Management Flows for Aquatic Ecosystems in the Shag River/Waihemo

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Otago Regional Council

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

Report writer: Dean Olsen, Freshwater Scientist, Otago Regional Council
Internal reviewer: Dave Stewart, Consultant Hydrologist, Raineffects Ltd

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Executive summary

The Shag River/Waihemo[1] is a medium-sized river, which rises in the Horse Range/Pakihiwitahi[2] and Kakanui Range/Pokohiwitahi[2] in North Otago, entering the Pacific Ocean near Shag Point/Matakaea[2]. Landcover in the upper Shag /Waihemo catchment is dominated by tall tussock grassland and low-producing grassland. Much of the lower part of the catchment and the flat land in the valley floor consists of high-producing grasslands, although some cropping areas exist.

Schedule 2A of the RPW specifies minimum flows for primary allocation at Craig Road (150 l/s) and Goodwood Pump (28 l/s). The primary allocation limit set for the Shag/Waihemo catchment in Schedule 2A is 280 l/s. The primary allocation at the time of writing is 264.1 l/s.

This report presents information to assist water management decision-making in the Shag/Waihemo catchment, including hydrological data, information on aquatic values, application of instream habitat modelling to guide flow-setting processes, and consideration of the current state of the Shag River/Waihemo compared to the proposed objectives for the North Otago FMU set out in the proposed Otago Land and Water Regional Plan.

In the lower Shag/Waihemo, the river interacts with the underlying aquifer with losing and gaining reaches identified by Mourot *et al.* (2022). Losing reaches between Munro Road and Switchback Road and between Blacks Road and Horse Range Road can dry during particularly low flows (as observed in 2015).

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

		Flow statistics (l/s)		
		Mean	**Median**	**7d MALF (Jul-Jun)**
Craig Road	Naturalised flows	2,388	825	223
	Observed flows	2,367	814	176
Goodwood Pump	Naturalised flows	2,650	-	235

There are 14 resource consents for primary water takes from the Shag River/Waihemo, with a total primary allocation of 264.1 l/s. Oceana Gold (New Zealand) Ltd. has six resource consents for water takes (including non-consumptive takes) as part of their operations at the Macraes gold mine. There are three resource consents in the first supplementary allocation block (combined maximum take 102.5 l/s). Other supplementary takes in the Shag/Waihemo catchment include a take of up to 200 l/s from Deepdell North Stage III Pit for dewatering and dust suppression and a small take from an unnamed

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

ephemeral tributary of the Shag River for lime kiln exhaust gas scrubbing and hydrated lime manufacture.

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

The macroinvertebrate community at the Goodwood Pump site was dominated by the cased caddis fly *Pycnocentrodes*, common mayfly *Deleatidium*, and mudsnail *Potamopyrgus*. However, the net-spinning caddis *Hydropsyche* and riffle beetle larvae are among the most abundant taxa at times. MCI scores for Goodwood Pump are in D-band, SQMCI scores are in C-band, and ASPM scores are in B-band. The Goodwood Pump site is in the lower reaches of the catchment, just upstream of tidal influence, and is likely to be affected by high periphyton biomasses, which may account for the low scores observed at these sites.

In comparison, macroinvertebrate samples collected from the Craig Road site (2007-2022) were typically dominated by the common mayfly *Deleatidium*, mudsnail *Potamopyrgus* and/or the net-spinning caddis fly *Hydropsyche*. MCI and SQMCI scores for Craig Road would put this site in C-band of the NOF, while ASPM scores put this site in B-band of the NOF.

The Shag River supports a highly diverse community of indigenous fish with thirteen indigenous fish species recorded, including several species that are at risk or threatened – longfin eel (at risk – declining), torrentfish (at risk – declining), bluegill bully (at risk – declining), kōaro (at risk – declining), inanga (at risk – declining), while lamprey and Taieri flathead galaxias are classified as threatened – nationally vulnerable). Brown trout are the only introduced fish species that have been collected from the Shag/Waihemo catchment. The Shag River/Waihemo supports a locally important sport fishery with low angler usage.

An instream habitat model developed for the mainstem of the Shag River/Waihemo below Craig Road has been applied to consider the effects of different flows on the physical characteristics of the Shag River/Waihemo and habitat for periphyton, macroinvertebrates and fish.

The current minimum flow in the Shag River/Waihemo catchment (150 l/s) is predicted to maintain between 51% (food-producing habitat) and 92% (the common mayfly *Deleatidium*) of habitat for macroinvertebrates at the naturalised 7-d MALF. It is predicted to maintain 44% of bluegill bully habitat compared to the naturalised 7-d MALF. The current minimum flow is expected to achieve >86% habitat retention for other indigenous species considered and between 80-89% habitat retention for the various brown trout life-stages considered.

Flows of 110-123 l/s are expected to retain 80% of the habitat for tuna/longfin eel available at the naturalised MALF. Bluegill bully are among the most flow-demanding indigenous fish species in the Shag River/Waihemo catchment, and a flow of 197 l/s is predicted to provide 80% habitat retention in the Shag River/Waihemo. Flows of 11 l/s and 83 l/s are predicted to provide 80% habitat retention for juvenile and adult flathead galaxias. Habitat for kanakana/lamprey was predicted to be highest at low flows.

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

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Glossary

Catchment	The area of land drained by a river or body of water.
Existing flows	The flows observed in a river under current water usage and with current water storage and transport.
Habitat suitability curves (HSC)	Representations of the suitability of different water depths, velocities and substrate types for a particular species or life-stage of a species. Values vary from 0 (not suitable) to ideal (1). HSC are used in instream habitat modelling to predict the amount of suitable habitat for a species/life-stage.
Instream habitat modelling	An instream habitat model used to assess the relationship between flow and available physical habitat for fish and invertebrates.
Irrigation	The artificial application of water to the soil, usually for assisting the growing of crops and pasture.
7-d Mean Annual Low Flow (7-d MALF)	The average of the lowest seven-day low flow for each year of record.
Mean flow	The average flow of a watercourse (i.e. the total volume of water measured divided by the number of sampling intervals).
Minimum flow	The flow below which the holder of any resource consent to take water must cease taking water from that river.
Natural flows	The flows that occur in a river in the absence of any water takes or any other flow modification.
Naturalised flows	Synthetic (calculated) flows created to simulate the natural flows of a river by removing the effect of water takes or other flow modifications.
Reach	A specific section of a stream or river.
River	A continually or intermittently flowing body of fresh water that includes a stream and modified watercourse but does not include any artificial watercourse (such as an irrigation canal, water-supply race, or canal for the supply of water for electricity power generation and farm drainage canal).
Seven-day low flow	The lowest seven-day low flow in any year is determined by calculating the average flow over seven consecutive days for every seven consecutive day period in the year and then choosing the lowest.

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

1. Introduction

The Shag River/Waihemo[2] is a medium-sized river, which rises in high-altitude tussock grasslands and extensively grazed grasslands in the Horse Range/Pakihiwitahi[2] and Kakanui Range/Pokohiwitahi[2] in North Otago flowing in an easterly direction to enter the Pacific Ocean near Shag Point/Matakaea[2]. Much of the remainder of the catchment is dominated by high-producing grasslands with areas of exotic forestry and cropping.

A significant māori settlement dating back to the 14th century once existed at the mouth of the Shag River/Waihemo. The mouth of the Shag River/Waihemo provided shelter for waka, access to marine and freshwater fisheries, a fur seal rookery nearby and vegetation attractive to moa, the south's most attractive protein source[2]. The Shag River/Waihemo is recognised as a kāinga mahinga kai (food-gathering place) where tuna (eel), inaka (whitebait), pātiki (flounder), raupō, aruhe (bracken fernroot), and pipi were gathered.

The Shag/Waihemo catchment is within the North Otago Freshwater Management Unit (FMU). The current minimum flow for the Shag River/Waihemo was included in the RPW, which was notified on 28 February 1998 and became operative on 1 January 2004. Schedule 2A of the RPW specifies minimum flows of 150 l/s for primary permits at the Craig Road flow site and 28 l/s for primary permits at Goodwood Pump. The primary allocation limit set for the Shag/Waihemo catchment in Schedule 2A is 280 l/s.

1.1. Purpose of the report

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

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

2. Background information

1.2. Catchment description

The Shag River/Waihemo rises in the Kakanui Mountains, before flowing almost 90 km in a south-easterly direction to the coast, entering the Pacific Ocean just south of Shag Point/Matakaea (Figure 1). It drains a total catchment area of 545 km^2. The largest single tributary of the Shag River/Waihemo is Deepdell Creek, which drains from Taieri Ridge near Macraes Flat (Figure 1).

Oceana Gold Ltd. operates a hard-rock goldmine at Macraes Flat, including several open pits and underground mining. The Macraes open pit mine has operated since 1990, and the Frasers underground mine was commissioned in 2008. Overall, the Macraes gold mining operation has produced over 3 million ounces of gold to date. The existing mine operation holds a resource consent to take and discharge water and potential contaminants from tailings storage facilities to the Deepdell Creek catchment, Tipperary Creek, a tributary of McCormicks Creek and Murphys Creek, a tributary of the Waikouaiti River North Branch.

1.2.1. Climate

The climate of most of the Shag River/Waihemo catchment is classified as 'cool-dry' (mean annual temperature <12°C, mean effective precipitation ≤500 mm), with limited areas classified as 'cool-wet' (mean annual temperature <12°C, mean effective precipitation 500-1,500 mm) (River Environment Classification, Ministry for the Environment & NIWA, 2004). The upper reaches in the Kakanui Mountains receive the greatest amount of rainfall (>1,000 mm), and the rainfall generally declines in a downstream direction, with the driest areas receiving less than 600 mm annually (Figure 2).

