# Management Flows for Aquatic Ecosystems in Luggate Creek

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Otago Regional Council

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# Executive summary

Luggate Creek is a small river which rises in the tussock grasslands and on the northern half of the Criffel and Pisa Ranges, flowing onto a flat terrace at the Luggate township before flowing into the upper Clutha/Mata-Au. The Luggate is within the Clutha Mata-Au Freshwater Management Unit (FMU) and the Dunstan Rohe. Like many waterways within the Dunstan Rohe, Luggate Creek has a long history of water abstraction. Water takes within the Luggate catchment have historically been authorised by deemed permits (also known as mining rights) were not subject environmental restrictions, such as minimum flows.

The purpose of this report is to present information to inform decision making on water allocation and flow management in the Luggate Creek catchment. This includes hydrological information (including flow naturalisation and flow statistics), data on aquatic values (including the distribution of indigenous fish). application of instream habitat modelling to guide flow-setting processes, and consideration of the current state of Luggate Creek compared to the proposed objectives for the Dunstan Rohe set out in the proposed Otago Land and Water Regional Plan.

Hydrological statistics for Luggate Creek at SH6 bridge used in this report are from Lu (2023):

| Site | Type | Flow statistics (l/s) | | | Return interval analysis (7-day period) | |
|---|---|---|---|---|---|---|
| | | Mean | Median | 7d MALF (Jul-Jun) | 5-year return (Q7,5) | 10-year return (Q7,10) |
| Luggate at SH6 | Naturalised flows | 1,595 | 1,294 | 644 | 548 | 513 |
| | Observed flows | 1,344 | 1,078 | 312 | - | - |

Schedule 2A of the Regional Plan: Water specifies a minimum flow for primary allocation in Luggate Creek at the SH6 bridge of 180 l/s. The primary allocation limit specified for the Luggate Creek catchment in Schedule 2A is 500 l/s.

There are three resource consents to take surface water from the Luggate Creek catchment: the first is from a large weir on the mainstem of Luggate Creek, the other two are from five locations in Luggate Creek and the Alice Burn. Total primary allocation in the Luggate catchment is 538 l/s. In addition to the primary allocations, both consents include allocation within the first (minimum flow: 788 l/s, allocation block: 250 l/s) and second supplementary blocks (minimum flow: 1,038 l/s, allocation block: 166 l/s).

The periphyton community in Luggate Creek is usually dominated by thin light brown films (dominated by diatoms) with medium to thick cyanobacteria (usually consisting of the colonial taxon *Nostoc*) often present. Long brown/reddish filamentous taxa have also been abundant at times. Chlorophyll *a* concentrations did not exceed 200 mg/m$^2$ over the July 2019 – June 2022 period, and the chlorophyll *a* concentrations observed at this site over this period placed this site in Band B of the NOF.

Macroinvertebrate community index scores for this site varied between B and C-bands, indicative of a mild to moderate organic pollution or nutrient enrichment. Meanwhile, SQMCI scores were more variable, ranging between A and D bands, although the median score was in B-band, indicating mild organic pollution or nutrient enrichment. ASPM scores consistently indicated 'mild to moderate loss of ecological integrity' (B-band).

Two species of indigenous freshwater fish have been recorded from the Luggate Creek catchment – longfin eel/tuna and kōaro. Brown trout have been collected from the lower reaches of Luggate Creek, while rainbow trout are more widespread, having been recorded from Luggate Creek upstream of the Criffel weir No angler effort has been recorded in the Luggate catchment in the National Angler Survey, although brown and rainbow trout spawning in Luggate Creek likely contributes to recruitment and juvenile rearing for the upper Clutha/Mata-Au fishery to some degree, although the significance of this contribution is unknown. The F-IBI score for Luggate Creek at SH6 is in D-band (5-year average: 16), indicating *"Severe loss of fish community integrity. There is substantial loss of habitat and/or migratory access, causing a high level of stress on the community"*. In the case of Luggate Creek, this reflects the naturally low diversity of native fish expected to be present in this catchment with the presence of non-native species at this site.

Comparison of the current state of Luggate Creek with objectives for the Dunstan Rohe provides insight into whether current conditions are consistent with the objectives proposed in the Land & Water Regional Plan. MCI scores in Luggate Creek (C-band) do not meet the proposed target states for Ecosystem Health – Aquatic life (B-band), although other macroinvertebrate metrics (QMCI and ASPM) do meet proposed targets. In addition, trend analyses for macroinvertebrate indices suggest improving trends since 2004.

Luggate Creek does not meet proposed objectives for some water quality attributes (deposited fine sediment, *E. coli* concentrations, DRP). Of these, water allocation is unlikely to account for the exceedances of *E. coli* and DRP but may contribute to the exceedance of targets for deposited fine sediments, as higher flows are expected to enhance flushing of fine sediments.

An instream habitat model developed for the mainstem of Luggate Creek by Jowett (2004) was updated and applied to consider the effects of different flows on the physical characteristics of Luggate Creek and habitat for periphyton, macroinvertebrates and fish. The current minimum flow is predicted to be associated with a significant increase in habitat suitability for long filamentous algae. The current minimum flow in the Luggate catchment (180 l/s) is predicted to maintain between 9% (the stonefly *Zelandoperla*) and 73% (the common mayfly *Deleatidium*) of habitat for macroinvertebrates at the naturalised 7-d MALF. It is predicted to maintain 77-87% of habitat for longfin eel compared to the naturalised 7-d MALF. The current minimum flow is predicted to achieve between 42% (brown trout adult) and 83% (brown trout fry to 15 cm) habitat retention for the various brown trout life-stages considered.

Flows of less than 290 l/s are predicted to significantly increase habitat suitability for long filamentous algae. Flows of 114-522 l/s are predicted to retain 80% of the habitat available for the macroinvertebrate taxa considered at the naturalised MALF. Flows of 84-221 l/s are predicted to retain 80% of the habitat for tuna/longfin eel available at the naturalised MALF. Flows of 169-371 l/s are predicted to retain 80% of the habitat available for the various species/life-stages of trout at the naturalised MALF.

Comparison of minimum flow/allocation limit scenarios using the DHRAM hydrological suggests that the observed flows represent a degree of hydrological alteration that overall is “unimpacted” compared to naturalised flows. All allocation scenarios with minimum flows of 180 l/s, 240 l/s and 300 l/s were predicted to be a low risk of environmental impact while scenarios with a minimum flow of 450 l/s and allocation limits of either 538 l/s or 450 l/s were predicted to represent a moderate risk of impact.

The predicted effects of climate change in Luggate Creek include higher mean flow and higher flood magnitudes, which may enhance flushing of fine sediments and periphyton and is expected to be a positive ecological effect, particularly on the macroinvertebrate community of Luggate Creek.

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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 |
| Mean flow | The average flow of a watercourse, usually calculated as the average of all complete water years of record whether or not they are consecutive. |
| 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

Luggate Creek is a small river which rises in the tussock grasslands and on the northern half of the Criffel and Pisa Ranges in Central Otago, flowing through steep, rocky gorges before emerging onto a flat terrace at the Luggate township before flowing into the upper Clutha/Mata-Au.

The Luggate catchment is within the Clutha Mata-Au Freshwater Management Unit (FMU) and the Dunstan Rohe. Like many waterways within the Dunstan Rohe, the Luggate catchment has a long history of water abstraction, with many of the water takes within the Luggate catchment historically been authorised by deemed permits (also known as mining rights). These permits, often originally issued for the purposes of mining and later used for irrigation, were not subject environmental restrictions, such as minimum flows.

Deemed permits expired on 1 October 2021 and the deemed permits in the Luggate catchment were replaced with resource consents in November 2019. Water is taken from Luggate Creek at a large weir on the mainstem of Luggate Creek, the upper reaches of the Alice Burn and at the confluence of the Alice Burn and Luggate Creek. Collectively, these takes can irrigate up to 1590 ha, including areas outside the Luggate catchment near Mount Barker Road and towards Wanaka Aerodrome. The new resource consents expire on 12 April 2045.

## 1.1. Purpose of the report

The purpose of this report is to present information to inform water management decision making in the Luggate catchment. This includes hydrological information (including flow naturalisation and flow statistics), data on aquatic values (including the distribution of indigenous fish), application of instream habitat modelling to guide flow-setting processes, and consideration of the current state of Luggate Creek compared to the proposed objectives for the Dunstan Rohe set out in the proposed Otago Land and Water Regional Plan.

# 2. Background information

## 2.1. Catchment description

Luggate Creek drains a catchment area of 123 $km^2$, starting in tussock grasslands and wetlands high on the Criffel and Pisa Ranges before flowing in steep, rocky gorges before emerging onto terraces of the Clutha/Mata-Au at the Luggate township before flowing into the Clutha/Mata-Au approximately 1.8 km downstream of the red bridge over the Clutha/Mata-Au.

### 2.1.1. Climate

The climate within the Luggate 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, while mean annual rainfall in the lower catchment is as low as 600 mm (Figure 2). Mean annual rainfall at the nearby Wanaka (Airport) climate station is 594 mm (Macara 2015).

The mean monthly air temperature at Wanaka Airport is 13°C in summer (January-February), with an average of 3 day per year with a maximum temperature exceeding 30°C and 35 days exceeding 25°C (Macara 2015). The highest air temperature recorded at Wanaka Airport was 34.5°C (Macara 2015). In contrast, mean monthly air temperatures at Wanaka Airport is 8.4 °C in winter (June), with a lowest temperature recorded of -8.6°C with an average of 73 days per year with a minimum temperature of less than 0°C (Macara 2015).

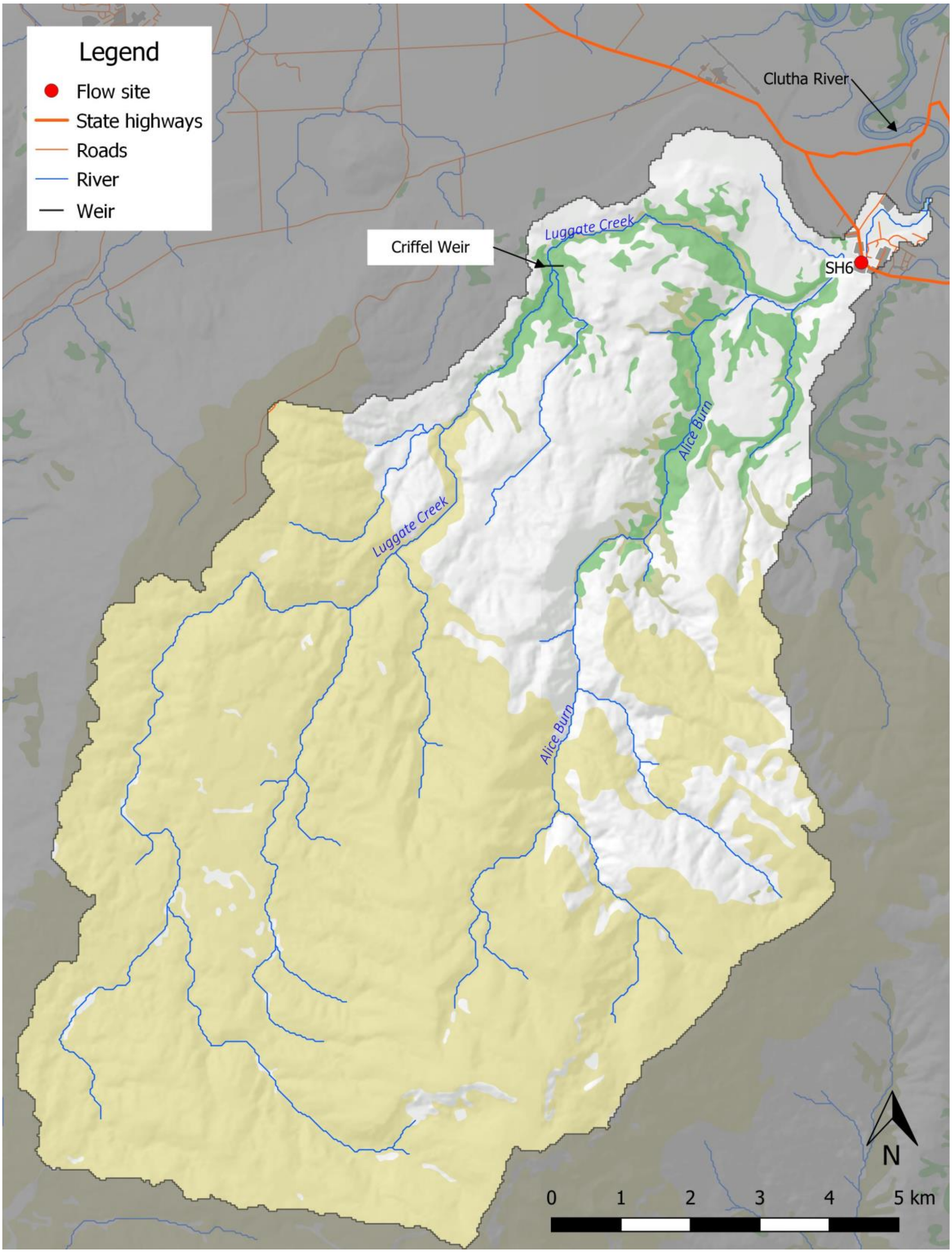


**Figure 1 Map of the Luggate catchment showing the location of flow recorder site.**

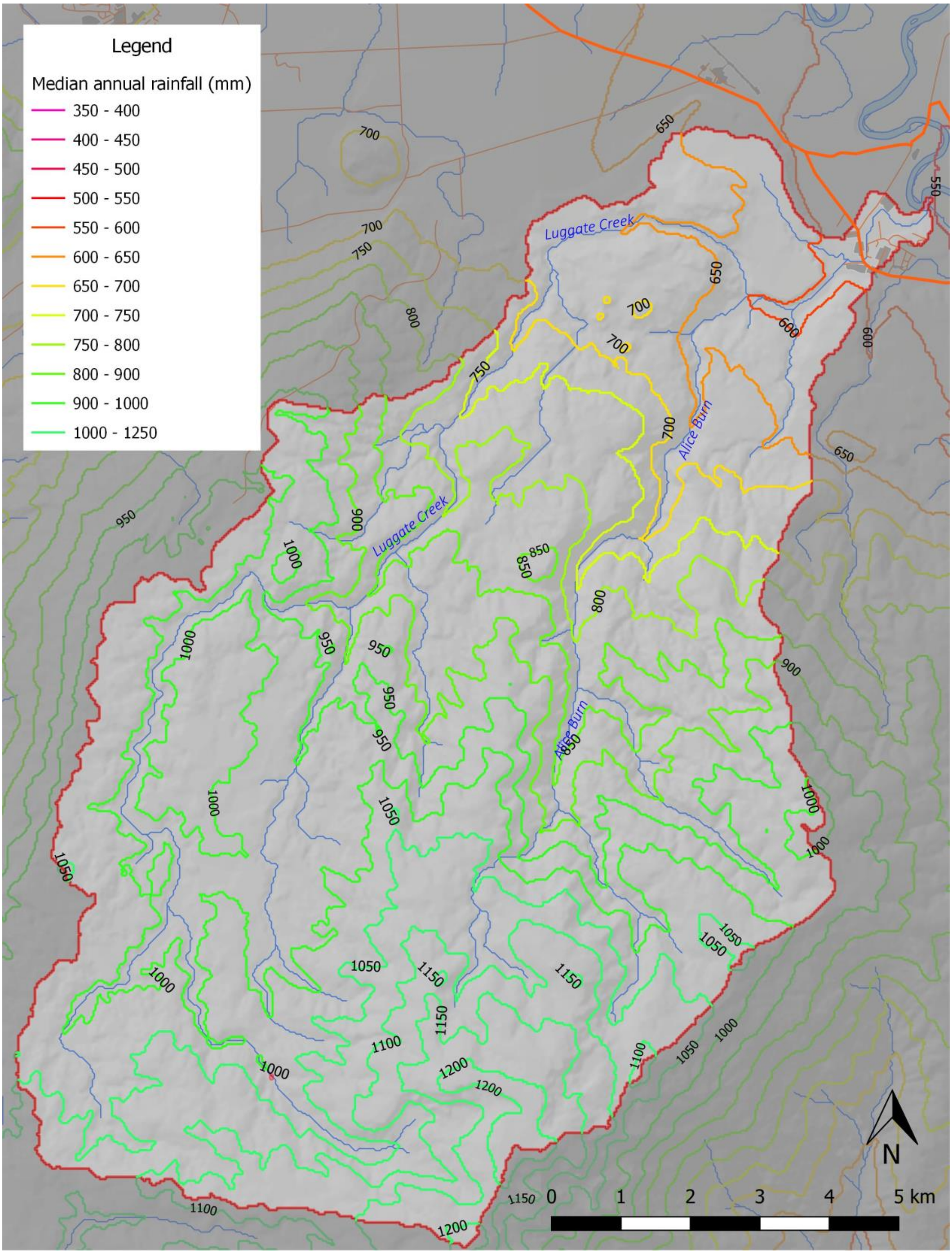


**Figure 2 Distribution of rainfall (annual median rainfall) in the Luggate catchment. From GrowOtago (ORC 2004).**

### 2.1.2. Geological setting

Much of the Luggate catchment is underlaid by schist (Rakaia terrane) with small pockets of glacial till (423,000-478,000 years ago) and mudstone (Bannockburn formation) (Turnbull 2000). The Luggate township is built on quaternary gravels of various ages (<245,000 years ago) (Turnbull 2000).

