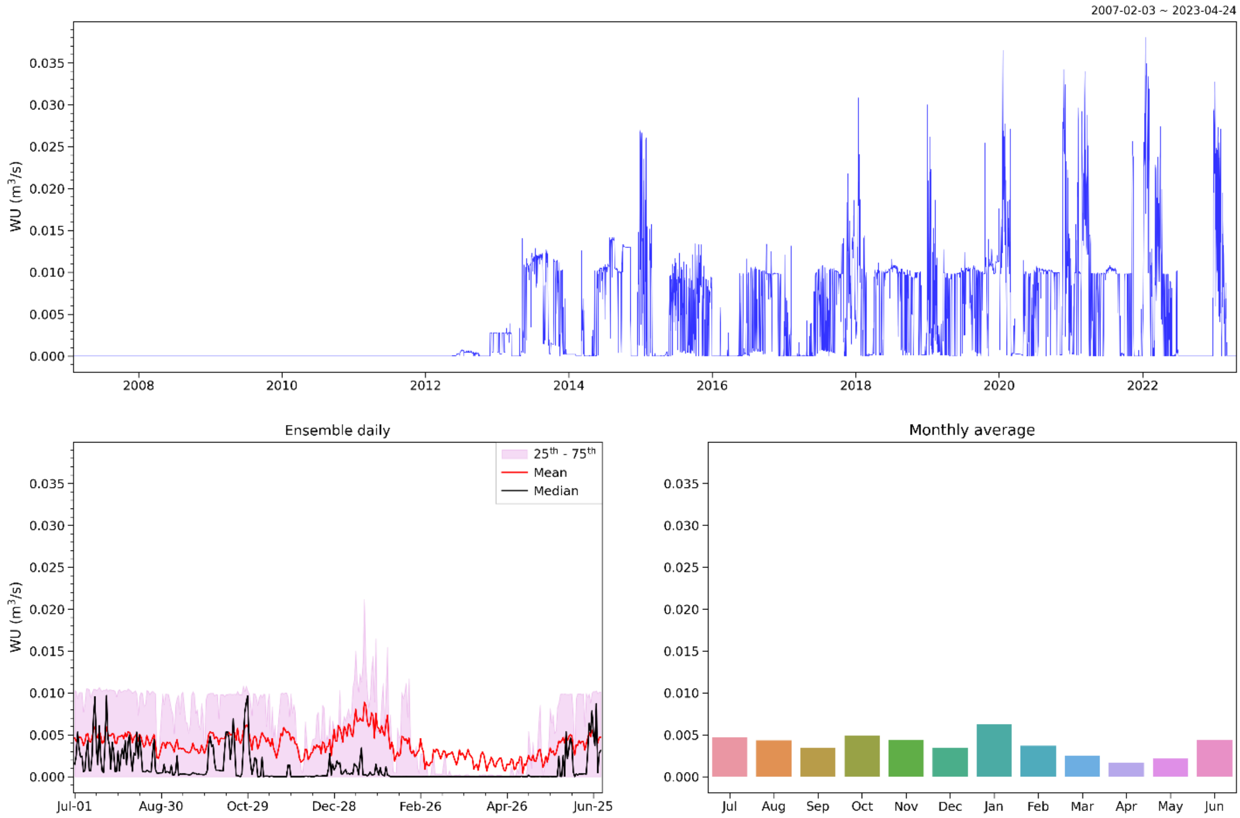

Figure 17: The total water use upstream of the recorder at Mill Creek at Fish trap.

As shown in **Figure 2**, the patterns before and after the water year 2013/14 are different due to water meter abstraction data not being available prior to the 2013/14 season. In this study, only the water use data after 2013/14 is available to be used. The average total WU during the water year (July - June) is 6 L/s after 2013/14.

10.4. Flow naturalisation

This section describes how the naturalised flow statistics are estimated for the flow recorder at Mill Creek at Fish Trap.

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

10.4.1. Method

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

Producing long-term flow statistics is the key goal for this study including the naturalised seven-day mean annual flow (7dMALF) and long-term median and mean flows for the flow recorder at Mill Creek at Fish Trap.

10.4.2. Naturalised flow Statistics

1.1.1.1 Basic flow statistics (Table 2).

Table 14: Naturalised flow statistics for the recorder at Mill Creek at Fish Trap (01/07/2013 ~ 24/04/2023).

Site	Mean (m^3/s)	Median (m^3/s)	FRE3[18] ($year^{-1}$)	7dMALF (m^3/s) (Jul - Jun)
Mill Creek at Fish Trap (Naturalised)	0.431	0.394	1.7	0.247
Mill Creek at Fish Trap (observed)	0.425	0.388	1.7	0.243

[18] 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.

10.5. Appendix

10.5.1. Table A1. The consents used for flow naturalisation at site Mill Creek at Fish Trap

Consent	Status	Water meter	Allocation type	Category	Consented rate	Stream depletion rate
WR1791Q	Cancelled			Surface Take	20.8	
2004.011.V1	Current	WM0742, WM1462		Surface Take	4.3	
2004.013	Current		Primary	Surface Take	1.5	
RM12.113.01	Current	WM0622	Primary	Surface Take	16.2	
RM14.124.01	Current	WM0536	Primary	Surface Take	50	
RM18.439.01	Current	WM1517	Primary	Groundwater Take	15	4.9
RM20.296.02	Current			Surface Take		
RM21.284.01	Current			Surface Take	13.7	
2000.383	Expired	WM0015	Primary	Surface Take	9.84	
2002.542.V1	Expired		Primary	Surface Take	28	
2038	Expired			Surface Take		
2167	Expired			Surface Take		
2271	Expired			Surface Take		
2380	Expired			Surface Take		
2392A	Expired			Surface Take		
2656A	Expired			Surface Take		
2884	Expired			Surface Take		
2992	Expired			Surface Take		
3058	Expired			Surface Take		
3252B	Expired			Surface Take		
3734	Expired			Surface Take		
3760	Expired			Surface Take		
3766	Expired			Surface Take		
3766C	Expired			Surface Take		
3800	Expired			Surface Take		
3802	Expired			Surface Take		
4041	Expired			Surface Take		
4086B	Expired			Surface Take		
4086D	Expired			Surface Take		
4225	Expired			Surface Take		

Consent	**Status**	**Water meter**	**Allocation type**	**Category**	**Consented rate**	**Stream depletion rate**
95A17	Expired			Surface Take	14	
97031	Expired			Surface Take	0.14	
99260	Expired			Surface Take	0.092	
99390	Expired			Surface Take	0.12	
RM21.260.02	Rejected			Surface Take		
RM21.362.02	Rejected			Surface Take		
93246	Surrendered			Surface Take		
95521	Surrendered			Surface Take		
96030	Surrendered	WM0536		Surface Take	27.8	
RM17.360.01	Surrendered	WM1517		Groundwater Take	15	4
2000.284	Withdrawn			Surface Take		