1.2.2. Geology & geomorphology

Much of the course of the Shag River/Waihemo parallels the Waihemo fault system (Forsyth, 2001). The geology of the majority of the Shag/Waihemo catchment consists of schistose to non-schistose quartzofeldspathic sandstone, with areas of igneous rock (Dunedin volcanics group) to the south of the Waihemo fault system (Figure 3; Forsyth, 2001). The lower catchment consists of alluvial deposits, marine and non-marine quartzose sandstone and siltstones (Figure 3; Forsyth, 2001). The upper reaches of Deepdell Creek and McCormicks Creek include the Hyde-Macraes Shear Zone, a metamorphosed rock with significant mineralisation of gold that the Macraes gold mine is based on.

For much of its course, the Shag /Waihemo flows through confined, meandering channels with a bed of mixed gravel, boulder, and bedrock. Previous geomorphological assessments in the Shag /Waihemo catchment have identified bed and bank degradation and limited replenishment of gravels (ORC, undated), leading to a halt to gravel extraction consents in the catchment. The most recent assessment has noted aggradation in most monitored cross-sections, indicating that the river may have changed from a state of overall degradation to aggradation/stability (Williams 2014).

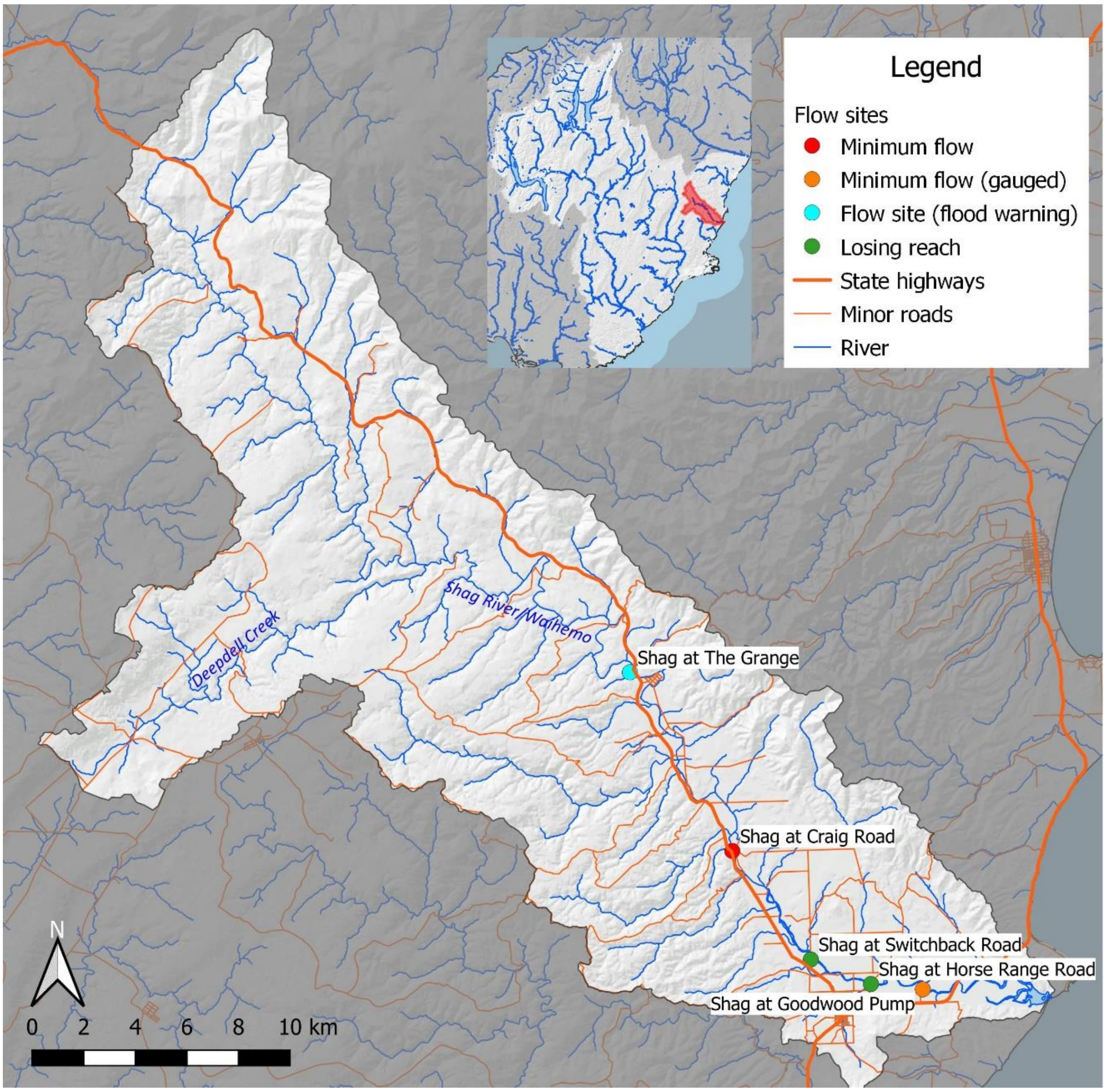

Figure 1 Map of the Shag/Waihemo catchment and flow recorder sites.

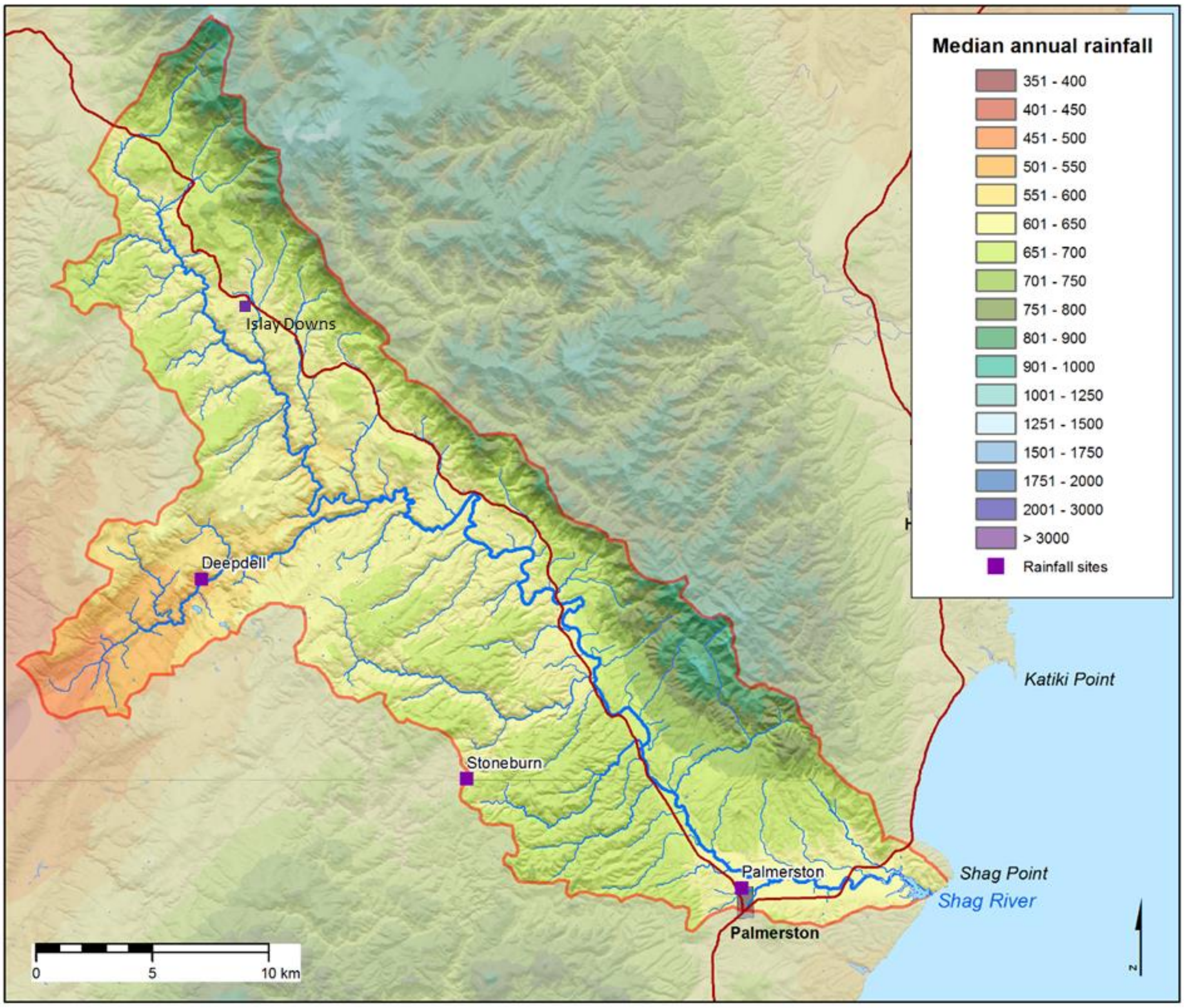

Figure 2 Distribution of rainfall (annual median rainfall) in the Shag/Waihemo catchment.