### 2.1.3. Vegetation and land use

The vegetation of the upper Luggate catchment is mostly tussock grasslands with some wetlands and an area of depleted grasslands in the eastern portion of the Alice Burn (Figure 3). Vegetation at intermediate elevations is dominated by low-producing grasslands, while the steep gullies are dominated by manuka and/or kanuka with areas of shrublands (Figure 3). The land cover of the lower portions of the Luggate catchment are mostly high producing pasture, with limited areas of cropping, exotic forestry and Luggate township (Figure 3).

Much of the upper reaches of the Alice Burn catchment and part of the upper catchment of the North Branch are in the Pisa Conservation Area.

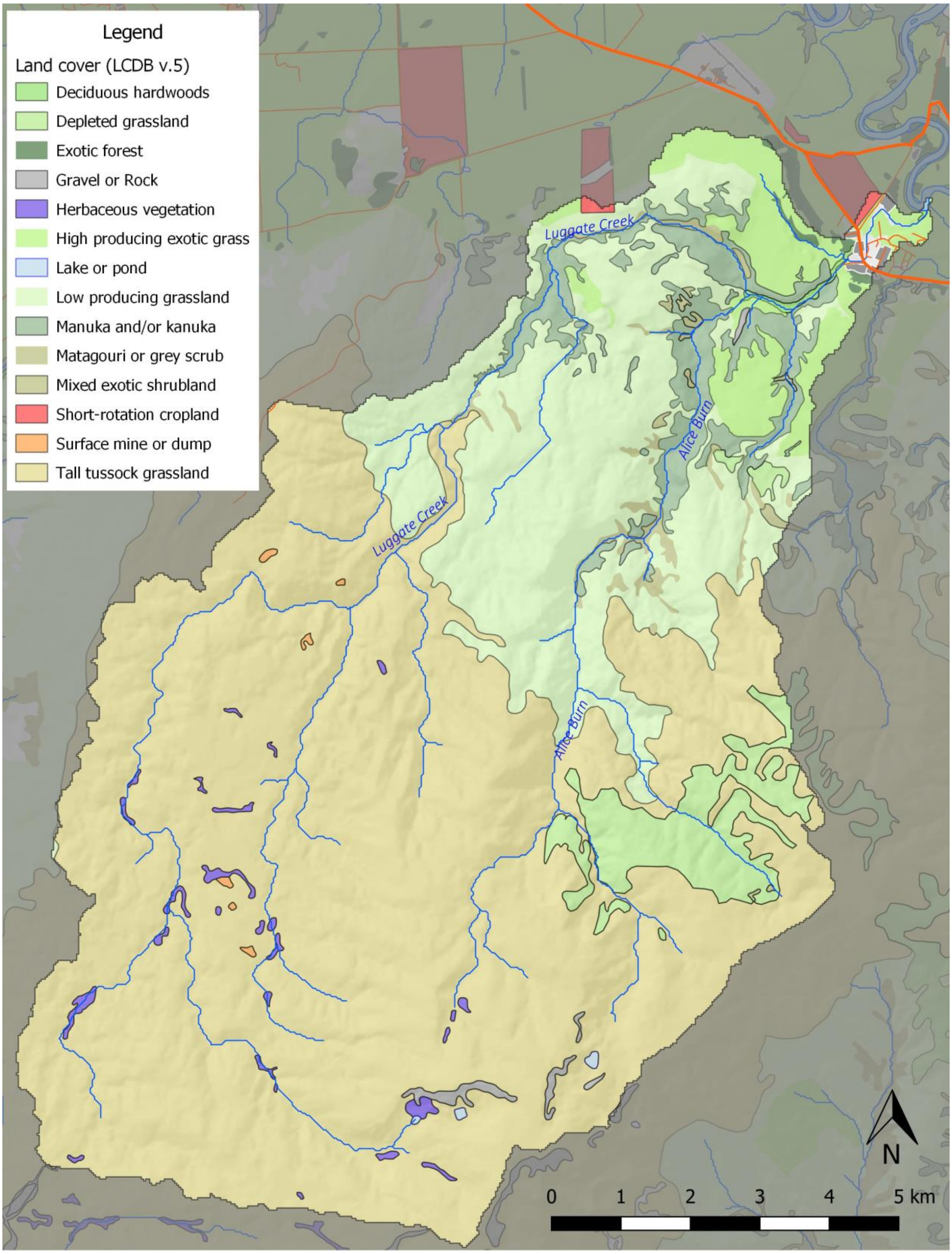


**Figure 3  Land cover in the Luggate catchment based on the land cover database (version 5).**

# 3. Regulatory setting

## 3.1. Regional Plan: Water (RPW)

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

Schedule 2A of the RPW specifies a minimum flow for primary allocation at State Highway 6 (SH6) of 180 l/s (1 November to 30 April) or 500 l/s (1 May to 30 October). Schedule 2A of the RPW specifies a primary allocation limit of 500 l/s for the Luggate catchment. Total consented primary allocation in the Luggate catchment at the time of writing is 538 l/s (see Section 4.2.2).

Schedule 2B of the RPW does not specify supplementary allocation blocks or supplementary minimum flows. However, two supplementary blocks of 250 l/s currently exist in the Luggate catchment, with minimum flows of 788 l/s and 1,038 l/s (as per Method 15.8.1A).

## 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. Luggate 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 set out in Table 1 apply to the Luggate catchment. For the sake of brevity, only objectives that apply to flowing water bodies are shown in Table 2.

**Table 1 Possible environmental outcomes for the values identified in the Dunstan Rohe and their attributes and target attributes in Luggate Creek. Baseline and Target attribute states are based on the attribute tables in the National Objectives Framework of the National Policy Statement for Freshwater Management (2022).**

| Attribute | Luggate Creek at SH6 Bridge | |
|---|---|---|
| | Baseline State | Target 2030 |
| Periphyton Biomass | B | B |
| Periphyton TN | B | B |
| Periphyton TP | C | B |
| Ammonia - median | A | A |
| Ammonia – 95$^{th}$ percentile | A | A |
| *E. coli* 260 cfu/100 mL | A | A |
| *E. coli* 540 cfu/100 mL | A (B - A) | A |
| *E. coli* median | A | A |
| *E. coli* Q95 | A (B - A) | B |
| DRP-median | C (C - B) | C |
| DRP Q95 | A | A |
| MCI | C | C |
| ASPM | B | B |
| FISH IBI | | |
| Suspended fine sediment | A | A |
| NNN - median | A | A |
| NNN - 95th percentile | A | A |

# 4. Hydrology

## 4.1. Catchment description

The headwaters of Luggate Creek arise as low-gradient streams at high altitudes (>1963 m a.s.l. at the summit of Mt Pisa) on the Pisa before flowing into steep gorges before entering the Clutha/Mata-Au near the township of Luggate just downstream of the Red Bridge (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.

## 4.2. Flow statistics

A continuous flow recorder in Luggate Creek at SH6 has been operating since 2 February 2016. The flow statistics based on the analysis of Lu (2023) are summarised in Table 2. Lu (2023) is attached as Appendix A.

**Table 2 Flow statistics for hydrological sites in Luggate Creek**

| Site | Type | Flow statistics (l/s) | | | Return interval analysis (7-day period) | |
|---|---|---|---|---|---|---|
| | | Mean | Median | 7d MALF (Jul-Jun) | 5-year return (Q7,5) | 10-year return (Q7,10) |
| Luggate at SH6 | Naturalised flows | 1,595 | 1,294 | 644 | 548 | 513 |
| | Observed flows | 1,344 | 1,078 | 312 | - | - |

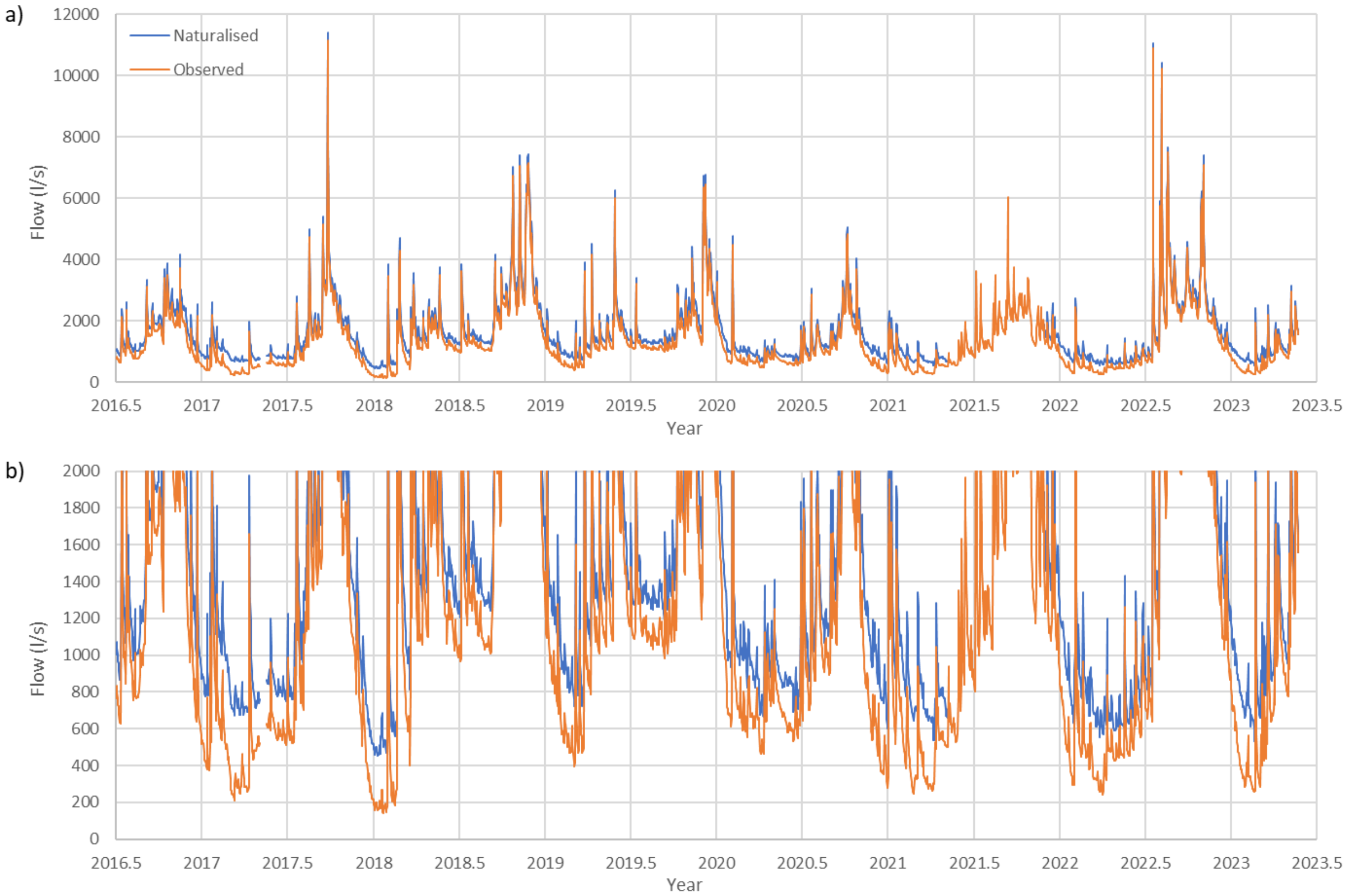


**Figure 4 Observed flows (orange line) and synthetic naturalised flows (blue line) for Luggate Creek at SH6 bridge for the period 2016-2023. A) Full flow range, b) Flows <2,000 l/s.**

### 4.2.1. Flow variability

The average number of events per year that exceed three times the median flow (FRE3) in Luggate Creek is estimated to be 3.7 events per year naturally, while the observed flows feature 4.8 events per year (Lu 2023). The difference between the FRE3 between naturalised and observed time-series likely reflects the difference in median flows. Flow events of this magnitude are generally considered to be large enough to reduce periphyton biomass and cover and are referred to as flushing flows.

### 4.2.2. Water allocation & use

There are three resource consents for primary water takes from the Luggate catchment: the first is from a large weir on the mainstem of Luggate Creek, the second is from five locations in Luggate Creek and the third takes from the Alice Burn. Total primary allocation in the Luggate catchment is 538 l/s (Table 3).

In addition to the primary allocations, both consents include allocation within the first (250 l/s) and second (166 l/s) supplementary blocks (Table 3).

**Table 3 Active resource consents in the Luggate catchment.**

| Consent # | Max. instant. Take (l/s) | Monthly volume ($m^3/m$) | Annual volume ($m^3/y$) | Minimum flow summer/winter (l/s) | Waterway | Purpose |
|---|---|---|---|---|---|---|
| **Primary** | | | | | | |
| RM16.093.01 | 358 | 769,417 | 3,879,273 | 180/500 | Luggate Creek | Irrigation |
| RM18.345.01 | 87 | 422,000 | 2,755,187 | 180/500 | Luggate Creek | Irrigation and stock water |
| RM18.345.02 | 93 | | | | Alice Burn | Irrigation and stock water |
| **First supplementary block** | | | | | | |
| RM16.093.01 | 170 | | | 788 | Luggate Creek | Irrigation |
| RM18.345.01 | 80 | | | 788 | Alice Burn | Irrigation and stock water |
| **Secondary supplementary block** | | | | | | |
| RM16.093.01 | 80 | | | 1,038 | Luggate Creek | Irrigation |
| RM18.345.01 | 86 | | | 1,038 | Alice Burn | Irrigation and stock water |
| **Total abstraction (primary and supplementary)** | | | | | | |
| RM16.093.01 | | 1,273,017 | 6,409,673 | | | Irrigation |
| RM18.345.01 | | 926,013 | 4,222,573 | | | Irrigation and stock water |

Since the 2016/17 hydrological year, the average rate of water abstraction across the whole season is 286 l/s (Lu 2023). Available water take data for the Luggate catchment suggests that the water take is high from November to March, with peak usage in January and February (Figure 5). Water usage in winter months (June-August) is low (Figure 5).