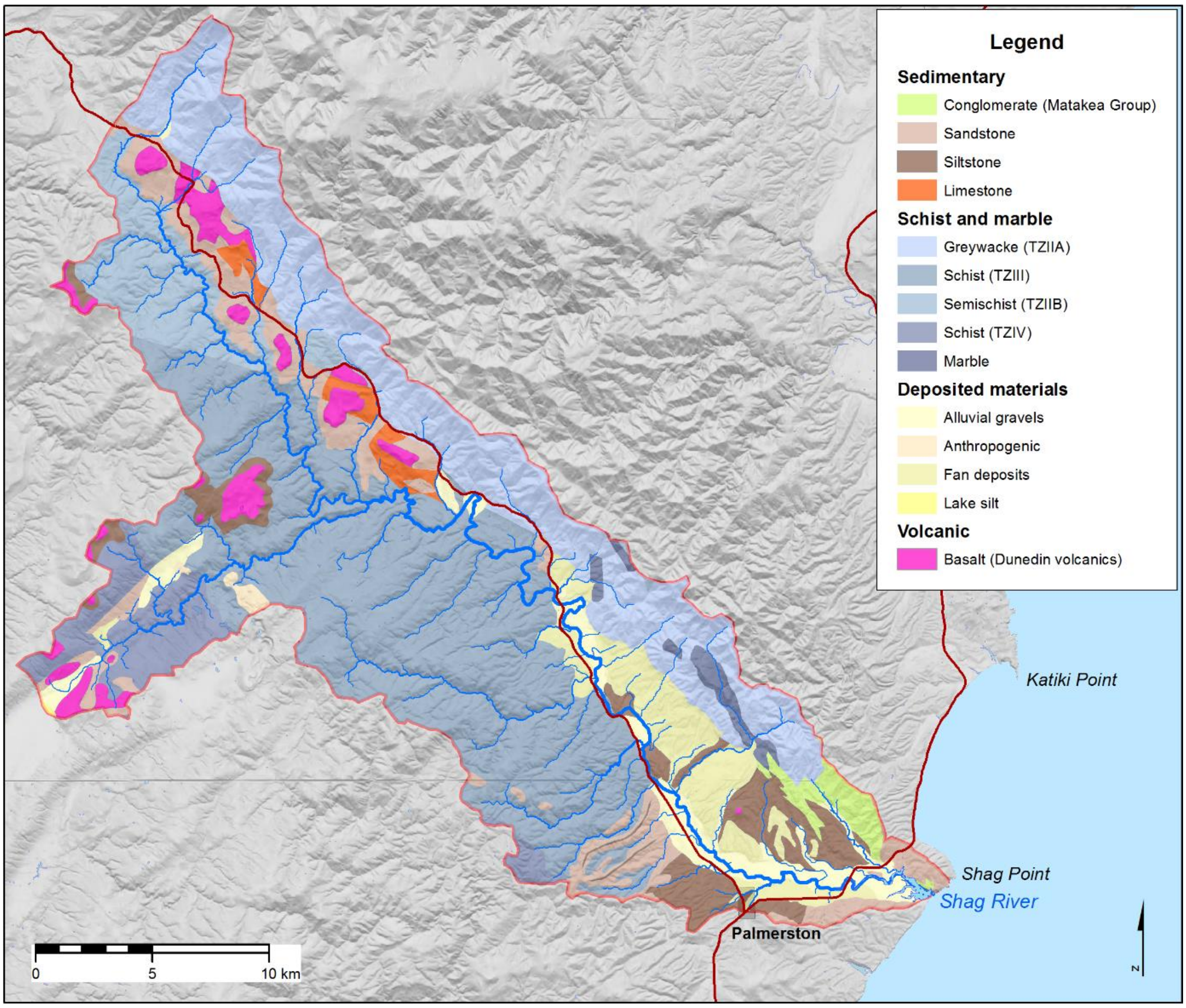

Figure 3 Geology of the Shag/Waihemo catchment

1.2.3. Vegetation and land use

The majority of the Shag/Waihemo catchment consists of agricultural grasslands (38% low-producing grassland, 32% high-producing exotic grassland; Figure 4). The upper Shag /Waihemo catchment is dominated by tall tussock grassland and low-producing grassland (Figure 4). Much of the lower part of the Shag/Waihemo catchment and the flat land in the valley floor consists of high-producing grasslands. However, there are areas of cropping in the lower catchment, with the largest of these downstream of Palmerston (Figure 4). Exotic forestry is the next most extensive land use, representing 11% of the catchment. The largest forestry blocks are in the upper catchment adjacent to the Collins Bridge and on the hill country north of the Shag River/Waihemo estuary (Figure 4). Two vegetation categories were common in riparian areas (areas adjacent to the river channel); gorse and broom and matagouri and grey shrub (Figure 4).

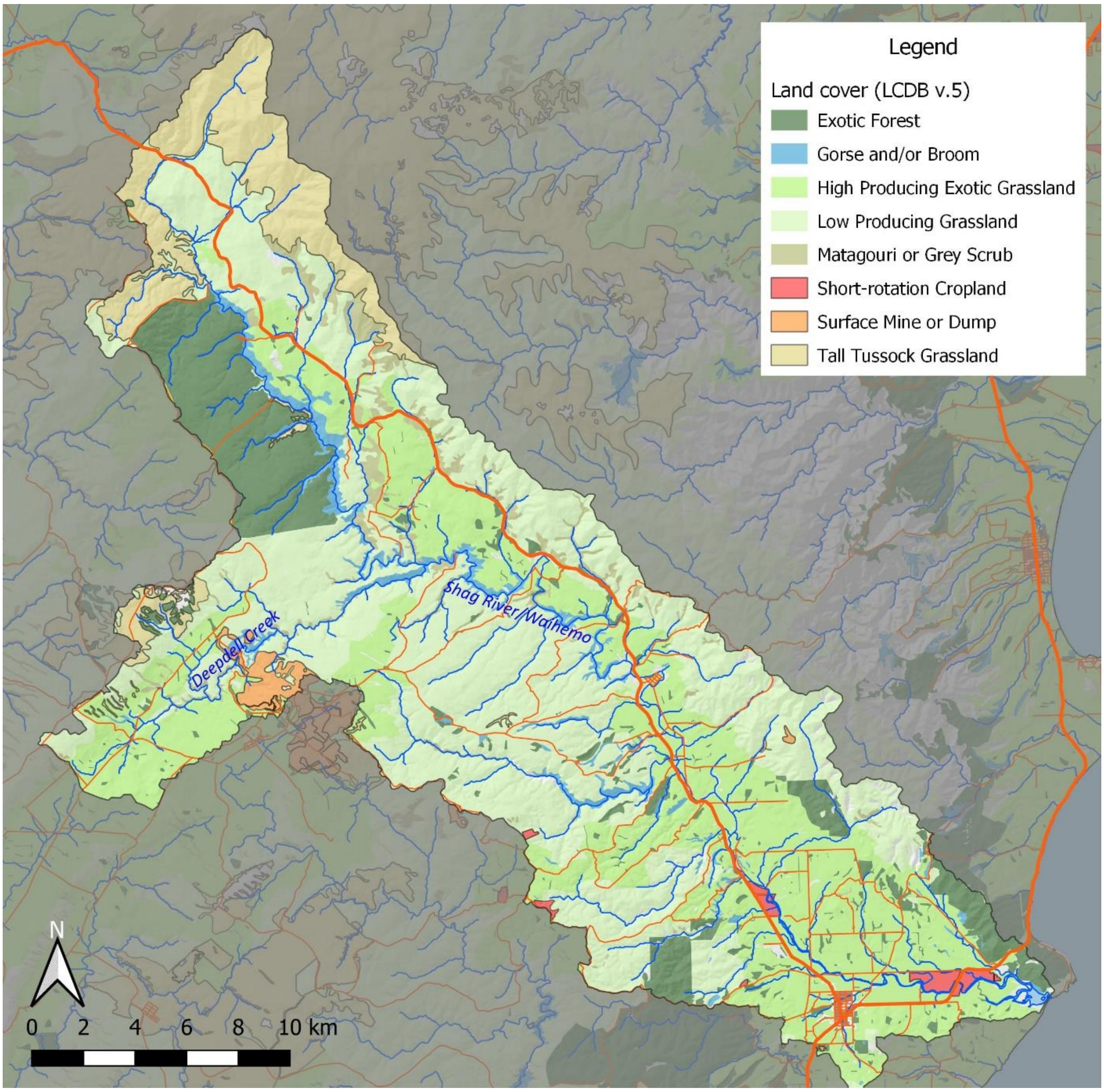

Figure 4 Land cover in the Shag/Waihemo catchment.

1.2.4. Estuary

Shag Estuary is a moderate-sized (120 ha), shallow, intertidal dominated (SIDE) estuary comprising a mix of several confined upper estuary river channels, a large central basin, two small side arm basins, and a 600m long sand spit on the southern coastal margin that creates a narrow entrance to the estuary (Robertson *et al.* 2017).

The Shag River/Waihemo estuary is an important habitat for wildlife, with the estuary mudflats being used for feeding and roosting various bird species and as a stop-over area for migratory species (ORC, 1991).

2. Regulatory setting

1.3. Regional Plan: Water (RPW)

Schedule 2A of the RPW specifies minimum flows for primary allocation at Craig Road (150 l/s) and Goodwood Pump (28 l/s). The primary allocation limit set for the Shag/Waihemo catchment in Schedule 2A is 280 l/s. The primary allocation at the time of writing is 264.1 l/s (see Section 0).

In addition, Schedule 2B of the RPW specifies minimum flows for the first supplementary allocation block of 650 l/s at Craig Road and 401 l/s at Goodwood Pump, with a supplementary allocation block size of 100 l/s. At the time of writing, the first supplementary allocation block is fully allocated (see Section 0). The minimum flow for the second supplementary block is 750 l/s at Craig Road and 501 l/s at Goodwood Pump, with a supplementary allocation block size of 100 l/s.

1.4. Proposed Land and Water Plan

The ORC has undertaken a full review of the RPW, and the results of this review will be incorporated into a new Land and Water Regional Plan (LWRP). As part of the consultation for the LWRP, objectives have been developed for the North Otago Freshwater Management Unit (FMU), which includes the Shag/Waihemo catchment. The proposed objectives, valid at the time of writing, are presented in Table 1.

Table 1 Possible environmental outcomes for the values identified in the North Otago FMU and their attributes and target attributes.