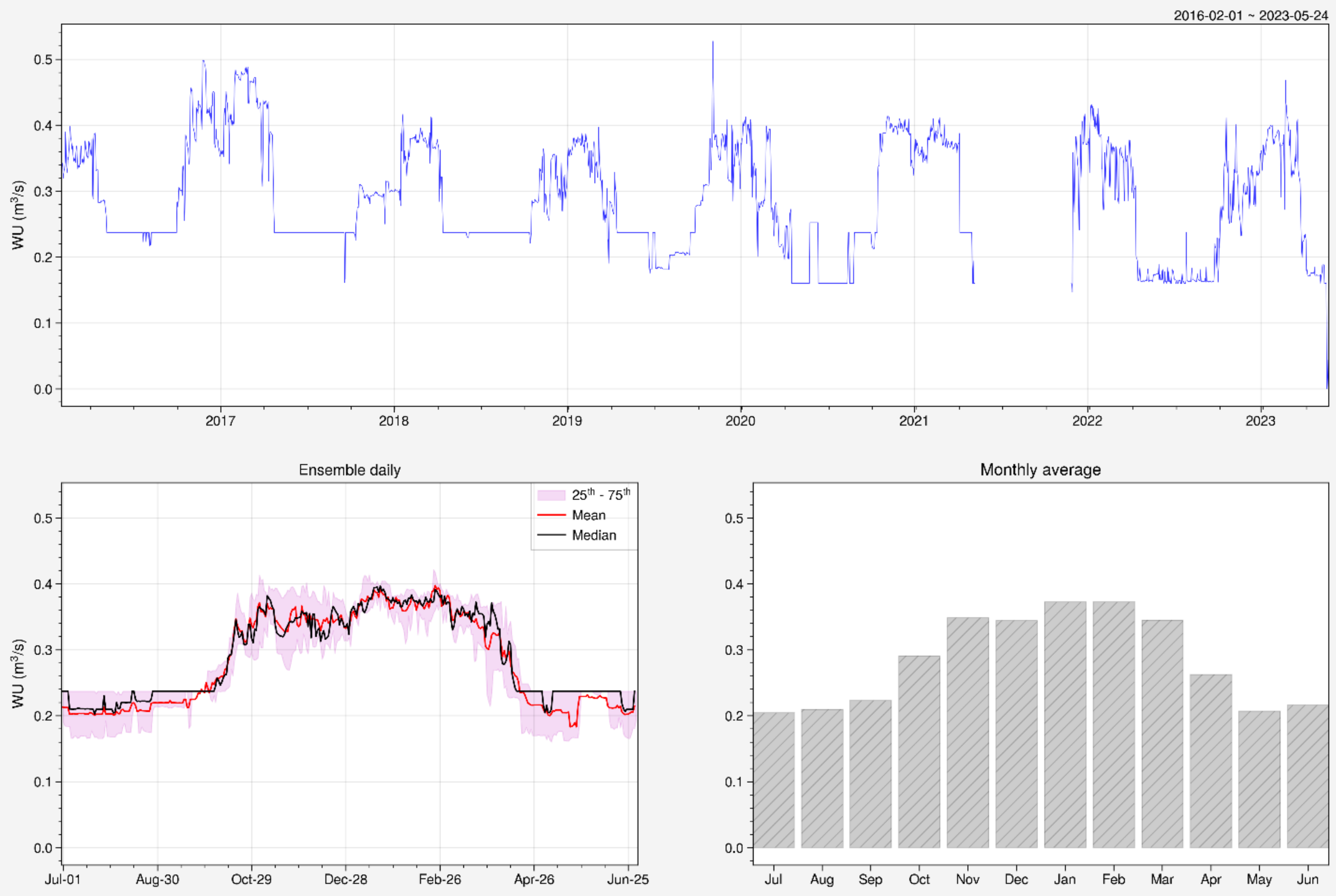


**Figure 5 Seasonality in water take for the Luggate Creek catchment based on water metering data from 2016-2023. From Lu (2023).**

# 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 Luggate catchment, brown trout (*Salmo trutta*) are likely to be the most sensitive to high water temperatures. Their thermal requirements are relatively well understood, and Todd *et al*. (2008) calculated acute and chronic thermal criteria for both of these species. The objective of acute criteria is to protect species from the lethal effects of short-lived high temperatures. In this case, acute criteria are applied as the highest two-hour average water temperature measured within any 24-hour period (Todd et al., 2008). In contrast, the intent of chronic criteria is to protect species from sub-lethal effects of prolonged periods of elevated temperatures. In this study, chronic criteria are expressed as the maximum weekly average temperature (Todd et al., 2008).

Water temperature data is available for Luggate Creek (Luggate at SH6) between 22 November 2018 and 16 January 2023 (Figure 6). These data are based on data recorded by flow monitoring equipment at 15-minute intervals. In addition, water temperature is measured using a hand-held meter during monthly water quality monitoring and these handheld measurements verify the accuracy of the continuous data (linear regression: $a$ = 0.1325, b = 0.9971, $R^2$=0.998, N=46).

Water temperatures in Luggate Creek were well within acute and chronic thermal criteria for brown trout (Figure 6). Most indigenous fish species with available thermal tolerance data are more tolerant of high temperatures than trout (Olsen et al. 2012). Of the indigenous species present in the Luggate 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 Luggate Creek were well within these criteria (Figure 6).

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

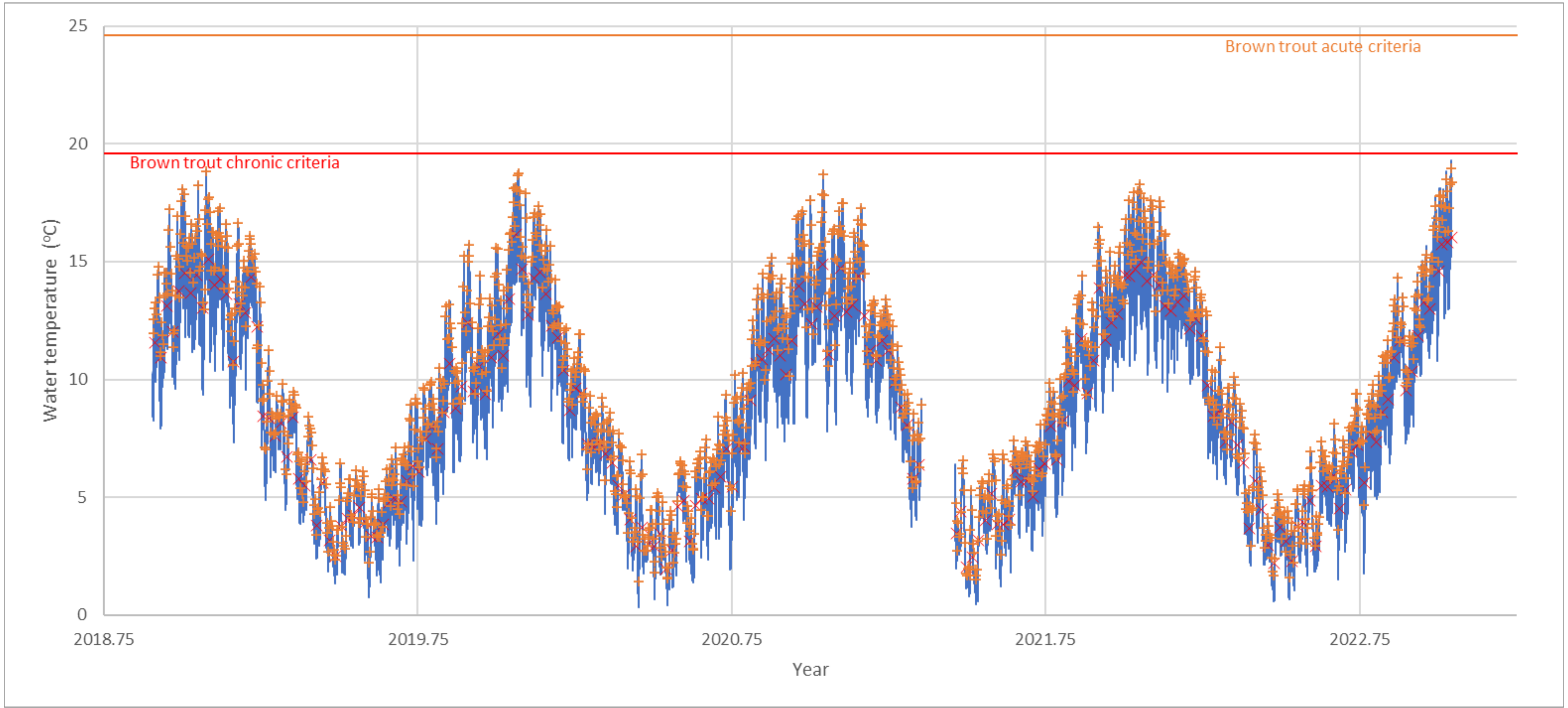


**Figure 6** **Water temperature in Luggate Creek (Luggate at SH6) between November 2018 and January 2023. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red circles are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.**

# 6. The aquatic ecosystem of the Luggate 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 (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 irritation of the skin.

Periphyton in Luggate Creek at SH6 has been monitored since 2019 as part of the State of the Environment monitoring network. The periphyton community in Luggate Creek is usually dominated by thin light brown films (dominated by diatoms) with medium to thick cyanobacteria (usually consisting of the colonial taxon *Nostoc*) often present. Long brown/reddish filamentous taxa have also been abundant at times.

Chlorophyll *a* concentrations in Luggate Creek at SH6 are typically low (71% <50 mg/m$^2$), while concentrations were between 50 mg/m$^2$ and 120 mg/m$^2$ on 29% of sampling occasions and exceeded 120 mg/m$^2$ on one occasion (3% of sampling occasions, 2 July 2022). Chlorophyll *a* concentrations did not exceed 200 mg/m$^2$ over the July 2019 – June 2022 period, and the chlorophyll *a* concentrations observed at this site over this period placed this site in Band B of the NOF.

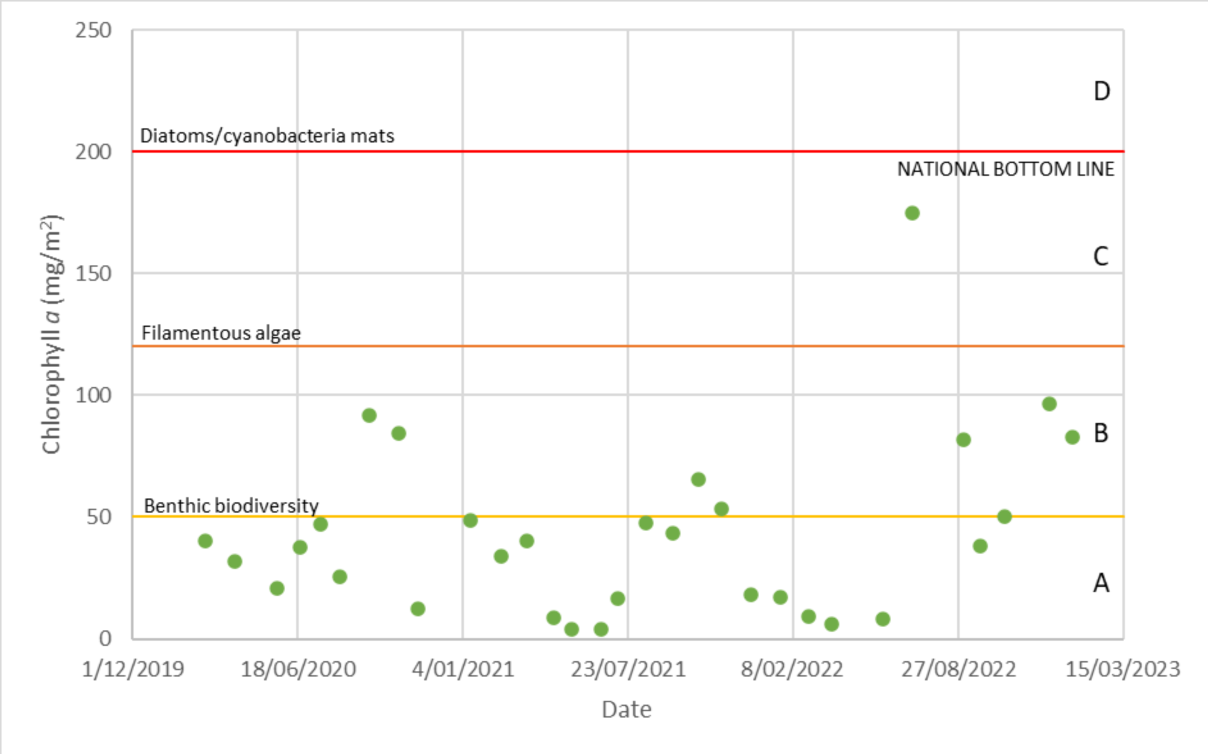


**Figure 7 Chlorophyll *a* concentrations in Luggate Creek at SH6 over the period 2019-2022. The periphyton biomass attribute is applied such that no more than three values can exceed the numeric attribute state in any three-year period (8% exceedence, based on monthly sampling over a 3-year period; NPSFM 2022).**

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

The macroinvertebrate community of Luggate Creek at SH6 was dominated on most occasions by the cased caddis fly *Pycnocentria*, with the mudsnail *Potamopyrgus* and chironomid midge larvae (Orthocladiinae) also the most abundant taxon on occasion. Other species that were among the most abundant taxa on occasion included the common mayfly *Deleatidium* and oligochaete worms.

Macroinvertebrate samples have been collected from Luggate Creek at SH6 between 2007 and 2021. Between 2017 and 2021 MCI scores for this site (Range: 100-110, median = 106, N=5), varied between B and C-bands, indicative of a mild to moderate organic pollution or nutrient enrichment (based on Table 14 of the NPSFM 2020) (Figure 8a). Meanwhile, SQMCI scores were more variable, ranging between A and D bands (Range: 4.96 – 6.51, median = 5.52, N=5), although the mean score was in B-band, indicating mild organic pollution or nutrient enrichment (based on Table 14 of the NPSFM 2020)

(Figure 8b). ASPM scores (Range: 0.41 -0.62, median = 0.50, N=5), consistently indicated ‘mild to moderate loss of ecological integrity’ (based on Table 15 of the NPSFM 2020) (Figure 8c).

Trend analyses conducted by Ozanne et al. (2023) indicate that there is a positive (improving) trend in ASPM, MCI and SQMCI metrics between 2005 and 2022 (Figure 8, Table 4).

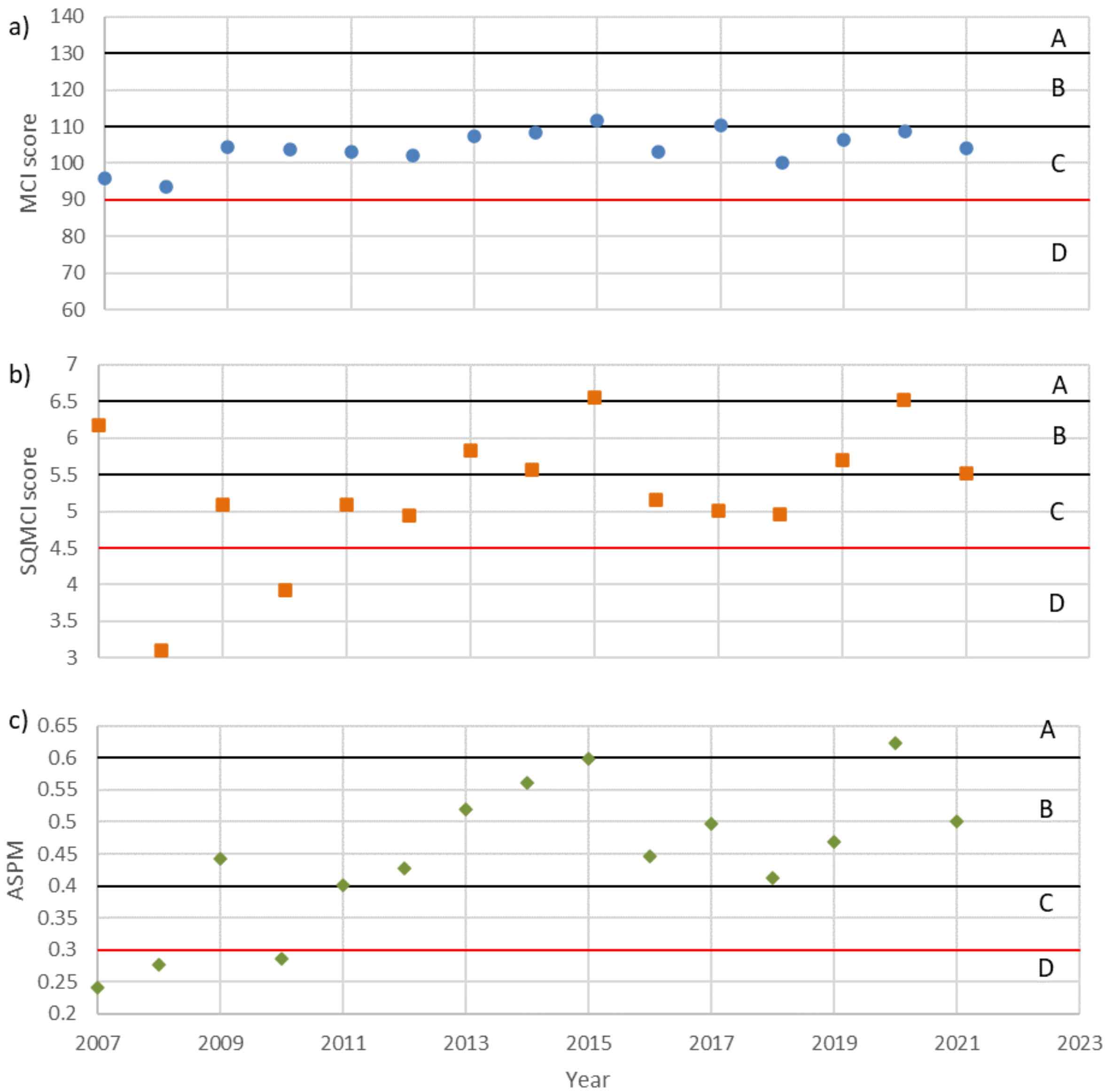


**Figure 8 Macroinvertebrate indices for Luggate Creek at SH6 between 2007 and 2021. a) Macroinvertebrate community index (MCI), b) semi-quantitative MCI (SQMCI) and c) average score per metric (ASPM). Each plot includes thresholds for attribute states based on Tables 14 and 15 of the National Objectives Framework.**

**Table 4 Trends in macroinvertebrate metrics in Luggate Creek at SH6 state of the environment monitoring site between 2004 and 2022 based on the analysis of Ozanne et al. (2023). The Z-statistic indicates the direction of any trend detected. Trends with a *P*-value of 0.05 or less (highlighted red) are considered to be statistically significant.**

| Metric | Z | P | Confidence of improving trend |
|---|---|---|---|
| ASPM | 1.983 | 0.047 | Extremely likely |
| MCI | 1.649 | 0.099 | Extremely likely |
| SQMCI | 1.532 | 0.125 | Very likely |

## 6.3. Fish

### 6.3.1. Indigenous fish

Two species of indigenous freshwater fish have been recorded from the Luggate catchment – longfin eel and kōaro (Table 5). Longfin eels and kōaro are classified as at risk – declining (Dunn et al. 2017).