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

Table 1 Possible environmental outcomes for the values identified in the North Otago FMU and their attributes and target attributes.

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

Table 1 Possible environmental outcomes for the values identified in the North Otago FMU and their attributes and target attributes.

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

3. Hydrology

1.5. Surface water-groundwater interactions

The māori name Waihemo (*wai* = water, *hemo* = to disappear) is likely to reference the loss of surface flows in its lower reaches during low flows. Stewart (2003) considered the pattern of flows in the lower Shag River/Waihemo. He found that:

- At flows between about 250 and 500 l/s in the Shag River at the Grange, Dunback or Craig Road sites, the flow measured at the Goodwood Pump site is close to that measured at these previous three sites when irrigation water is not being abstracted.

- At flows less than 250 l/s at the Grange, Dunback or Craig Road sites, natural flows at the Goodwood Pump site are always lower than those at these previous three sites.

- At low flows when no irrigation is occurring, there is a reduction in flows from Craig Road to Switchback Road, an increase to Palmerston Water Supply, a decrease to Horse Range Road and an increase to the Goodwood Pump site.

Based on concurrent gaugings between 1978 and 1988 (from Stewart 2003), flow losses between Craig Road[3] and Switchback Road ranged from 67-92 l/s (average: 79 l/s). These losses represented 15-28% (average: 22%) of the flow at Craig Road at the time.

Based on concurrent gaugings between May 1988 and June 1988 (from Stewart 2003), flow losses between the Palmerston Water Supply and Horse Range Road ranged from 43-114 l/s (average: 80 l/s). These losses represented 10-39% (average: 24%) of the flow at Craig Road at the time.

The surface water-groundwater interactions in the lower reaches of the Shag River/Waihemo were investigated by Mourot *et al.* (2022). The results of their investigations accord with the findings of Stewart (2003). They identified two losing reaches (Reach 2 – Munro Road to Switchback Road and Reach 4 – Blacks Road to just downstream of Horse Range Road) and four gaining reaches (Reach 1 – upstream of Munro Road, Reach 3 – Switchback Road to Blacks Road, Reach 4 – downstream of Horse Range Road to Goodwood Pump and Reach 5 – Goodwood Pump to the State Highway 1 bridge).

These results are consistent with observations during extremely low flows (50-128 l/s at the Craig Road flow monitoring site) in January 2015, with surface water disconnection observed within the two losing reaches (Figure 5, Figure 6).

[3] Where flows were available for the Grange, but not Craig Road, flows at the Grange were multiplied by 1.068 to account for inflows between these sites. Relationship between the Grange and Craig Road: $Q_{Craig\ Rd} = 1.068 * Q_{Grange}$, R^2=0.996, N=9.

Figure 5 Shag River/Waihemo upstream of the Switchback Road ford on 13 January 2015 showing sections beginning to disconnect. This photograph is at the lower end of Reach 2 of Mourot *et al*. (2022). The mean daily flow when this photograph was taken was 96 l/s at Craig Road.

Figure 6 Shag River/Waihemo immediately upstream of Horse Range Road on 13 January 2015 showing the surface water channel beginning to disconnect. This photograph is at the lower end of Reach 4 of Mourot *et al*. (2022). The mean daily flow when this photograph was taken was 96 l/s at Craig Road.

1.6. Flow statistics

A continuous flow recorder has been installed in the Shag River/Waihemo at Craig Road since September 1993. This site is located approximately 18.5 km upstream of where it enters the Pacific Ocean. A long-term hydrological monitoring site at The Grange (11 October 1989 to present) has primarily been used as a flood warning site.

Other hydrological sites have been established in the Shag River/Waihemo, including at Dunback Domain (25 March 1976 – 29 March 1990), Switchback Road (6 December 1985 – 18 October 1989; 12 September 2017 – 11 July 2018) and Collins Bridge (12 December 1985 – 9 October 1989; 12 October 2011 – 23 December 2013).

Lu (2023) used available flow data for the Shag River at Craig Road and water use data to produce a naturalised flow time-series from 1 July 2011 – 24 May 2023. The flow statistics based on the analysis of Lu (2023) are summarised in Table 2.

Table 2 Flow statistics for hydrological monitoring sites in the Shag River/Waihemo at Craig Road and Goodwood Pump from Lu (2023).

		Flow statistics (l/s)			Low flow recurrence interval analysis (l/s)	
		Mean	Median	7d MALF (Jul-Jun)	5-year (Q7,5)	10-year (Q7,5)
Craig Road	Naturalised flows	2,388	825	223	133	124
	Observed flows	2,367	814	176	-	-

1.6.1. Flow variability

The average number of events per year exceeding three times the median flow (FRE3) in the Shag River/Waihemo at Craig Road is 5.8 (Lu 2023).

1.6.2. Water allocation & use

Primary allocation

There are 14 resource consents for primary water takes from the Shag River/Waihemo catchment, with a total primary allocation of 264.1 l/s (Table 3).

Oceana Gold (New Zealand) Ltd. has six resource consents for water takes from the Shag River/Waihemo catchment as part of their operations at the Macraes gold mine, including for mining and mineral processing operations, post-mining rehabilitation, dewatering of tailings storage facilities, to create a pit lake (Deepdell North Pit Lake) and dust suppression as well as for the operation of a trout hatchery as part of their mitigation activities. These permits are considered to be non-consumptive.

Supplementary allocation

There are three resource consents for supplementary water takes in the first supplementary allocation block from the Shag River/Waihemo. All three of these consents are for irrigation. The combined maximum take authorised by these consents is 102.5 l/s.

Water permit RM20.024.01 allows Oceana Gold (New Zealand) Ltd. to take up to 200 l/s from Deepdell North stage III Pit for dewatering and dust suppression.

Graymont (NZ) Ltd. holds water permit RM15.021.01 to take and use surface water as supplementary allocation from an unnamed tributary of the Shag River for lime kiln exhaust gas scrubbing and hydrated lime manufacture. This take is considered supplementary allocation outside of primary allocation, given the small amount taken and the ephemeral nature of the tributary.

Table 3 Active resource consents for primary takes in the Shag/Waihemo catchment. Cells shaded green indicate takes from the Shag River, orange cells indicate takes from the Deepdell Creek.

Consent #	Max. instant. Take (l/s)	Waterway	Purpose
2003.105.V1	19	Shag River	Irrigation
2003.200.V1	28	Shag River	Irrigation
2003.213.V1	20	Shag River	Irrigation
2003.339.V1	21	Shag River	Irrigation
2003.377.V1	12	Shag River	Irrigation
2003.385.V1	14	Shag River	Irrigation
2003.515.V1	18	Shag River	Irrigation
2003.516.V1	8	Shag River	Irrigation
2003.545.V1	23	Shag River	Irrigation
2003.542.V1	12	Shag River	Irrigation
2009.240.V3	10.5	Shag River	Irrigation
2009.081.V1	40	Shag River	Irrigation
RM11.025.01	31.6	Shag Alluvium Aquifer	Community supply
RM16.162.01	7	Shag River	Irrigation
RM20.024.08*	0	Shag River	Mining/Quarry
2004.071*	0	Maori Tommy Gully	Mining/Quarry, Construction/Repairs Site, Silt Control
2004.080*	0	Tributary of Maori Tommy Gully	Mining/Quarry
2004.083*	0	Unnamed tributary to Deepdell Creek	Construction/Repairs Site, Mining/Quarry
RM10.351.V2*	0	Deepdell Creek	Mining/Quarry
RM20.024.13	0	Deepdell Creek	Mining/Quarry

* Non-consumptive

Table 4 Active resource consents for supplementary takes in the Shag/Waihemo catchment. Cells shaded green indicate takes from the Shag River, orange cells indicate takes from the Deepdell Creek.

Consent #	Max. instant. Take (l/s)	Monthly volume (m^3/m)	Annual volume (m^3/y)	Waterway	Purpose
First supplementary (650 l/s minimum flow)					
2008.169.V3	22.5	20,778	134,850	Shag	Irrigation
2008.487.V1	80		930,000	Shag	Irrigation
2009.188.V1				Unnamed tributary	Irrigation
Other supplementary					
RM15.021.01	2.2	2,700		Unnamed tributary	Commercial/Industrial
RM20.024.01	200			Tributary Of Deepdell Ck	Mining/Quarry

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

Water temperatures in the upper Shag River/Waihemo at Collins Bridge were within acute and chronic thermal criteria for brown trout and all indigenous species present (Table 5; Figure 7, Figure 8). Similarly, water temperatures in the lower Shag River/Waihemo at Craig Road were within acute and chronic thermal criteria for brown trout and most indigenous species present, the exception being the common mayfly *Deleatidium*, which was rarely exceeded (Table 5; Figure 9, Figure 10, Figure 11). However, the chronic criteria for brown trout (19.6°C as a 7-day mean) was exceeded in seven of the 22 years of record (Table 5), with the greatest exceedance in the 2022/2023 season (Figure 9, Figure 10, Figure 11). These data suggest that the thermal environment of the Shag/Waihemo at Craig Road is generally suitable for all the indigenous species present but can be unsuitable for brown trout at times. These results probably apply to neutral or losing reaches in the lower Shag/Waihemo, but groundwater inputs in gaining reaches may increase the thermal suitability of these sections.

Table 5 Number of exceedances of thermal criteria in the Shag River/Waihemo at Collins Bridge and Craig Road.

Site	Thermal criteria	Mean	Max	Years with no exceedances	Total number of years
Shag River at Collins Bridge	Brown trout acute (>24.6°C)	0	0	5	5
	Deleatidium acute (21°C)	0	0	5	5
	Longfin eel, *Pycnocentria* acute (23°C)	0	0	5	5
	Aoteapsyche acute (24°C)	0	0	5	5
	Brown trout chronic (>19.6°C)	0	0	5	5
Shag River at Craig Road	Brown trout acute (>24.6°C)	0	0	22	22
	Deleatidium acute (21°C)	0.1	2	21	22
	Common bully, *Paracalliope* acute (22°C)	0	0	0	0
	Longfin eel, *Pycnocentria* acute (23°C)	0	0	0	0
	Aoteapsyche acute (24°C)	0	0	0	0
	Shortfin eel acute (26°C)	0	0	0	0
	Brown trout chronic (>19.6°C)	3	24	15	22

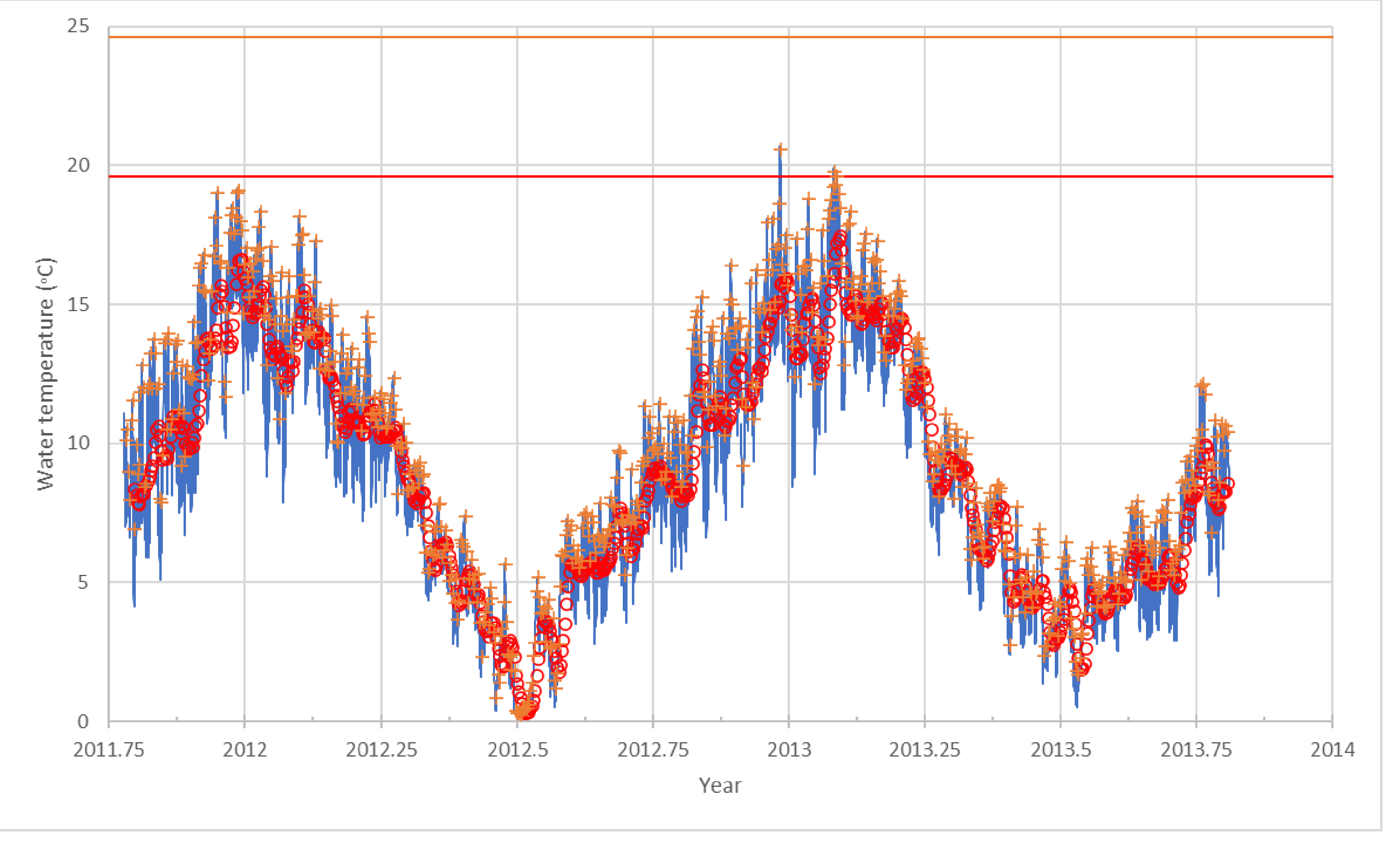

Figure 7 Water temperature in the Shag River/Waihemo at Collins Bridge between October 2011 and October 2013. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red circles are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.

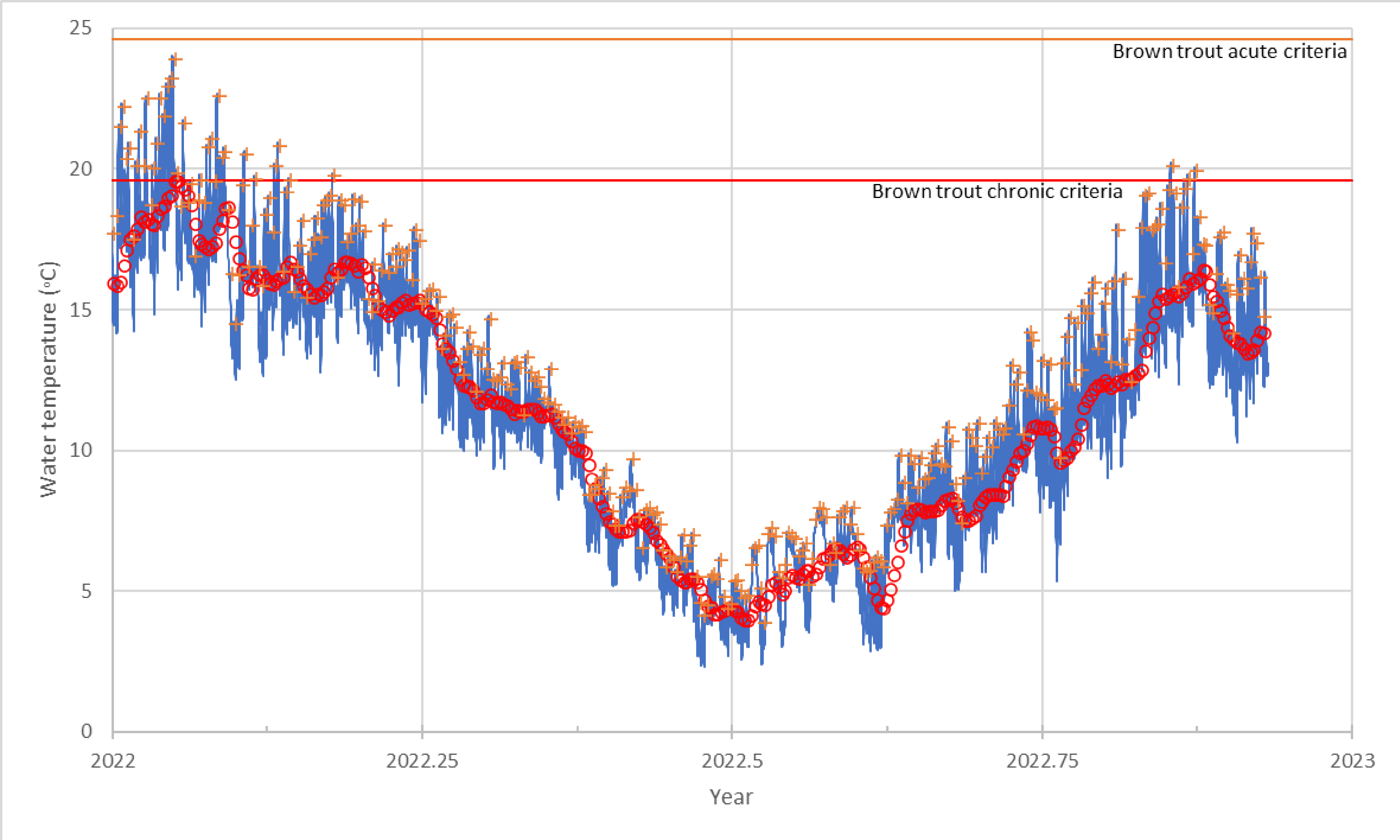

Figure 8 Water temperature in the Shag River/Waihemo at Collins Bridge between January 2022 and December 2022. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red circles are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.