Longfin eel and kōaro have been detected by eDNA collected from Luggate Creek at the Criffel Weir. Kōaro have also been collected from the lower reaches of Luggate Creek (Figure 9). Recent investigations in the Luggate Creek catchment by the Department of Conservation using eDNA and electric fishing have not detected Clutha flathead galaxias in the Luggate Creek catchment(Figure 9).

### 6.3.2. Introduced fish

Brown trout have been collected from the lower reaches of Luggate Creek, while rainbow trout are more widespread, having been recorded from Luggate Creek upstream of the Criffel weir (Figure 9).

No angler effort has been recorded in the Luggate catchment in the National Angler Survey (Unwin 2016), although brown and rainbow trout spawning in Luggate Creek likely contributes to recruitment and juvenile rearing for the upper Clutha/Mata-Au fishery to some degree, although the significance of this contribution is unknown.

**Table 5 Fish species recorded from the Luggate catchment.**

| Family | Common name | Species | Threat classification |
|---|---|---|---|
| Anguillidae | Longfin eel | *Anguilla dieffenbachii* | Declining |
| Galaxidae | Kōaro | *Galaxias brevipinnis* | Declining |
| Salmonidae | Brown trout | *Salmo trutta* | Introduced and naturalised |
| | Rainbow trout | *Oncorhynchus mykiss* | Introduced and naturalised |

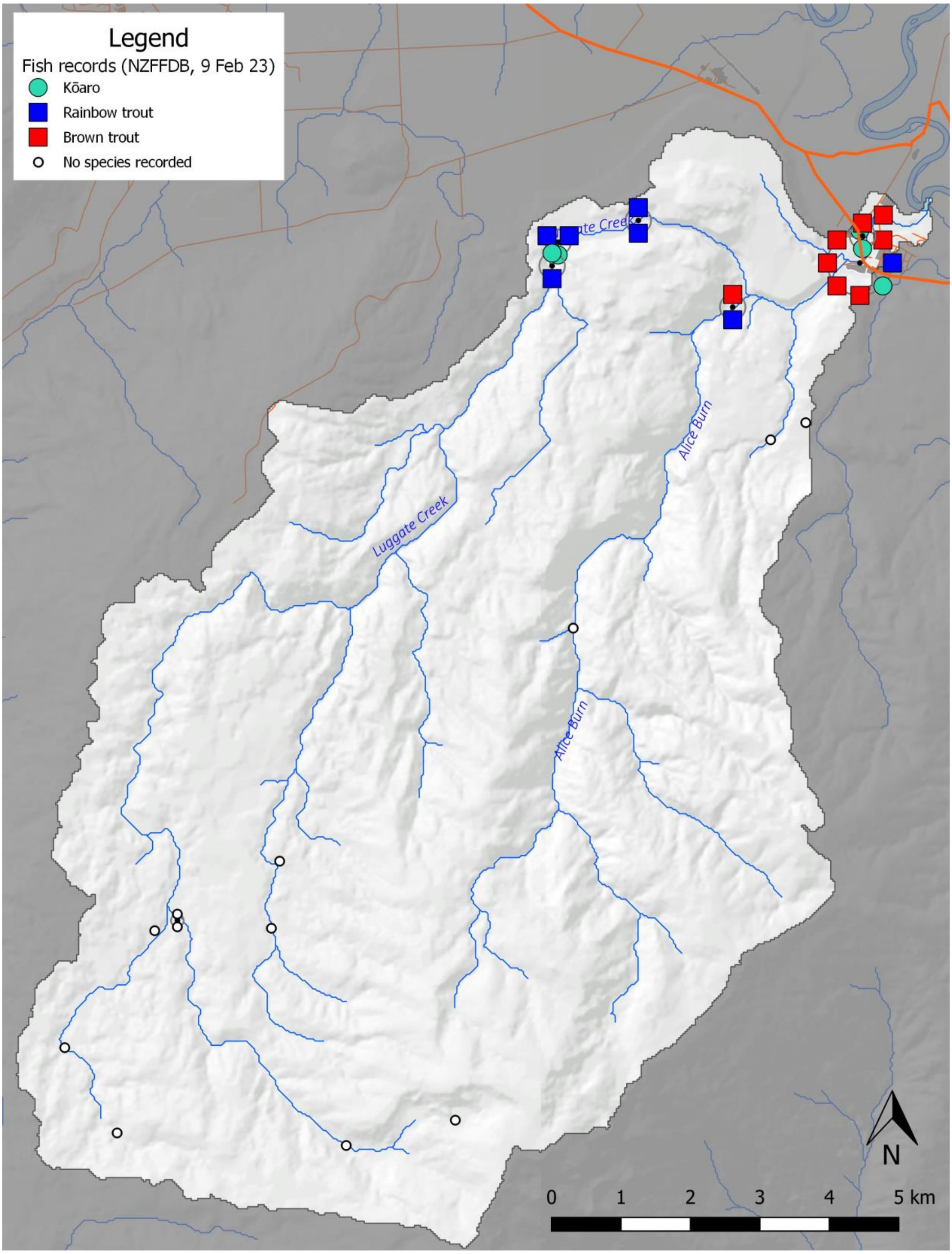


**Figure 9 Fish distribution in the Luggate Creek catchment based on records from the NZ Freshwater Fish Database (downloaded 9 February 2023).**

## 6.4. Current ecological state

The current state of Luggate Creek reflects the effects of long-term water abstraction as well as the presence of introduced sportsfish. Comparison of the current state of Luggate Creek with objectives for the Dunstan Rohe provides insight into whether current conditions are consistent with the objectives proposed in the Land & Water Regional Plan.

At the time of writing, the proposed objectives for the Roxburgh Rohe include the following narrative objectives: *"Freshwater bodies within the Roxburgh 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 6 below.

### 6.4.1. Ecosystem health

In addition to the ecosystem health and human contact values identified in Table 6, 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 6. Attributes for natural form and character and threatened species within the Dunstan Rohe are under development, so it is not possible to consider the current state of the Luggate catchment relative to these attributes.

Table 6 presents the limited information available on the current attribute state for Luggate Creek at SH6 and compares the current state to the proposed target attribute state for the Dunstan Rohe. Attributes for Ecosystem Health – Aquatic life do not meet the target states for MCI scores (Table 6). 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). In this case, the low MCI scores observed in Luggate Creek are likely to reflect the dominance of chironomid midges and oligochaete worms, while high MCI scores reflected greater abundance of the cased caddis flies (*Pycnocentria* and *Olinga*), and the common mayfly *Deleatidium.* The abundance of oligochaete worms are consistent with deposits of fine sediment, while chironomid midges can be more abundant during periods with high periphyton biomasses, suggesting that low MCI scores in Luggate Creek may be associated with periods of fine sediments and/or periphyton blooms. Long-term trend analyses indicate that invertebrate metrics have increased over the period 2005-2022.

The Fish Index of Biotic Integrity (F-IBI; Joy & Death 2004) can be used to assess river condition based on the presence (or absence) of native fish species, the presence of native fish species in specific environments, the presence of sensitive native species, and the presence of exotic fish species. The F-IBI score for Luggate Creek at SH6 is low (5-year average: 16), indicating *"Severe loss of fish community integrity. There is substantial loss of habitat and/or migratory access, causing a high level of stress on the community"*. In the case of Luggate Creek, this reflects the naturally low diversity of native fish and the presence of non-native species (i.e. brown and/or rainbow trout).

### 6.4.2. Water quality

Water quality in Luggate Creek is generally very good (A-band) based on the data available (Table 6). The exceptions to this were dissolved reactive phosphorus and the faecal indicator bacterium *Escherichia coli (E. coli*), which exceeded the target attribute state (Table 6).

Water allocation is not expected to directly affect the concentrations of dissolved reactive phosphorus and *E. coli* in Luggate Creek, other than in its potential to support irrigated land uses that may support higher stocking rates, which may increase the risk of high concentrations of dissolved reactive phosphorus and *E. coli*.

**Table 6 Comparison of the current attribute state in Luggate Creek at SH6 with proposed objectives for the Dunstan Rohe based on Ozanne, Borges & Levy (2023).**

| | Luggate Creek at SH6 Bridge | | |
|---|---|---|---|
| | Baseline State[1] | Target state 2030 | Current state[2] |
| Periphyton Biomass | B | B | B |
| Periphyton TN | B | B | B |
| Periphyton TP | C | B | B |
| Ammonia - median | A | A | A |
| Ammonia - 95th Percentile | A | A | A |
| *E. coli* >260 cfu/100 mL | A | A | A |
| *E. coli* >540 cfu/100 mL | A (B - A) | A | B |
| *E. coli* median | A | A | A |
| *E. coli* Q95 | A (B - A) | B | B |
| DRP-median | C (C - B) | C | B |
| DRP Q95 | A | A | A |
| MCI | C | C | C |
| ASPM | B | B | B |
| FISH IBI | | | D |
| Suspended fine sediment | A | A | A |
| NNN - median | A | A | A |
| NNN - 95th percentile | A | A | A |

[1] Baseline state is defined as: (1) The state of the attribute on the date it is first identified by a regional council under clause 3.10(1)(b) or (c), (2) The state of the attribute on the date on which a regional council set a freshwater objective for the attribute under the NPSFM 2014 (as amended in 2017), or (3) The state of the attribute on 7 September 2017.

[2] Current state was calculated for the period to June 2022, from Ozanne, Borges & Levy (2023)

# 7. Instream Habitat Assessment

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).

## 7.1. Instream habitat modelling in Luggate Creek

Instream habitat modelling was undertaken in two reaches of Luggate Creek by Jowett (2004): between the main highway and the Clutha River confluence (lower), and between the large intake weir and the main highway (upper).

The lower survey site was surveyed at a flow of 180 l/s, with calibration surveys at 370 l/s and 850 l/s (Jowett 2004). Habitat mapping at the lower survey flow classified the reach as 32% pool, 37% run and 31% riffle habitats at the survey flow (Jowett 2004). Habitat mapping at the upper survey flow (850 l/s) classified the reach as 32% pool, 37% run and 31% riffle habitats at the survey flow (Jowett 2004).

### 7.1.1. Habitat preferences and suitability curves

For this analysis, the model of Jowett (2004) for the lower reach was updated with more recent habitat suitability curves (HSC) available for periphyton, macroinvertebrates and fish taxa present in Luggate Creek (Table 7) by Waterways Consulting.

The analyses presented in this report consider HSC for five classes of periphyton: cyanobacteria, diatoms, short filamentous algae and long filamentous algae. These periphyton classes were included in these analyses to consider how changes in flow in the modelled reaches may affect periphyton cover and composition, and the potential impacts on other instream values. Cyanobacteria were included because some types may produce toxins that pose a health risk to humans and animals. Native diatoms are generally considered a desirable component of the periphyton community. Filamentous algae, and in particular long filamentous algae, can form nuisance blooms during periods of stable flows and under nutrient-conditions. Such blooms can affect a range of instream values including aesthetics, biodiversity, recreation (swimming and angling), water takes (irrigation, stock/drinking water and industrial) and water quality.

Food producing habitat is an overseas HSC that describes the most productive habitat conditions for macroinvertebrates (i.e. analogous to riffle and shallow run habitat). The mayfly *Deleatidium* is arguably the most abundant and widespread aquatic macroinvertebrate in New Zealand and is consistently abundant in the Luggate River, and habitat for *Deleatidium* was modelled for this reason. The spine-gilled mayfly *Coloburiscus* is a filter-feeder, and consequently prefers high water velocities. *Coloburiscus* can be abundant in Luggate Creek at times, so it is included in this analysis for this reason. The stonefly *Zelandoperla* spp. favours habitats with high water velocities and it is an abundant taxon in Luggate Creek at times. 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 it can be abundant in the Luggate River at times. The horn-cased caddis fly *Olinga* can be abundant in Luggate Creek and is included in this analysis for this reason. It is included in habitat modelling to represent taxa that prefer slower-flowing habitats.

HSC for various two size-classes of longfin eels were included in these analyses to consider how changes in flow in the modelled reaches will affect habitat availability for them. However, recruitment of longfin eels to the Luggate Creek catchment (and the rest of the upper Clutha/Mata-Au) is low due to the presence of Roxburgh Dam.

Brown trout are found in the lower Luggate Creek, while rainbow trout are abundant in Luggate Creek to a point upstream of Criffel Weir. Several HSC for different life-stages of brown trout and general trout HSC (the HSC of Wilding were based on data for brown and rainbow trout) were included in these analyses to consider how changes in flow in the modelled reaches will affect habitat availability for sports fish.

**Table 7 Habitat suitability curves used in instream habitat modelling in Luggate Creek by Jowett (2019).**

| Group | HSC name | HSC source |
|---|---|---|
| Periphyton | Cyanobacteria<br>Diatoms<br>Long filamentous<br>Short filamentous | Ex Heath et al. (2013)<br>unpublished NIWA data<br>unpublished NIWA data<br>unpublished NIWA data |
| Macroinvertebrates | Food producing<br>Spiny-gilled mayfly (*Coloburiscus*)<br>Mayfly nymph (*Deleatidium*)<br>Stonefly nymph (*Zelandoperla*)<br>Net-spinning caddis fly (*Aoteapsyche*)[3]<br>Horn-cased caddis fly (*Olinga*)<br>Benthic invertebrate density | Waters (1976)<br>Jowett et al. (1991)<br>Jowett et al. (1991)<br>Jowett et al. (1991)<br>Jowett et al. (1991)<br>Jowett et al. (1991)<br>Jowett (2018) |
| Indigenous fish | Tuna/longfin eel (>300 mm)<br>Tuna/longfin eel (<300 mm)<br>Tuna/longfin eel (>300 mm)<br>Tuna/longfin eel (<300 mm) | Jowett & Richardson (2008)<br>Jowett & Richardson (2008)<br>Jellyman et al. (2003)<br>Jellyman et al. (2003) |
| Sports fish | Brown trout adult<br>Brown trout fry<br>Brown trout (< 100 mm)<br>Brown trout spawning<br>Juvenile trout T1<br>Adult trout T2 | Hayes & Jowett (1994)<br>Bovee (1978)<br>Jowett & Richardson (2008)<br>Shirvell & Dungey (1983)<br>Wilding et al. (2014)<br>Wilding et al. (2014) |

### 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 Luggate River are shown in Figure 10.

[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)

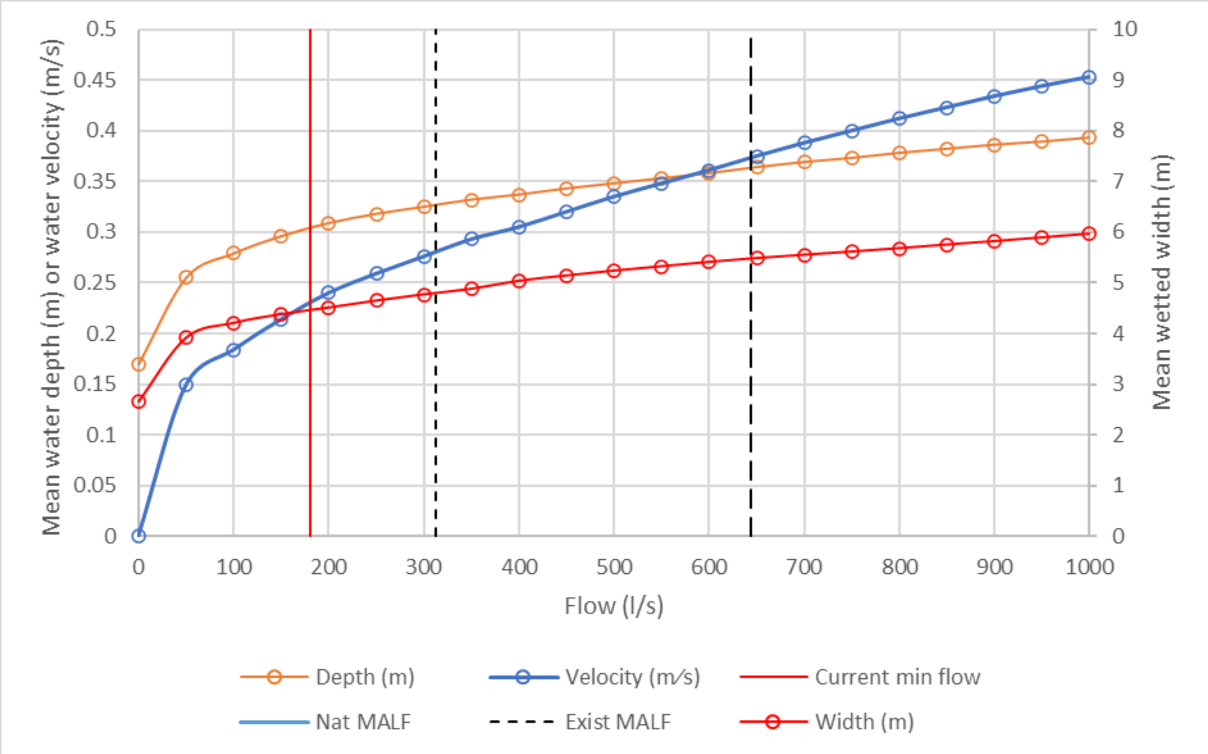


**Figure 10 Changes in mean channel width, mean water depth and mean water velocity with changes in flow in the survey reach of Luggate Creek. Updated from Jowett (2004).**

## 7.2. Periphyton

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

Flow was predicted to have little effect on habitat quality for cyanobacteria (*Phormidium*) with habitat quality predicted to decrease gradually as flows increased above 200 l/s (Figure 11). Habitat quality for native diatoms was predicted to be low but increase with increasing flow across the modelled flow range (Figure 11). Habitat quality for short filamentous algae was predicted to increase with increasing flows to 550 l/s before gradually decreasing at higher flows, while habitat quality for long filamentous algae was predicted to be highest at zero flow and to decline with increasing flows across the modelled flow range (Figure 11).