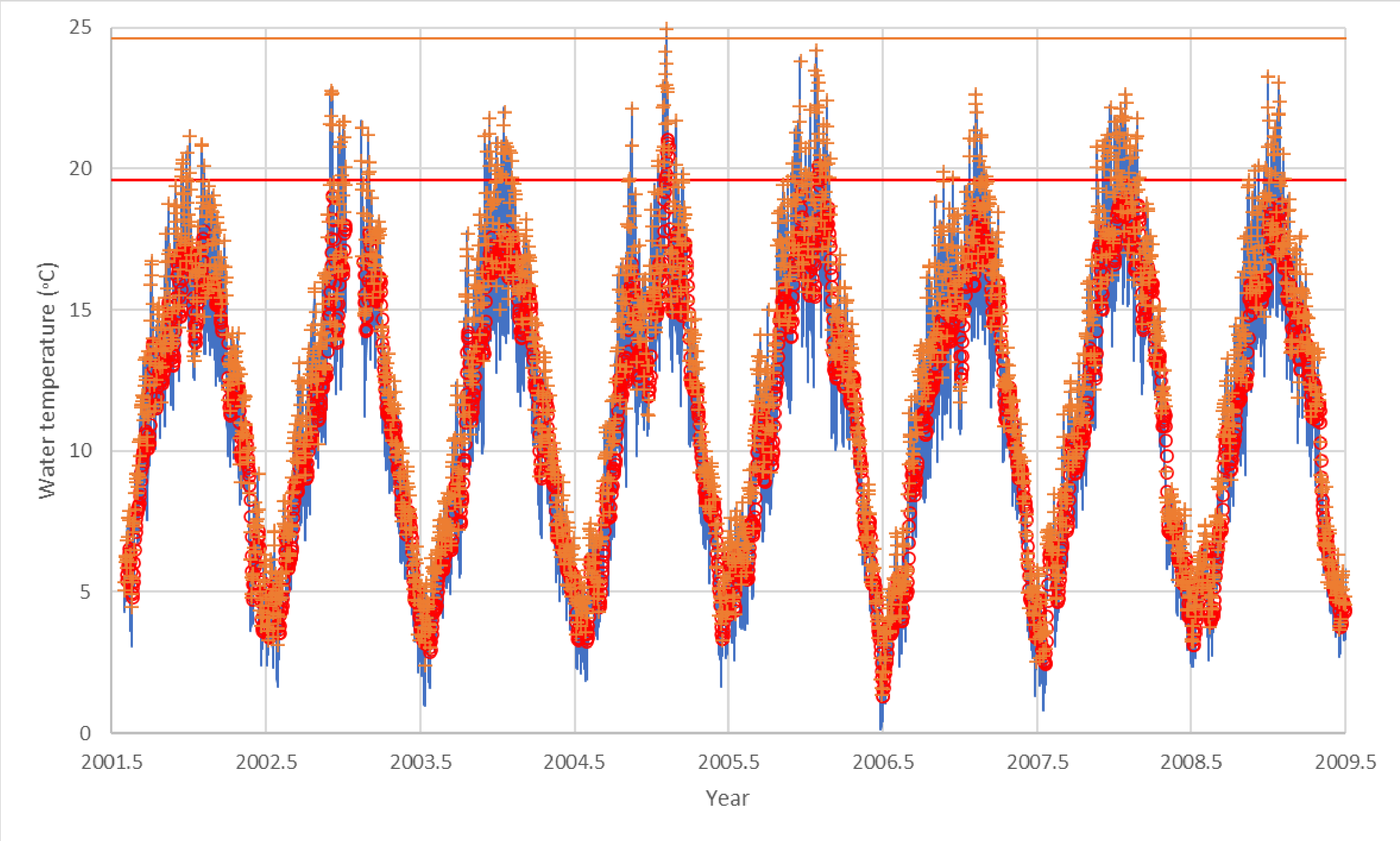

Figure 9 Water temperature in the Shag River/Waihemo at Craig Road between July 2001 and June 2009. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red circles are the seven-day average of mean daily temperatures for comparison with chronic thermal

criteria.

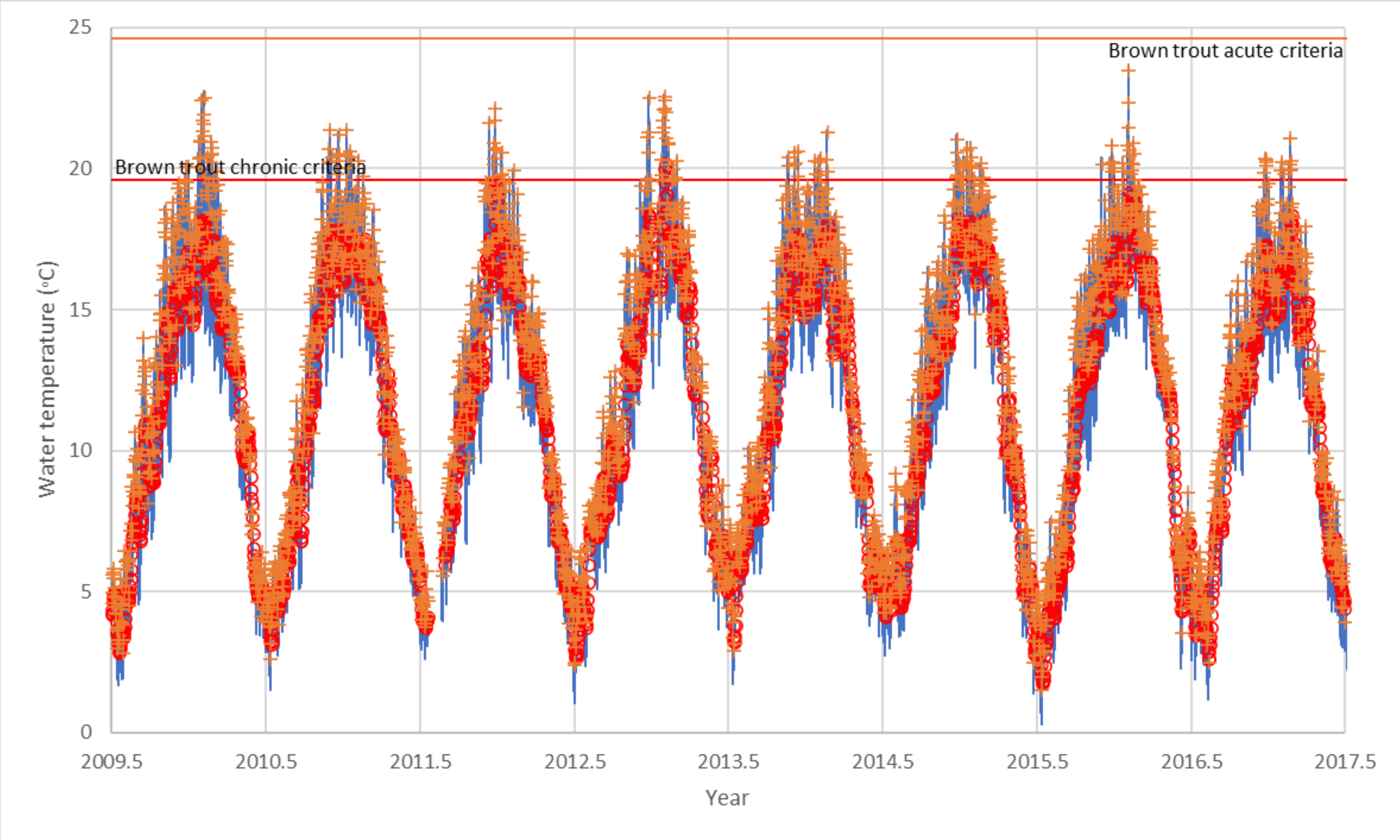

Figure 10 Water temperature in the Shag River/Waihemo at Craig Road between July 2009 and June 2017. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red circles are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.

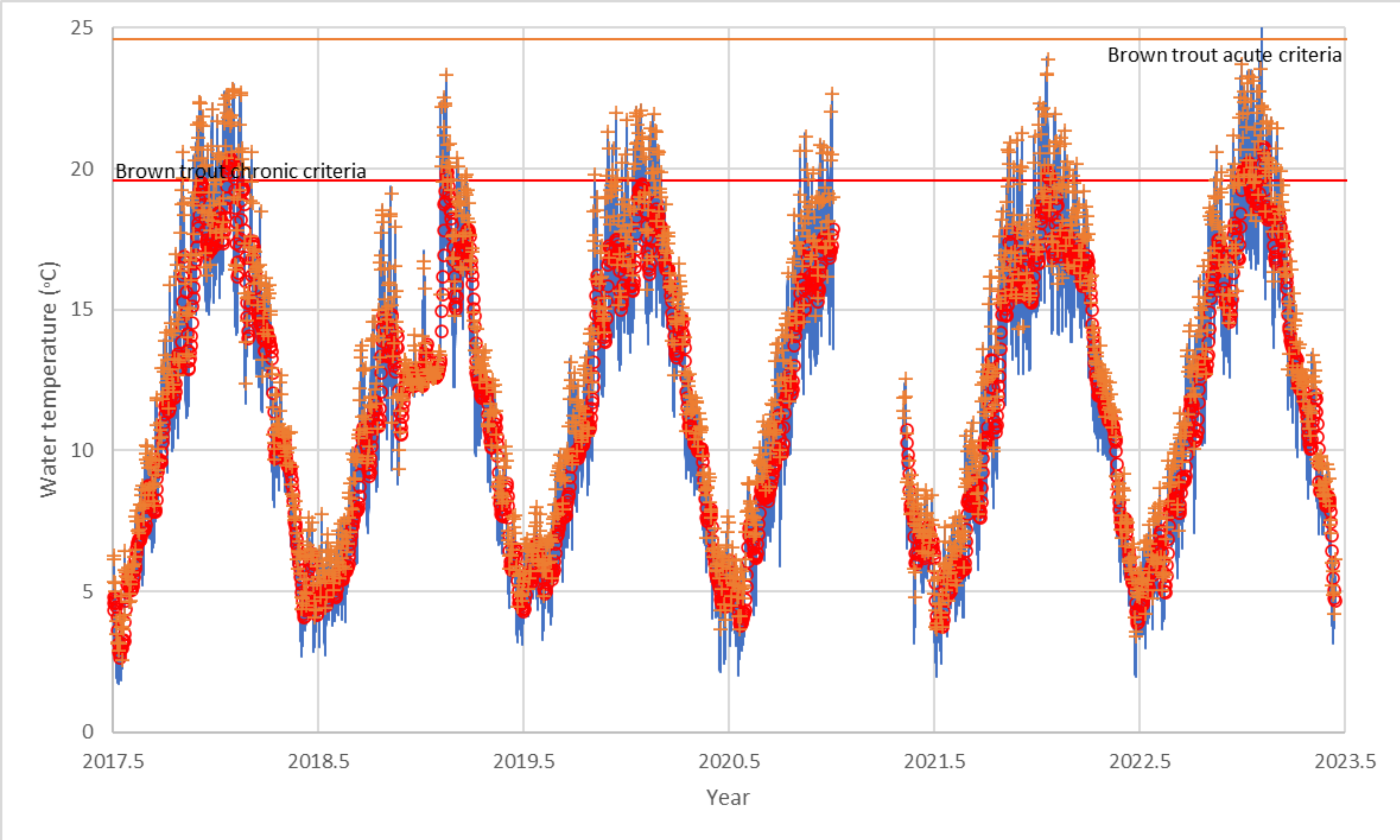

Figure 11 Water temperature in the Shag River/Waihemo at Craig Road between July 2017 and June 2023. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red circles are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.

5. The aquatic ecosystem of the Shag/Waihemo catchment

1.7. Periphyton

The periphyton community forms the slimy coating on the surface of stones and other freshwater substrates 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 and fish.

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

The presence of potentially toxic cyanobacteria is undesirable as it can affect the suitability of a waterway for drinking, recreation (swimming), dogs, stock drinking water and food-gathering (by affecting palatability or through accumulation of toxins in organs such as the liver). Cyanobacteria-produced neurotoxins have been implicated in the deaths of numerous dogs in New Zealand (Hamill, 2001; Wood et al., 2007).

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

Filamentous algae, and particularly long filamentous algae, can form nuisance blooms during stable flows and under enriched nutrient conditions. Such blooms can affect instream values, including aesthetics, biodiversity, recreation (swimming and angling), water-takes (irrigation, stock/drinking water and industrial) and water quality.

Chlorophyll *a* concentrations at Goodwood Pump exceeded 200 mg/m^2 on eight occasions (21%) of sampling occasions over the July 2019 –February 2023 period, placing this site in Band D of the NOF, which exceeds the national bottom line for periphyton (trophic state).

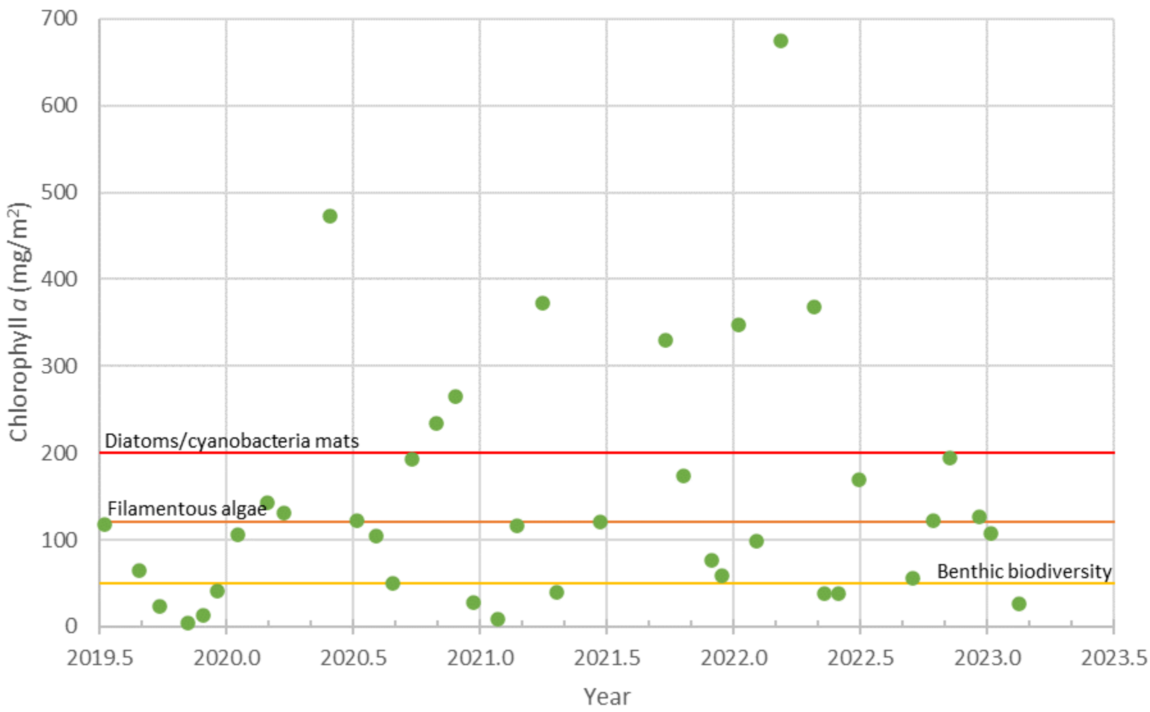

Figure 12 Chlorophyll *a* concentrations in the Shag River/Waihemo at Goodwood Pump over the period July 2019- February 2023. The periphyton biomass attribute is applied such that no more than three values can exceed the numeric attribute state in any three-year period (8% exceedence, based on monthly sampling over a 3-year period).

1.8. Macroinvertebrates

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

In a survey in 2013, the common mayfly *Deleatidium* was the most abundant macroinvertebrate taxa collected at all sites in the Shag River/Waihemo, while the cased caddis flies *Pycnocentrodes, Hudsonema* and *Pycnocentria*, the net-spinning caddis fly *Hydropsyche*[4] and the mudsnail *Potamopyrgus* were also abundant at some sites (Olsen 2014).

In State of the Environment (SoE) sampling, the macroinvertebrate communities in the Shag River/Waihemo at Goodwood Pump were dominated by the cased caddis fly *Pycnocentrodes*, common mayfly *Deleatidium*, mudsnail *Potamopyrgus*. However, the net-spinning caddis *Hydropsyche* and riffle beetle larvae were also occasionally abundant at this site. In historical sampling between 2001 and 2010, the macroinvertebrate communities at The Grange were dominated by the common mayfly, the

[4] Formerly this taxon was known as the genus *Aoteapsyche*, however, taxonomic revision has demoted *Aoteapsyche* to sub-genus.

mudsnail *Potamopyrgus*, the stony-cased caddis *Pycnocentrodes* and riffle beetle larvae (Elmidae). Macroinvertebrate samples collected from the Craig Road site (2007-2022) were typically dominated by the common mayfly *Deleatidium*, mudsnail *Potamopyrgus* and/or the net-spinning caddis fly *Hydropsyche*. Seed shrimp (Ostracoda), oligochaete worms, the stony-cased caddis *Pycnocentrodes,* the sand-cased caddis *Pycnocentria* and riffle beetle larvae were among the most abundant taxa at this site on occasion.

MCI scores for Goodwood Pump (Range: 80-103, median = 86, N=16) put this site in D-band of the NOF (Figure 13a). Historical MCI scores for Craig Road (range: 90-105, median = 95, N=13) would put this site in C-band of the NOF (Figure 13a). The two historical MCI scores for The Grange (range: 98-106, N=2) would put this site in C-band of the NOF (Figure 13a).

SQMCI scores for the Goodwood Pump site (Range: 4.07-5.95, median = 5.40, N=16) put this site in C-band of the NOF (Figure 13b; Table 6). Historical SQMCI scores for Craig Road (range: 3.65-6.71, median = 5.28, N=13) would put this site in C-band of the NOF (Figure 13b). The two historical ASPM scores for The Grange (range: 6.41-7.03, N=2) would put this site in A- or B band of the NOF (Figure 13b).

ASPM scores for the Goodwood Pump site (Range: 0.23-0.53, median = 0.41, N=16) put this site in the B-band of the NOF (Figure 13c; Table 6). Historical ASPM scores for Craig Road (range: 0.35-0.53, median = 0.45, N=13) would put this site in B-band of the NOF (Figure 13b). The two historical ASPM scores for The Grange (range: 0.51-0.60, N=2) would put this site in B-band of the NOF (Figure 13b).

Trends in macroinvertebrate metrics were detected for the Goodwood Pump monitoring site – MCI and ASPM were very likely decreasing, while SMCI probably increased (Table 6).