Flows required to achieve different levels of habitat retention for each of the periphyton classes taxa are presented in Table 8.

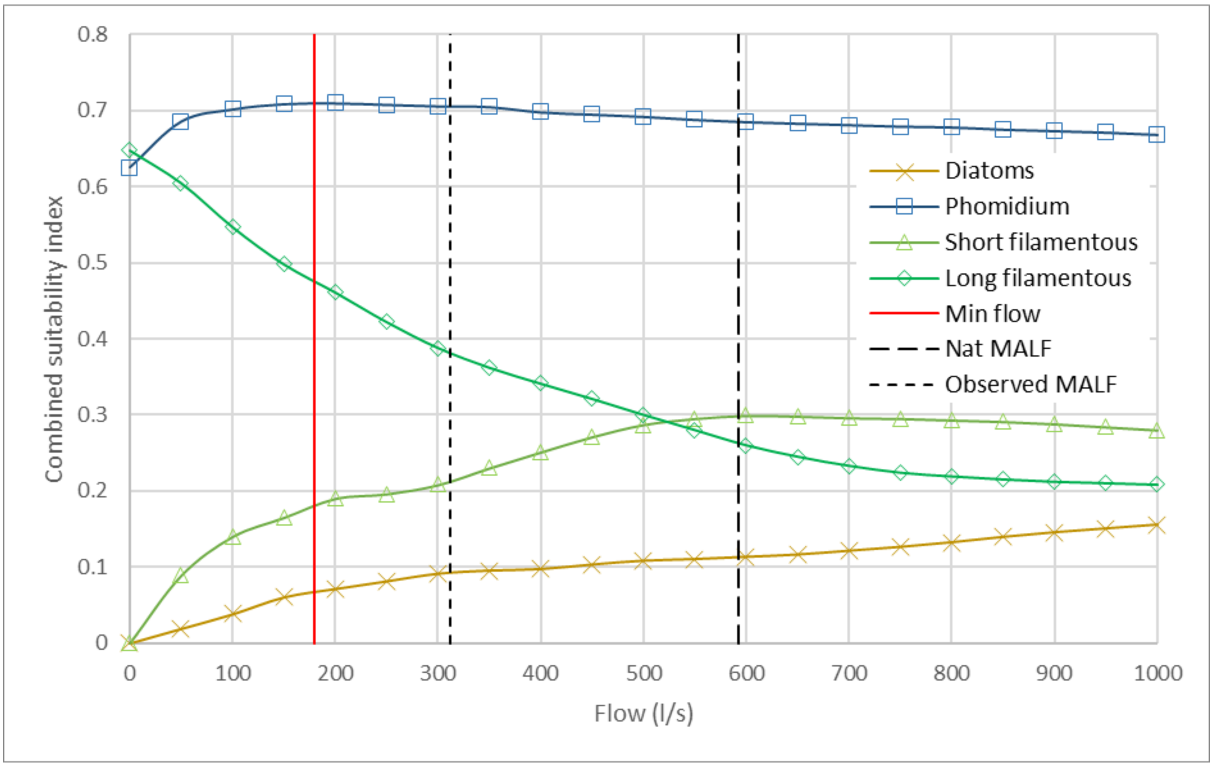


**Figure 11 Variation in instream habitat for indigenous fish relative to flow in the survey reach of Luggate Creek. Updated from Jowett (2004).**

**Table 8 Predicted effects of flow on periphyton habitat quality in Luggate Creek. Flows that the various habitat retention values occur at are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction). Updated from Jowett (2004).**

| Species | Optimum flow (l/s) | Flow at which % habitat retention occurs (l/s) | | | | Habitat retention at 180 l/s (%) |
|---|---|---|---|---|---|---|
| | | 120% | 150% | 200% | 300% | |
| Cyanobacteria (*Phormidium*) | 100-400 | - | - | - | - | 104 |
| Diatoms | >1,000 | - | - | - | - | 58 |
| Short filamentous | 600-700 | - | - | - | - | 60 |
| Long filamentous | 0 | 510 | 334 | 156 | 36 | 193 |

## 7.3. Macroinvertebrates

Food producing habitat and habitat for all macroinvertebrate taxa increased with flow across the modelled flow range (Figure 12). Flows required to achieve different levels of habitat retention for each of the macroinvertebrate taxa are presented in Table 9.

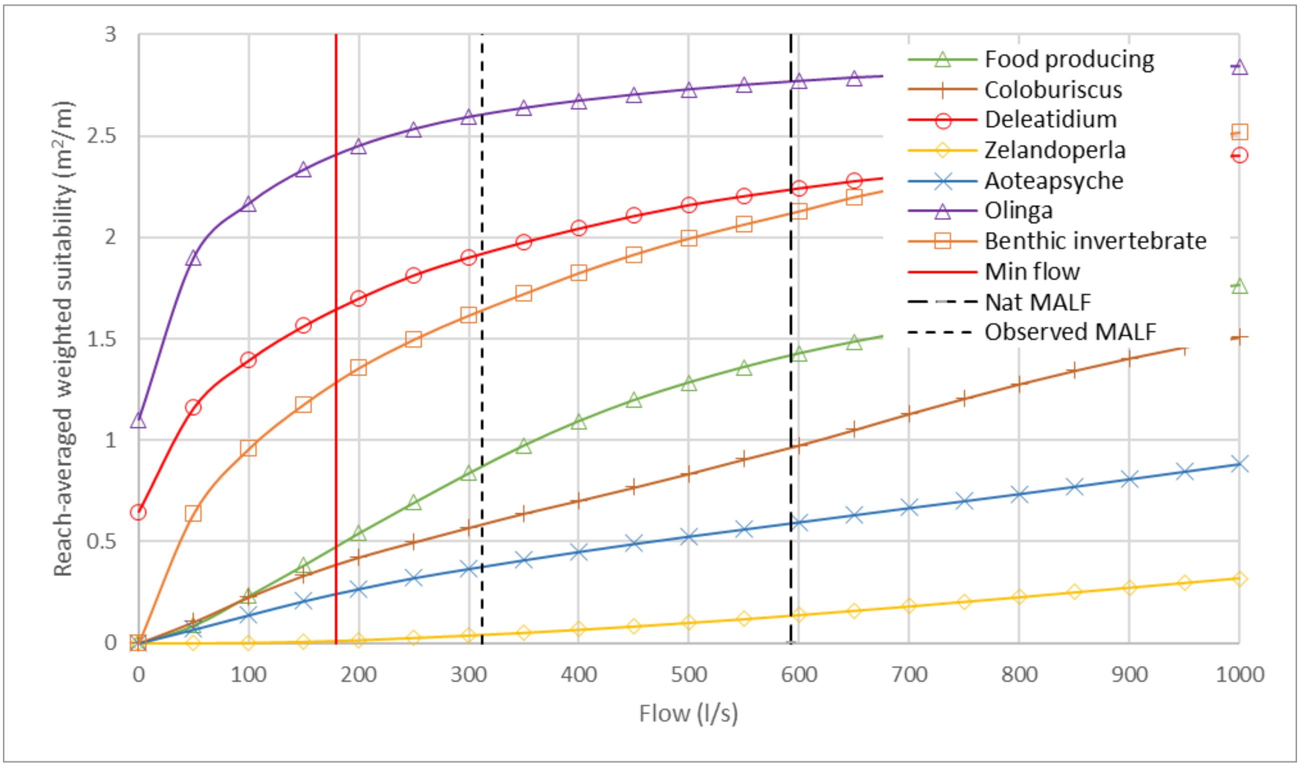


**Figure 12 Variation in instream habitat for common macroinvertebrates relative to flow in the survey reach of Luggate Creek. Updated from Jowett (2004).**

**Table 9 Flow requirements for macroinvertebrate habitat in Luggate Creek. 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). Updated from Jowett (2004).**

| Species | Optimum flow (l/s) | Flow at which % habitat retention occurs (l/s) | | | | Habitat retention at 180 l/s (%) |
|---|---|---|---|---|---|---|
| | | 60% | 70% | 80% | 90% | |
| Food producing | >1,000 | 318 | 375 | 442 | 530 | 32 |
| Spiny-gilled mayfly (*Coloburiscus*) | >1,000 | 340 | 421 | 499 | 573 | 37 |
| Mayfly nymph (*Deleatidium*) | >1,000 | 94 | 161 | 253 | 402 | 72 |
| Stonefly nymph (*Zelandoperla*) | >1,000 | 482 | 526 | 567 | 607 | 8 |
| Net-spinning caddis fly (*Aoteapsyche*)[4] | >1,000 | 311 | 386 | 467 | 554 | 39 |
| Horn-cased caddis fly (*Olinga*) | >1,000 | 36 | 59 | 119 | 234 | 86 |

[4] 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)

## 7.4. Indigenous fish

Two different sets of HSC available for two different size-classes of longfin eel were considered – those of Jellyman et al. (2003) and those of Jowett & Richardson (2008). The HSC of Jellyman et al. predicts that habitat for small longfin eel (<300 mm) increased across the modelled flow range, while the HSC of Jowett & Richardson (2008) predicts that habitat for small longfin eel (<300 mm) will increase markedly with flow up to 400 l/s, but increases at a lower rate with increasing flows between 400 and 1,000 l/s (Figure 13). For large (>300 mm) longfin eels, the HSC of Jellyman et al. predict that habitat will increase gradually across the modelled flow range, while those of Jowett & Richardson (2008) predict that habitat will increase with flow to an optimum at 500 l/s and dropping at higher flows (Figure 13).

Flows required to achieve different levels of habitat retention for each of the indigenous fish species are presented in Table 10.

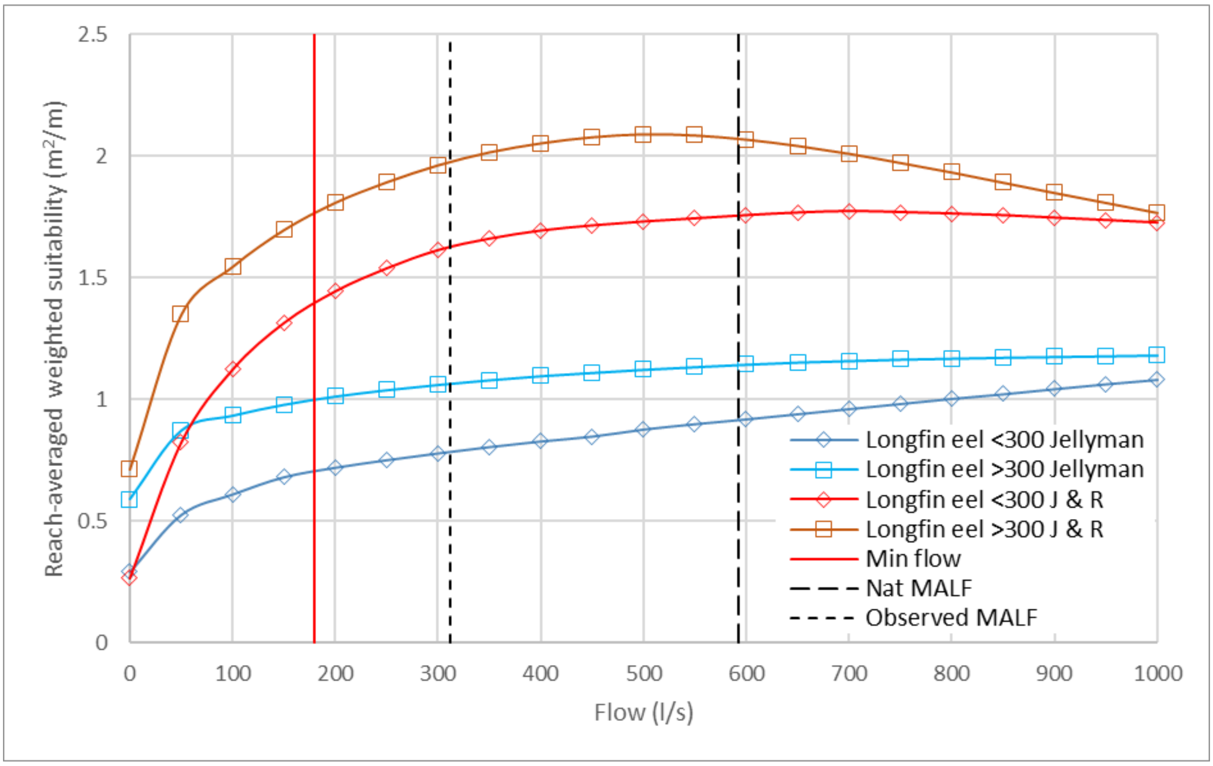


**Figure 13 Variation in instream habitat for indigenous fish relative to flow in the survey reach of Luggate Creek. Updated from Jowett (2004).**

**Table 10 Flow requirements for indigenous fish habitat in Luggate Creek. 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). Updated from Jowett (2004).**

| Species | Optimum flow (l/s) | Flow at which % habitat retention occurs (l/s) | | | | Habitat retention at 180 l/s (%) |
|---|---|---|---|---|---|---|
| | | 60% | 70% | 80% | 90% | |
| Longfin eel (<300 mm) Jellyman | >1,000 | 72 | 133 | 248 | 439 | 75 |
| Longfin eel (<300 mm) Jowett & Richardson | 400-1000 | 89 | 130 | 188 | 284 | 79 |
| Longfin eel (>300 mm) Jellyman | >1,000 | 18 | 38 | 90 | 246 | 87 |
| Longfin eel (>300 mm) Jowett & Richardson | 400-600 | 40 | 71 | 130 | 219 | 86 |

## 7.5. Sports fish

Habitat for juvenile brown trout (<100 mm) is predicted to increase with flow up to 700 l/s but flow is predicted to have little effect on habitat between 700 l/s and 1,000 l/s (Figure 14). In contrast, habitat for brown trout fry is predicted to increase with flow up to 190 l/s but to slowly decline at higher flows (Figure 14). Brown trout spawning habitat is predicted to increase with flow up to 325 l/s, be stable between 325 l/s and 600 l/s, before gradually declining at higher flows (Figure 14).

Flows required to achieve different levels of habitat retention for each of the fish taxa are presented in Table 11.

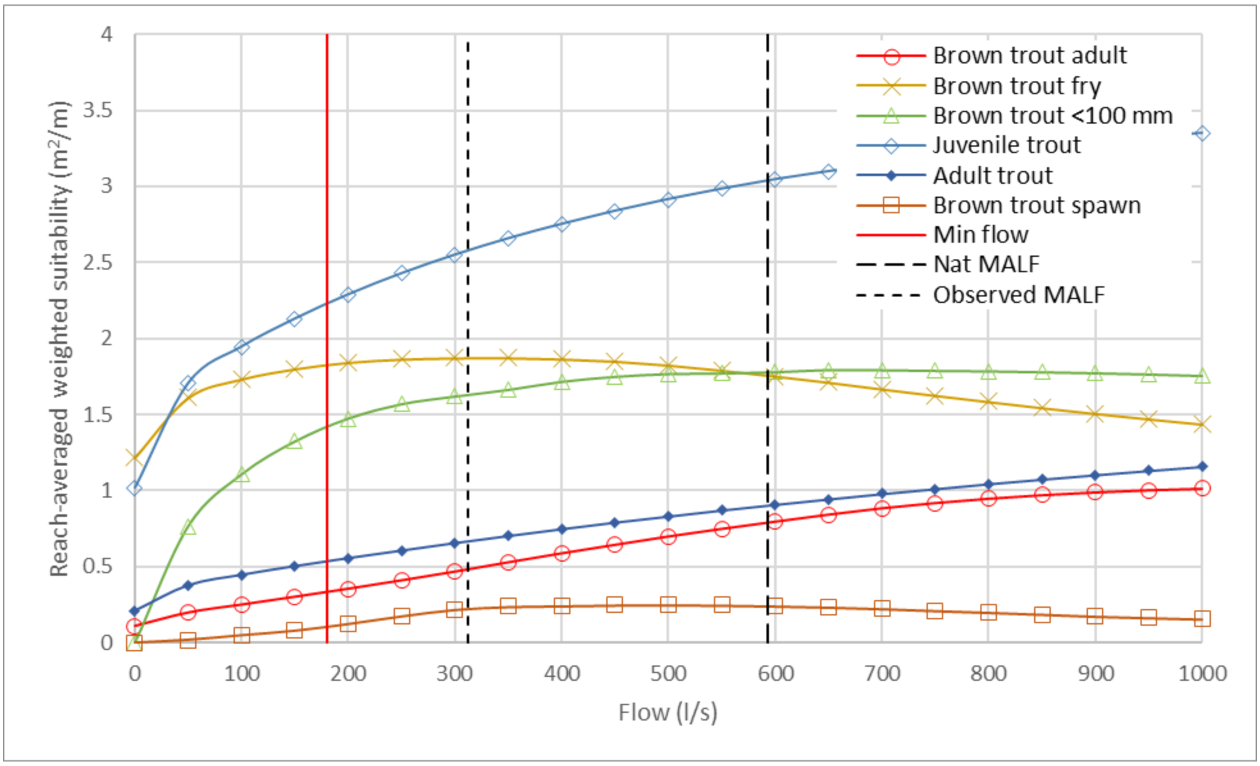


**Figure 14 Variation in instream habitat for sportsfish relative to flow in the survey reach of Luggate Creek. Updated from Jowett (2004).**

**Table 11 Flow requirements for sportsfish habitat in Luggate Creek. 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). Updated from Jowett (2004).**

| Species | Optimum flow (l/s) | Flow at which % habitat retention occurs (l/s) | | | | Habitat retention at 180 l/s (%) |
|---|---|---|---|---|---|---|
| | | 60% | 70% | 80% | 90% | |
| Brown trout adult | >1,000 | 328 | 399 | 474 | 555 | 40 |
| Brown trout fry to 15 cm | 350 | 101 | 131 | 165 | 208 | 84 |
| Brown trout <100 mm | 650 | 95 | 134 | 187 | 294 | 79 |
| Brown trout spawning | 500 | 216 | 239 | 264 | 291 | 46 |
| Juvenile trout (Wilding) | >1,000 | 81 | 161 | 269 | 418 | 72 |
| Adult trout (Wilding) | >1,000 | 207 | 302 | 404 | 518 | 57 |

## 7.6. Summary of instream habitat assessments

The objective of imposing a minimum flow and allocation regime 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 Dunstan Rohe outlined in Table 1.

Luggate Creek supports a low number of indigenous fish species, with a single detection of longfin eel and scattered records of kōaro. The updated habitat modelling of Jowett (2004) predicts that 80% habitat retention (relative to naturalised flows) for longfin eels occurs at 90-248 l/s, while flows of 219-439 l/s are predicted to retain 90% of longfin eel habitat (Table 12).

Trout spawning and rearing in Luggate Creek likely contributes recruitment to the trout fishery in the upper Clutha. The existing winter minimum flow (500 l/s) is predicted to provide optimum habitat for brown trout spawning (Table 12). Trout spawning occurs in the winter months (April-June) for brown trout, while rainbow trout spawn in late winter/spring (July-September), outside of the irrigation season in the Luggate Creek area.

**Table 12 Flow requirements for habitat objectives in Luggate Creek. 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). Based on the analysis of Jowett (2019).**

| Value | Season | Significance | Level of habitat retention | Flow to maintain suggested level of habitat retention (l/s) | Habitat retention at 180 l/s (%) |
|---|---|---|---|---|---|
| Long filamentous algae | Summer | Nuisance growths | <150% relative to naturalised | >334 | 193% |
| Macroinvertebrates | All year | Life-supporting capacity<br>Indigenous biodiversity | 80% relative to naturalised | 119-567 | 8-86% |
| Longfin eel | All year | Life-supporting capacity, | 80% relative to naturalised | 90-248 | 75-87% |
| | | indigenous biodiversity, mahika kai | 90% relative to naturalised | 219-439 | |
| Juvenile trout | All year | Sports fish, recruitment to upper Clutha/Mata-Au | Maintain or enhance | 180 | 72-84% |
| | | | 80% relative to naturalised | 165-269 | |
| Trout spawning | Winter | Sports fish, recruitment to Upper Clutha | Maintain or enhance | 500 | 106% |
| | (May-Oct) | | Optimum | 500 | |

# 8. Assessment of alternative minimum flows and allocation limits

Four minimum flow and four allocation regime combinations were considered representing different proportions of the (naturalised??) 7-day MALF (Table 13). To consider the hydrological effects of the various combinations of minimum flow/allocation, simulations were run for the period 1 July 2016 – 20 March 2023 using naturalised flows estimated by adding water take (based on water metering data) back onto the observed flows at Luggate Creek at SH6.

**Table 13 Minimum flow and allocation limits considered in this analysis.**

| Minimum flow | % 7-d MALF | Allocation limit | % 7-d MALF | Description |
|---|---|---|---|---|
| 180 l/s | 28% | 538 l/s | 84% | Current minimum flow and allocation. |
| | | 450 l/s | 70% | Current minimum flow and allocation at 70% of 7-d MALF. |
| | | 320 l/s | 50% | Current minimum flow and allocation at 47% of 7-d MALF. |
| | | 160 l/s | 25% | Current minimum flow and allocation at 31% of 7-d MALF. |
| 240 l/s | 37% | 538 l/s | 84% | 240 l/s minimum flow and current allocation. |
| | | 450 l/s | 70% | 240 l/s minimum flow and allocation at 70% of 7-d MALF. |
| | | 320 l/s | 50% | 240 l/s minimum flow and allocation at 47% of 7-d MALF. |
| | | 160 l/s | 25% | Current minimum flow and allocation at 31% of 7-d MALF. |
| 320 l/s | 50% | 538 l/s | 84% | 320 l/s minimum flow and current allocation. |
| | | 450 l/s | 70% | 320 l/s minimum flow and allocation at 70% of 7-d MALF. |
| | | 320 l/s | 50% | 320 l/s minimum flow and allocation at 47% of 7-d MALF. |
| | | 160 l/s | 25% | 320 l/s minimum flow and allocation at 31% of 7-d MALF. |
| 450 l/s | 70% | 538 l/s | 84% | 450 l/s minimum flow and current allocation. |
| | | 450 l/s | 70% | 450 l/s minimum flow and allocation at 70% of 7-d MALF. |
| | | 320 l/s | 50% | 450 l/s minimum flow and allocation at 50% of 7-d MALF. |
| | | 160 l/s | 25% | 450 l/s minimum flow and allocation at 25% of 7-d 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). The results of these simulations are presented in Table 15.

**Table 14 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 |

The observed flows in Luggate Creek over the period July 2016 – June 2023 were markedly closer to the natural flows than predicted by the scenario with a minimum flow of 180 l/sand 538 l/s allocation limit (Figure 15). This is reflected in the DHRAM scores for these two scenarios, with observed flows reflecting “unimpacted conditions” compared to natural, while the 180 l/s minimum flow/538 l/s allocation limit scenario was predicted to represent a low risk of impact (Table 15). All minimum flow/allocation limit scenarios considered were predicted to be a low risk of impact (Table 15). These results were unexpected and seem inconsistent with the difference between the natural and observed 7-d MALFs. However, the DHRAM approach is used here to consider the broader potential impacts of water allocation on the hydrology of Luggate Creek, rather than on the duration and magnitude of low flows. Thus, the results of the DHRAM analysis should be viewed alongside information on the current ecological state (as presented in Section 6.4) and the results of instream habitat modelling presented in Section 7.

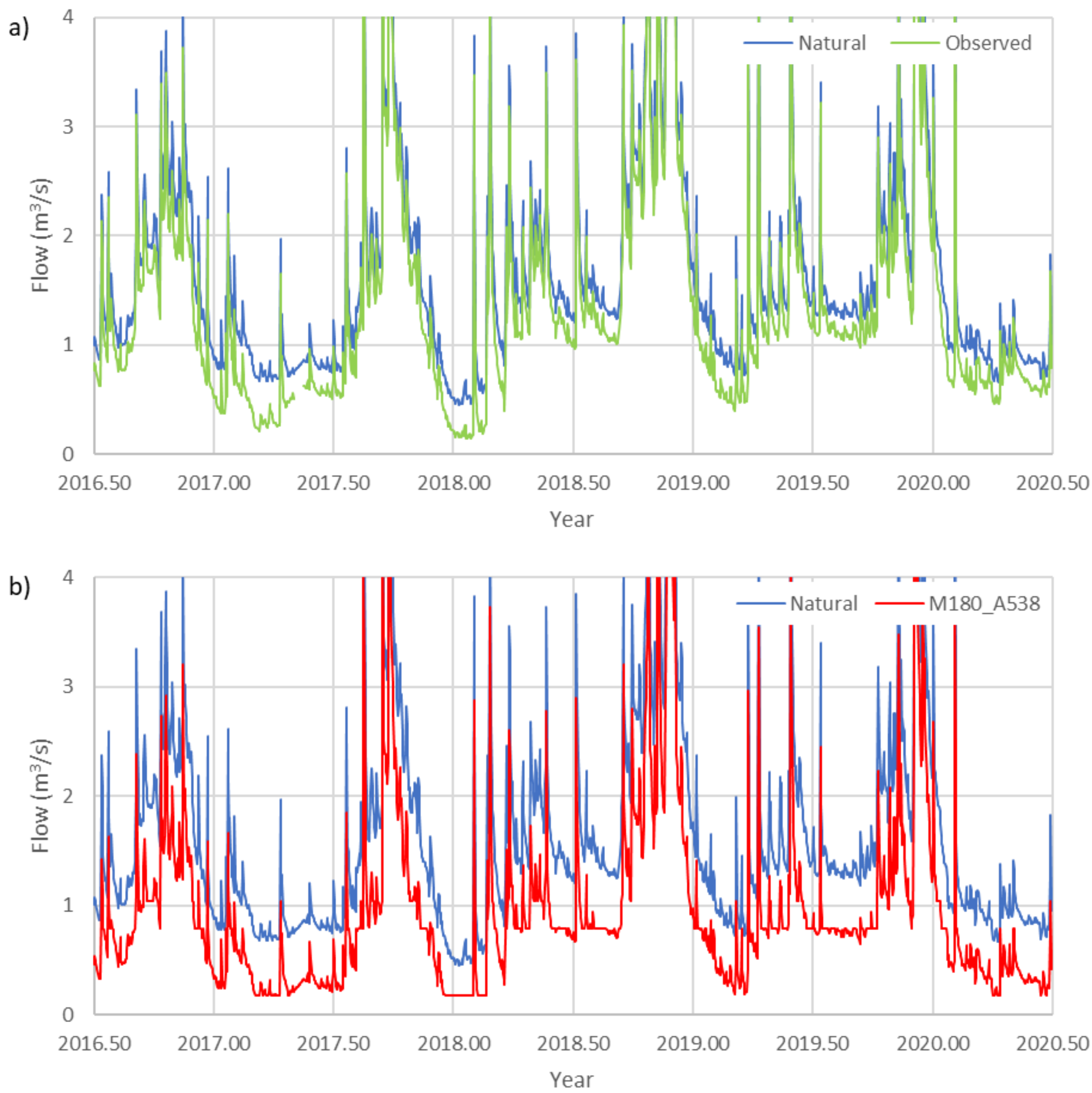


**Figure 15 Hydrographs of a) observed flows and b) current minimum flow (180 l/s) and allocation limit (538 l/s)**

**Table 15 Comparison of the hydrological effects of different minimum flow/allocation limit combinations in Luggate Creek.**

| | | Monthly | | Min/max means | | Date/timing | | Pulse count/duration | | Rate of change | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Min flow** | **Allocation** | **CV** | **Mean** | **CV** | **Mean** | **CV** | **Mean** | **CV** | **Mean** | **CV** | **Mean** | |
| Observed | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Unimpacted |
| 180 | 538 | 1 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | Low risk of impact |
| | 450 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | Low risk of impact |
| | 320 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | Low risk of impact |
| | 160 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Low risk of impact |
| 240 | 538 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | Low risk of impact |
| | 450 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | Low risk of impact |
| | 320 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | Low risk of impact |
| | 160 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Low risk of impact |
| 300 | 538 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | Low risk of impact |
| | 450 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | Low risk of impact |
| | 320 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | Low risk of impact |
| | 160 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Low risk of impact |
| 450 | 538 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 1 | 2 | 0 | Moderate risk of impact |
| | 450 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 1 | 1 | 0 | Moderate risk of impact |
| | 320 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Low risk of impact |
| | 160 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Low risk of impact |

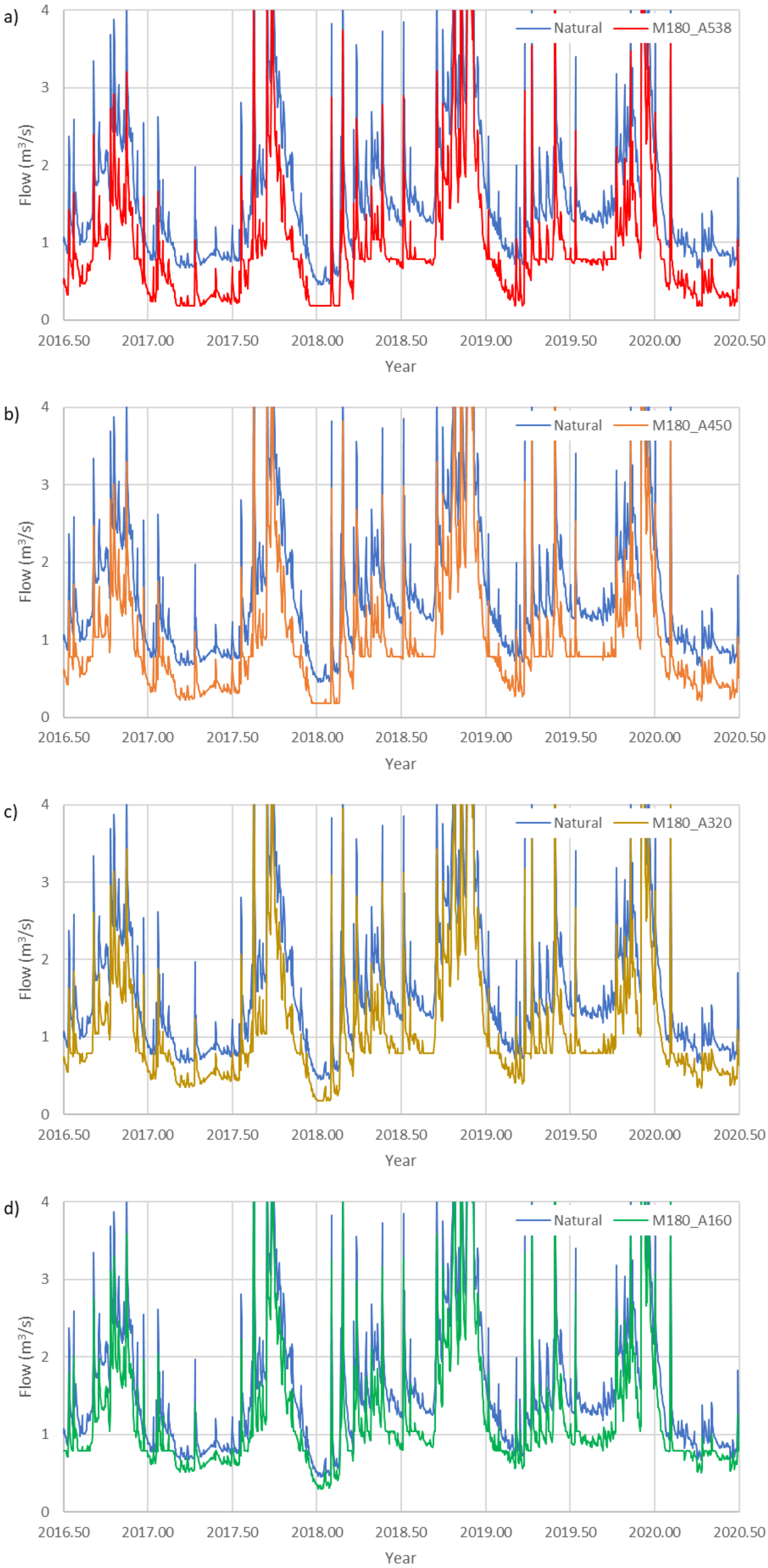


**Figure 16 Hydrographs of allocation scenarios with a minimum flow of 180 l/s. a) Current allocation limit 538 l/s, b) allocation limit of 450 l/s, c) allocation limit of 320 l/s. d) allocation limit of 160 l/s.**

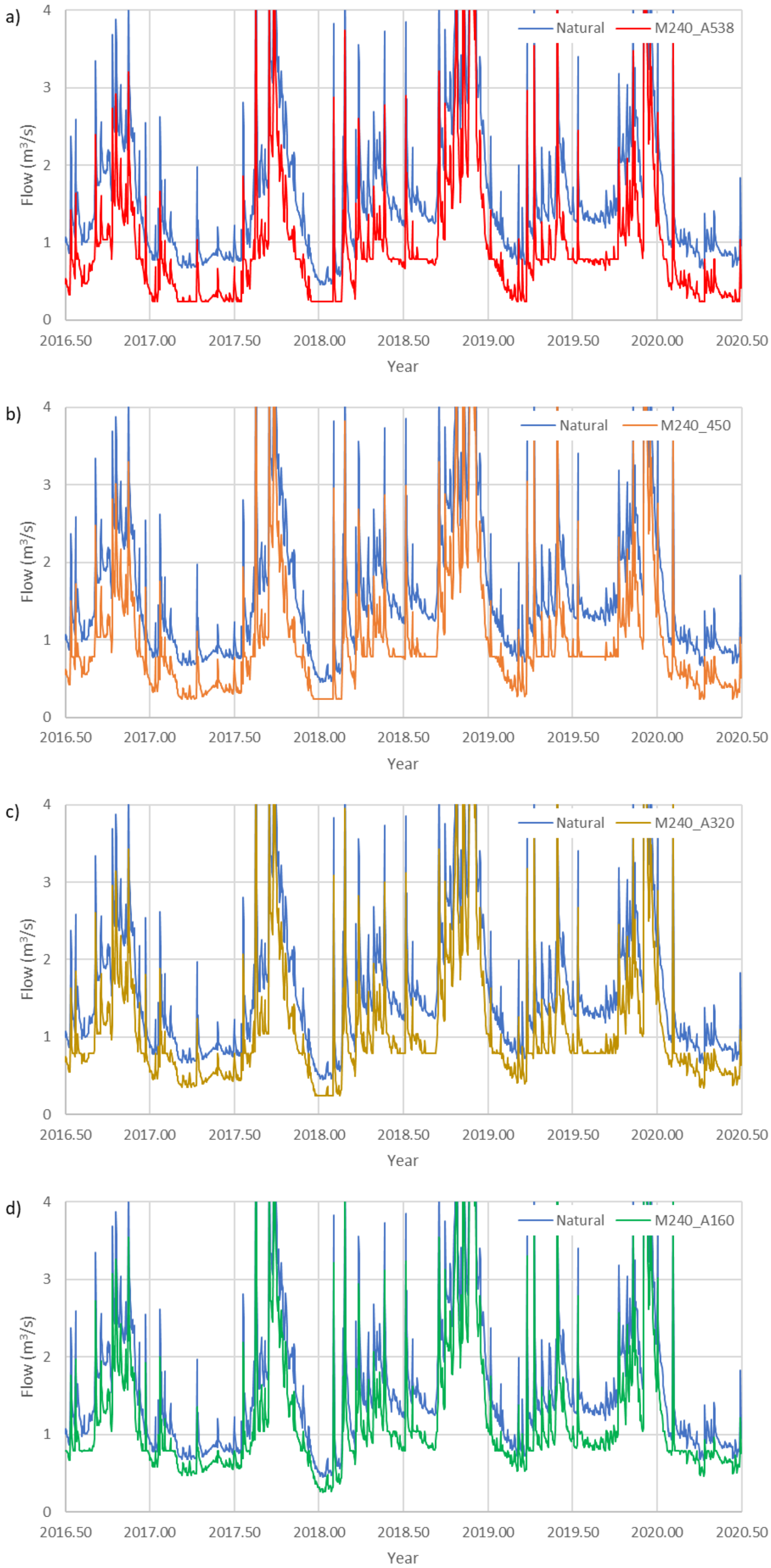


**Figure 17 Hydrographs of allocation scenarios with a minimum flow of 240 l/s. a) Current allocation limit 538 l/s, b) allocation limit of 450 l/s, c) allocation limit of 320 l/s. d) allocation limit of 160 l/s.**

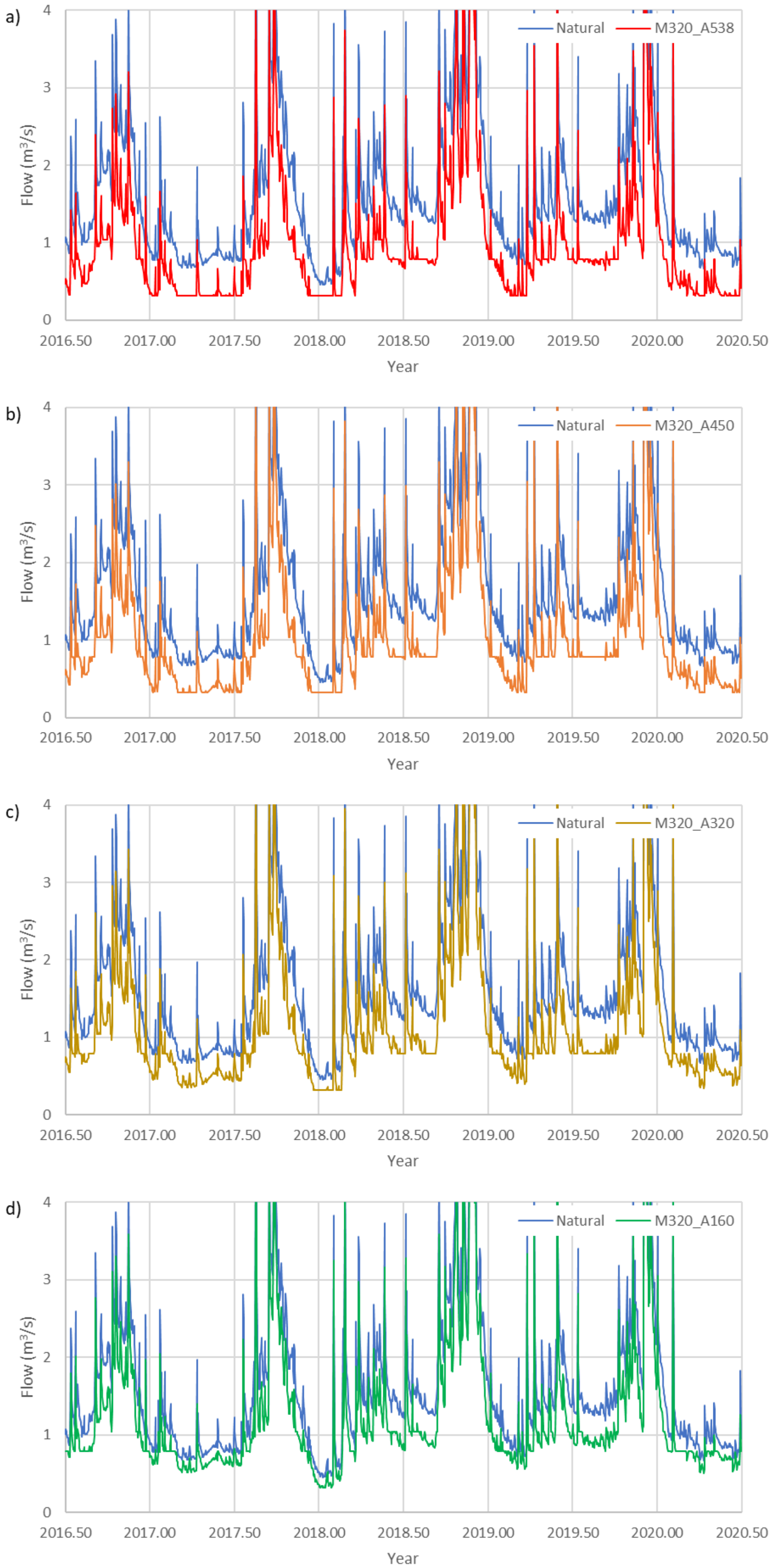


**Figure 18 Hydrographs of allocation scenarios with a minimum flow of 320 l/s. a) Current allocation limit 538 l/s, b) allocation limit of 450 l/s, c) allocation limit of 320 l/s. d) allocation limit of 160 l/s.**

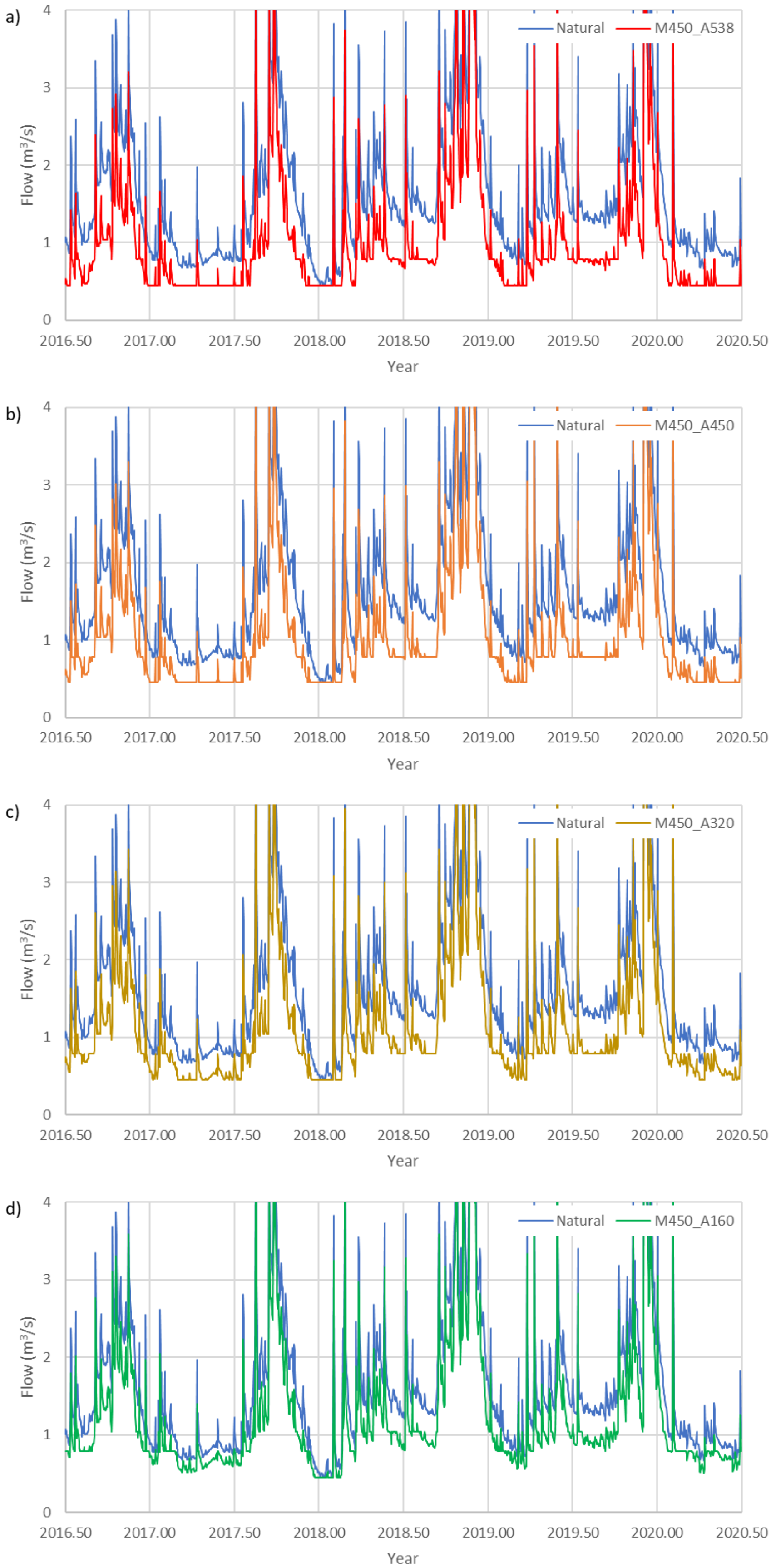


**Figure 19 Hydrographs of allocation scenarios with a minimum flow of 450 l/s. a) Current allocation limit 538 l/s, b) allocation limit of 450 l/s, c) allocation limit of 320 l/s. d) allocation limit of 160 l/s.**

## 8.1. Potential effects of climate change in the Luggate Creek 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 probability, magnitude and duration of low flow events in the Luggate Creek catchment are expected to be similar to, or slightly less than what is currently experienced (Table 16). Climate change is not expected to reduce habitat suitability for sensitive species (via increased water temperatures) in the Luggate Creek catchment by 2040 given that current temperatures are well within the tolerances of the most sensitive species present in the catchment (see Section 5).

The predicted changes in the hydrology of Luggate Creek resulting from climate change include higher mean flow and higher flood magnitudes, which may enhance flushing of fine sediments and periphyton (Table 16), which is expected to be a positive ecological effect, particularly on the macroinvertebrate community of Luggate Creek.

**Table 16 Potential effects of climate change on the Luggate Creek 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 (0.9-1.0°C)<br>• Increased annual mean maximum temperature (1.1-1.3°C)<br>• Increase in number of hot days (>30°C) (increase by 5.9-6.3 days per annum)<br>• Reduced frost days (-10.7--12.2days per year) fewer frost days per annum) | • Increased evapotranspiration<br>• Faster flow recession<br>• Increased irrigation demand | • Higher water temperatures, reduced suitability for sensitive species<br>• Faster accrual of periphyton biomass |
| Rainfall | • Small increase in annual mean rainfall (4%)<br>• Increase in summer mean rainfall (7-8%)<br>• Increased winter rainfall (4-6%)<br>• Similar risk of low rainfall events<br>• Little change in heavy rain days (>25 mm; +0.3-+0.4 days per annum)<br>• Increase in peak rainfall intensity | • Similar or slightly reduced likelihood and/or magnitude of low flow events<br>• Potential increase in magnitude of high flow events | • Enhanced flushing of sediment and periphyton |
| Snow | • Reduction in snow days | • Reduced snowpack<br>• Earlier and/or shorter spring snowmelt<br>• Larger winter floods | • Enhanced flushing of sediment and periphyton |
| Hydrology | • Slight increase in Q95 flow (-5-+10%)<br>• Increase in mean flow (up to 10-20% increase)<br>• Increased mean annual flood | • Low flows similar magnitude to existing<br>• Irrigation demand may slightly decrease<br>• Increased frequency and/or magnitude of flushing flows<br>• Reliability for irrigators similar or slightly higher than present | • Enhanced flushing of sediment and periphyton |

# 9. Conclusions

Luggate Creek is a small river which rises in the tussock grasslands and on the northern half of the Criffel and Pisa Ranges, flowing onto a flat terrace at the Luggate township before flowing into the upper Clutha/Mata-Au. Water takes within the Luggate catchment have historically been authorised by deemed permits (also known as mining rights) and were not subject environmental restrictions, such as minimum flows, however these were replaced with resource consents, including minimum flows in 2019.

The Luggate is within the Clutha Mata-Au Freshwater Management Unit (FMU) and the Dunstan Rohe. Like many waterways within the Dunstan Rohe, Luggate Creek has a long history of water abstraction. Schedule 2A of the Regional Plan: Water specifies a minimum flow for primary allocation in Luggate Creek at the SH6 bridge of 180 l/s. The primary allocation limit specified for the Luggate Creek catchment in Schedule 2A is 500 l/s.

Hydrological statistics for Luggate Creek at SH6 bridge based on Lu (2023) are summarised below:

| Site | Type | Flow statistics (l/s) | | | Return interval analysis (7-day period) | |
|---|---|---|---|---|---|---|
| | | Mean | Median | 7d MALF (Jul-Jun) | 5-year return (Q7,5) | 10-year return (Q7,10) |
| Luggate at SH6 | Naturalised flows | 1,595 | 1,294 | 644 | 548 | 513 |
| | Observed flows | 1,344 | 1,078 | 312 | - | - |

There are three resource consents to take surface water from the Luggate Creek catchment: the first is from a large weir on the mainstem of Luggate Creek, the second is from five locations in Luggate Creek and the Alice Burn. Total primary allocation in the Luggate catchment is 538 l/s. In addition to the primary allocations, both consents include allocation within the first (minimum flow: 788 l/s, allocation block: 250 l/s) and second supplementary blocks (minimum flow: 1,038 l/s, allocation block: 166 l/s).

The periphyton community in Luggate Creek is usually dominated by thin light brown films (dominated by diatoms) with medium to thick cyanobacteria (usually consisting of the colonial taxon *Nostoc*) often present. Long brown/reddish filamentous taxa have also been abundant at times. Chlorophyll *a* concentrations did not exceed 200 mg/m$^2$ over the July 2019 – June 2022 period, and the chlorophyll *a* concentrations observed at this site over this period placed this site in B-band of the NOF.

Macroinvertebrate community index scores for this site varied between B and C-bands, indicative of mild to moderate organic pollution or nutrient enrichment. Meanwhile, SQMCI scores were more variable, ranging between A and D bands, although the median score was in B-band, indicating mild organic pollution or nutrient enrichment. ASPM scores consistently indicated 'mild to moderate loss of ecological integrity' (B-band), Two species of indigenous freshwater fish have been recorded from the Luggate Creek catchment – longfin eel/tuna and kōaro. Brown trout have been collected from the lower reaches of Luggate Creek, while rainbow trout are more widespread, having been recorded from Luggate Creek upstream of the Criffel weir. No angler effort has been recorded in the Luggate catchment in the National Angler Survey, although brown and rainbow trout spawning in Luggate Creek likely contributes to recruitment and juvenile rearing for the upper Clutha/Mata-Au fishery to some degree, although the significance of this contribution is unknown. The F-IBI score for Luggate Creek at SH6 is in D-band (5-year average: 16), indicating *"Severe loss of fish community integrity. There is substantial loss of habitat and/or migratory access, causing a high level of stress on the community"*. In the case of Luggate Creek, this reflects the effects of migration barriers for longfin eel presented by the Roxburgh and Clyde Dams. Kōaro, whilst native, are likely to be more abundant in Luggate Creek today than historically, because of migrants from the artificial Lake Dunstan entering Luggate Creek.

Comparison of the current state of Luggate Creek with objectives for the Dunstan Rohe provides insight into whether current conditions are consistent with the objectives proposed in the Land & Water Regional Plan. MCI scores in Luggate Creek (C-band) do not meet the proposed target states for Ecosystem Health – Aquatic life (B-band), although other macroinvertebrate metrics (QMCI and ASPM) do meet proposed targets. In addition, trend analyses for macroinvertebrate indices suggest improving trends since 2004.

Luggate Creek does not meet proposed objectives for some water quality attributes (deposited fine sediment, *E. coli* concentrations, DRP). Of these, water allocation is unlikely to account for the exceedances of *E. coli* and DRP but may contribute to the exceedance of targets for deposited fine sediments, as higher flows are expected to enhance flushing of fine sediments.

An instream habitat model developed for the mainstem of Luggate Creek by Jowett (2004) was updated and applied to consider the effects of different flows on the physical characteristics of Luggate Creek and habitat for periphyton, macroinvertebrates and fish. The current minimum flow is predicted to be associated with a significant increase in habitat suitability for long filamentous algae. The current minimum flow in the Luggate catchment (180 l/s) is predicted to maintain between 9% (the stonefly *Zelandoperla*) and 73% (the common mayfly *Deleatidium*) of habitat for macroinvertebrates at the naturalised 7-d MALF. It is predicted to maintain 77-87% of habitat for longfin eel compared to the naturalised 7-d MALF. The current minimum flow is predicted to achieve between 42% (brown trout adult) and 83% (brown trout fry to 15 cm) habitat retention for the various brown trout life-stages considered.

Flows of less than 290 l/s are predicted to significantly increase habitat suitability for long filamentous algae. Flows of 114-522 l/s are predicted to retain 80% of the habitat available for the macroinvertebrate taxa considered at the naturalised MALF. Flows of 84-221 l/s are predicted to retain 80% of the habitat for tuna/longfin eel available at the naturalised MALF. Flows of 169-371 l/s are predicted to retain 80% of the habitat available for the various species/life-stages of trout at the naturalised MALF.

Comparison of minimum flow/allocation limit scenarios suggests that the observed flows represent a degree of hydrological alteration that is unimpacted compared to naturalised flows. All allocation scenarios with minimum flows of 180 l/s, 240 l/s and 300 l/s were predicted to be a low risk of impact while scenarios with a minimum flow of 450 l/s and allocation limits of either 538 l/s or 450 l/s were predicted to represent a moderate risk of impact.

The predicted effects of climate change in Luggate Creek include higher mean flow and higher flood magnitudes, which may enhance flushing of fine sediments and periphyton and is expected to be a positive ecological effect, particularly on the macroinvertebrate community of Luggate Creek.

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## Appendix A

## Flow naturalisation of Luggate Creek at SH6 Bridge

# Flow naturalisation of Luggate Creek at SH6 Bridge

## Contents



Otago Regional Council

## 10.1. Document Review

| Name | Role | Date Completed |
|---|---|---|
| Lu Xiaofeng | Author | 18th April 2023 |
| Helen Manly | Readability Review | 18th April 2023 |
| Dave Stewart | Technical Review | 7th July 2023 |
| Lu Xiaofeng | Final Version completion | 7th July 2023 |

This document describes how naturalised flow statistics at the flow recorder at SH6 Bridge on Luggate Creek were derived.

## 10.2. Daily flow time series data

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

**Table 17: The daily flow time series data available for analysis above Luggate Creek at SH6 Bridge.**

| Sites | Start | End | Length (year) |
|---|---|---|---|
| Luggate Creek at SH6 Bridge | *17/12/2015* | *13/06/2023* | 7.5 |

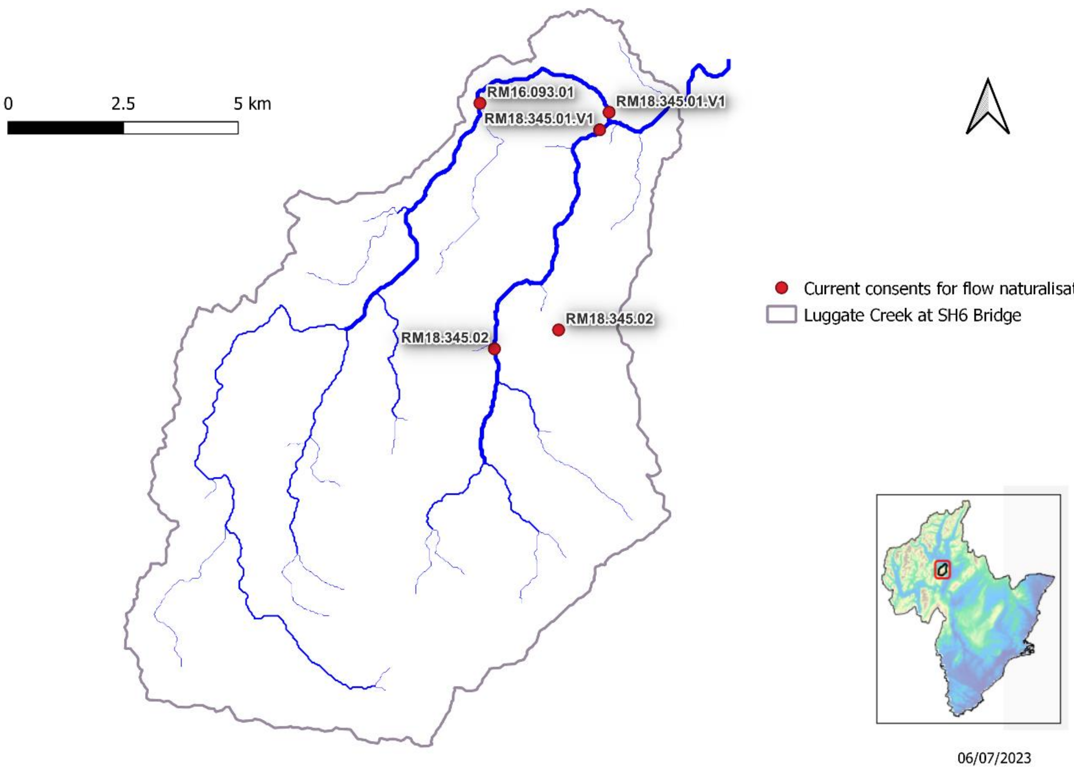


**Figure 20: The locations of the current consents in the upstream area above the flow recorder at Luggate Creek at SH6 Bridge.**

## 10.3. Daily water use time series

Time series data of water use (WU) is needed to naturalise the flow at Luggate Creek at SH6 Bridge flow recorder. All consents for water use must first be identified above the flow recorder.

### 10.3.1. Total water use above the SH6 Bridge flow recorder on Luggate Creek

As listed in **Table A1** in the **Appendix**, 29 consents are used to estimate the naturalised flows at SH6 Bridge flow recorder in Luggate Creek. Of these, only 3 are currently active. **Figure 2** shows the total combined WU above Luggate Creek at SH6 Bridge flow recorder.

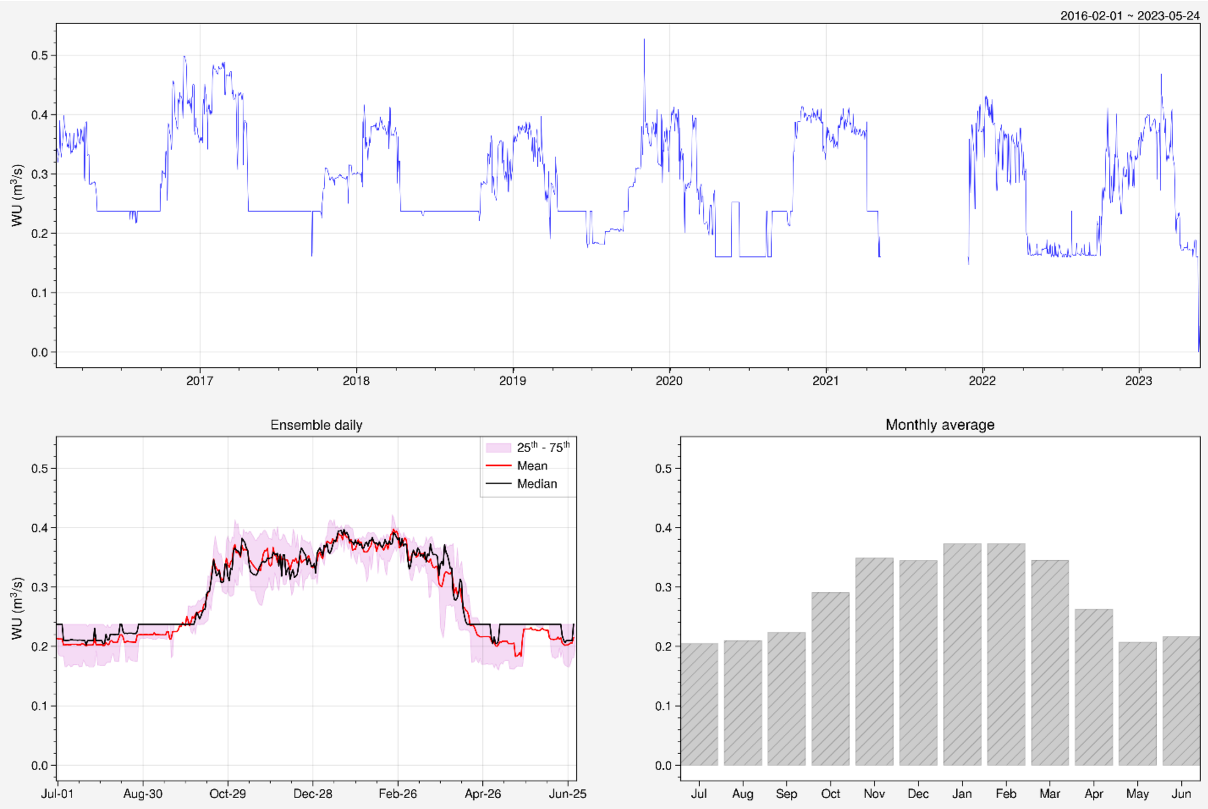


**Figure 21: The total water use upstream of the recorder on Luggate Creek at SH6 Bridge.**

As shown in **Figure 2**, the period from the water year 2016/17 onwards is used to naturalise the flows of Luggate Creek at SH6 Bridge. The average total WU across the whole season is 286 L/s since the water year 2016/17.

## 10.4. Flow naturalisation

This section describes how the naturalised flow statistics are estimated for the flow recorder on Luggate Creek at SH6 Bridge.

### 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 on Luggate Creek at SH6 Bridge.

### 10.4.2. Naturalised flow statistics

#### *1.1.1.1 Basic flow statistics (Table 2).*

**Table 18: Naturalised flow statistics for the recorder at Luggate Creek at SH6 Bridge (01/07/2016 ~ present).**

| Site | Mean ($m^3/s$) | Median ($m^3/s$) | FRE3[5] ($year^{-1}$) | 7dMALF ($m^3/s$) (Jul - Jun) |
|---|---|---|---|---|
| Luggate Creek at SH6 Bridge (naturalised) | 1.595 | 1.294 | 3.7 | 0.644 |
| Luggate Creek at SH6 Bridge (observed) | 1.344 | 1.078 | 4.8 | 0.312 |

The naturalised mean annual 7-day moving average flows of 5- and 10-year return periods at Luggate Creek at SH6 Bridge are estimated as $Q_{7,5}$ = 0.548 and $Q_{7,10}$ = 0.513 $m^3/s$, respectively.

It must be noted that the $Q_{7,5}$ and $Q_{7,10}$ values were estimated using a relatively shorter naturalised time series and they may vary dramatically when more data is available in the future. Using different distributions could also vary the results.

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

## 10.5. Appendix

### 10.5.1. Table A1. The consents used to naturalise the flows at the SH6 Bridge on Luggate Creek

| Consent | Status | Water meter | Allocation type | Category | Consented rate |
|---|---|---|---|---|---|
| RM16.093.01 | Current | WM0730 | Primary | Surface Take | 358 |
| RM18.345.01.01 | Current | WM0671 | Primary | Surface Take | 87 |
| RM18.345.02 | Current | WM0487 | Primary | Surface Take | 93 |
| 1480A | Expired | | | Surface Take | |
| 1480B | Expired | | | Surface Take | |
| 1480C | Expired | | | Surface Take | |
| 1670 | Expired | | | Surface Take | |
| 2001.011.V1 | Expired | WM0730 | | Surface Take | 13.9 |
| 2008.519.V1 | Expired | WM0487 | Primary | Surface Take | 169.8 |
| 2585A | Expired | | | Surface Take | |
| 2585B | Expired | | | Surface Take | |
| 2754 | Expired | | | Surface Take | |
| 3295B | Expired | | | Surface Take | |
| 3295C | Expired | | | Surface Take | |
| 3296 | Expired | | | Surface Take | |
| 94201 | Expired | WM0730 | | Surface Take | 20.83 |
| 950 | Expired | | | Surface Take | |
| 95541 | Expired | WM0730 | | Surface Take | 27.77 |
| 95560 | Expired | WM0730 | | Surface Take | 34.7 |
| 96588 | Expired | WM0730 | | Surface Take | 55.6 |

| Consent | Status | Water meter | Allocation type | Category | Consented rate |
|---|---|---|---|---|---|
| 97629 | Expired | WM0730 | | Surface Take | 222.22 |
| 97803.V1 | Expired | WM0487 | Primary | Surface Take | 111.1 |
| WR412CR | Expired | WM0730 | Primary | Surface Take | 194.44 |
| WR7284CR.V1 | Expired | WM0671 | Primary | Surface Take | 55.55 |
| WR7285CR.V1 | Expired | WM0671 | Primary | Surface Take | 83.33 |
| WR7286CR.V1 | Expired | WM0671 | Primary | Surface Take | 55.55 |
| WR7298CR.V1 | Expired | WM0671 | Primary | Surface Take | 55.6 |
| 95603 | Surrendered | | | Surface Take | |
| WR625CR | Surrendered | | | Surface Take | |