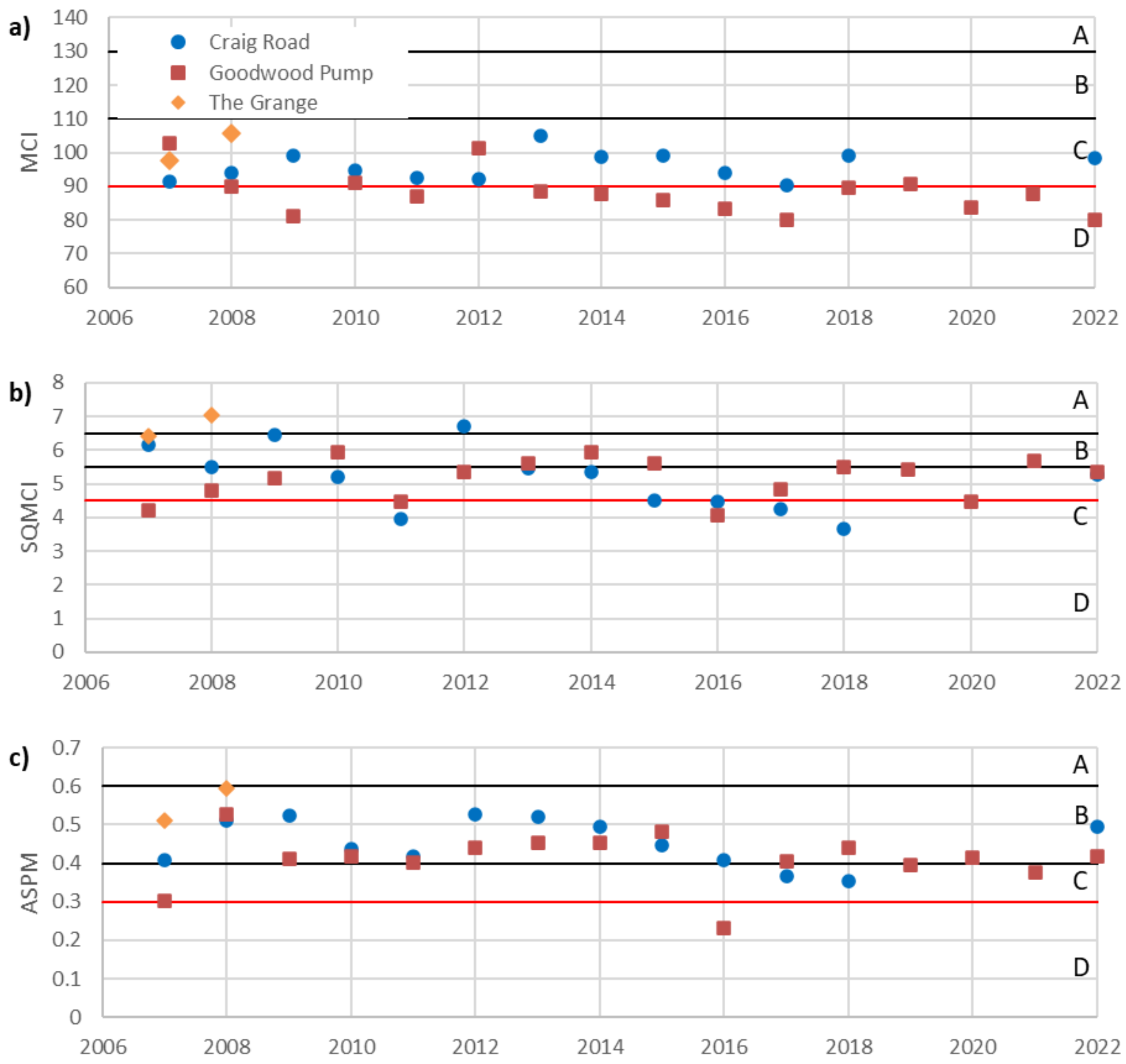

Figure 13 Macroinvertebrate indices for Shag River at Goodwood Pump (red squares), Craig Road (blue circles) and The Grange (orange diamonds) between 2007 and 2022. a) Macroinvertebrate community index (MCI), b) semi-quantitative MCI (SQMCI) and c) average score per metric (ASPM). Each plot includes thresholds for attribute states based on Tables 14 and 15 of the National Objectives Framework.

Table 6 Trends in macroinvertebrate metrics in Shag River at Goodwood Pump state of the environment monitoring site between 2014 and 2023. From Ozanne et al (2023). The Z-statistic indicates the direction of any trend detected.

Site	Metric	Z	P	Trend
Shag at Goodwood Pump	MCI	-1.48	0.14	Decreasing trend very likely
	SQMCI	1.26	0.21	Increasing trend likely
	ASPM	-1.58	0.11	Decreasing trend very likely

1.9. Fish

1.9.1. Indigenous fish

Thirteen species of indigenous freshwater fish have been recorded from the Shag/Waihemo catchment, (Table 8). This represents a high level of indigenous biodiversity, and the species present include several species that are at risk or threatened – longfin eel, torrentfish, bluegill bully, kōaro and inanga are classified as at risk – declining, while lamprey and Taieri flathead galaxias are classified as threatened – nationally vulnerable (Dunn et al. 2017).

Shortfin eels have been recorded from the mainstem of the Shag River/Waihemo as far upstream as the confluence of Deepdell Creek, while longfin eels have been recorded from throughout the catchment (Figure 14). Torrentfish have been recorded from Goodwood Pump, while lamprey have been recorded as far upstream as the Switchback Road (Figure 14). Common smelt and black flounder have been recorded from the lower catchment as far upstream as Horse Range Road (Figure 14).

Upland bully have been recorded from much of the mainstem, while bluegill and redfin bully have been recorded as far upstream as Craig Road (Figure 14).

Three species of galaxiid have been recorded from the Shag/Waihemo catchment. Inanga have been recorded in the mainstem of the Shag/Waihemo downstream of Craig Road, while Taieri flathead galaxias have been recorded from much of the upper catchment including Deepdell Creek and McCormicks Creek (Figure 15). Kōaro have been recorded from the middle reaches of the mainstem (Figure 15).

1.9.2. Introduced fish

Brown trout and brook char have both been collected from the Shag/Waihemo catchment, although brook char have only been recorded from Pigroot Creek (Figure 16).

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

Table 7 Angler effort on the Shag River/Waihemo based on the National Angler Survey (Unwin, 2016)

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

Table 8 Fish species recorded from the Shag River/Waihemo catchment.

Family	Common name	Species	Threat classification
Anguillidae	Shortfin eel	*Anguilla australis*	Not threatened
	Longfin eel	*Anguilla dieffenbachii*	Declining
Cheimarrichthyidae	Torrentfish	*Cheimarrichthys fosteri*	Declining
Eleotridae	Upland bully	*Gobiomorphus breviceps*	Not threatened
	Common bully	*Gobiomorphus cotidianus*	Not threatened
	Bluegill bully	*Gobiomorphus hubbs*	Declining
	Redfin bully	*Gobiomorphus huttoni*	Not threatened
Galaxidae	Kōaro	*Galaxias brevipinnis*	Declining
	Flathead galaxias	*Galaxias depressiceps*	Nationally vulnerable
	Inanga	*Galaxias maculatus*	Declining
Geotriidae	Lamprey	*Geotria australis*	Nationally vulnerable
Mugilidae	Yelloweye mullet†	*Aldrichetta forsteri*	Not threatened
Pleuronectidae	Black flounder	*Rhombosolea retiaria*	Not threatened
Retropinnidae	Common smelt	*Retropinna*	Not threatened
Salmonidae	Brown trout	*Salmo trutta*	Introduced and naturalised
	Brook char	*Salvelinus fontinalis*	Introduced and naturalised

† Estuarine species

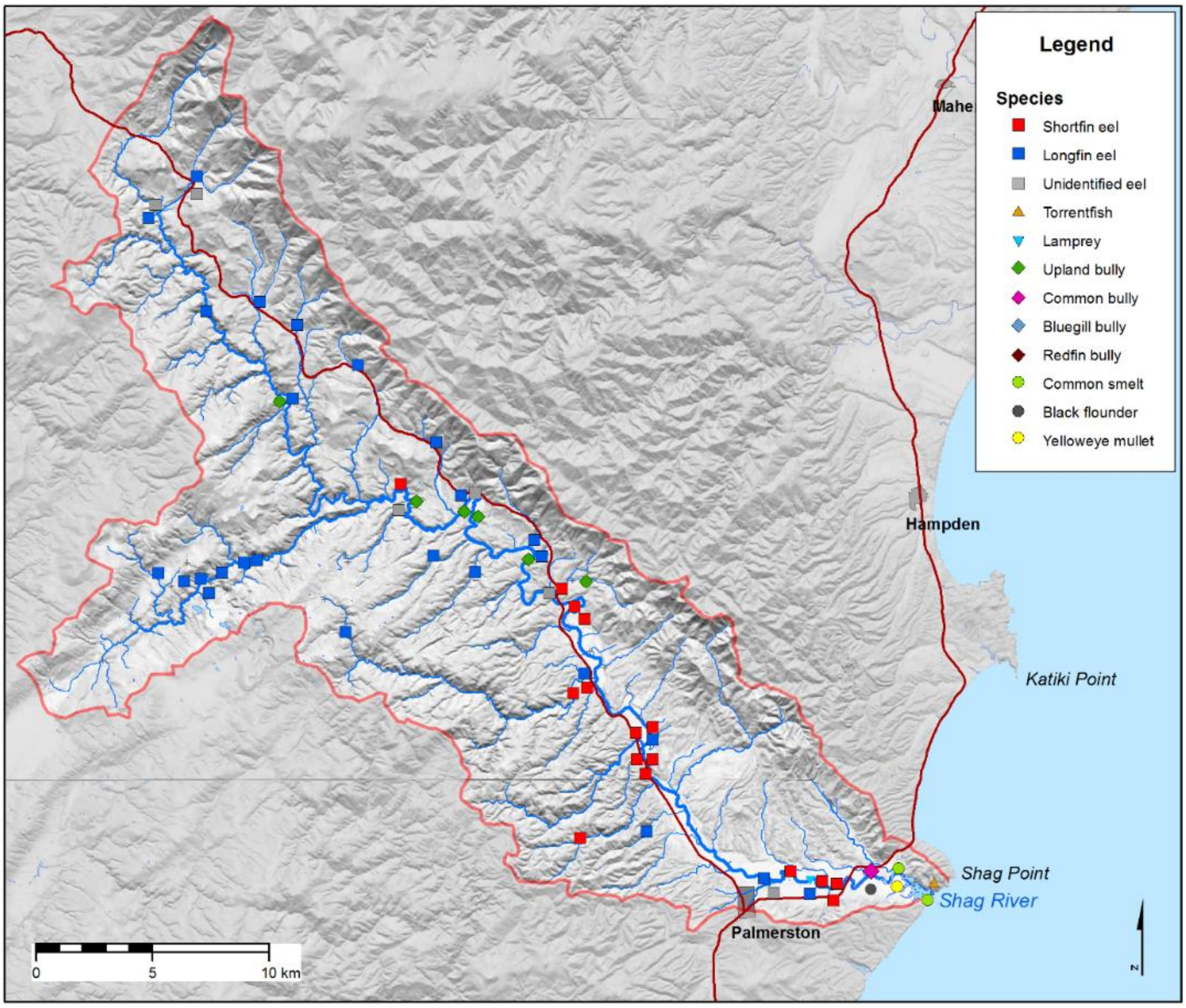

Figure 14 Distribution of indigenous fish species (excluding galaxiids – see Figure 15) within the Shag/Waihemo catchment.

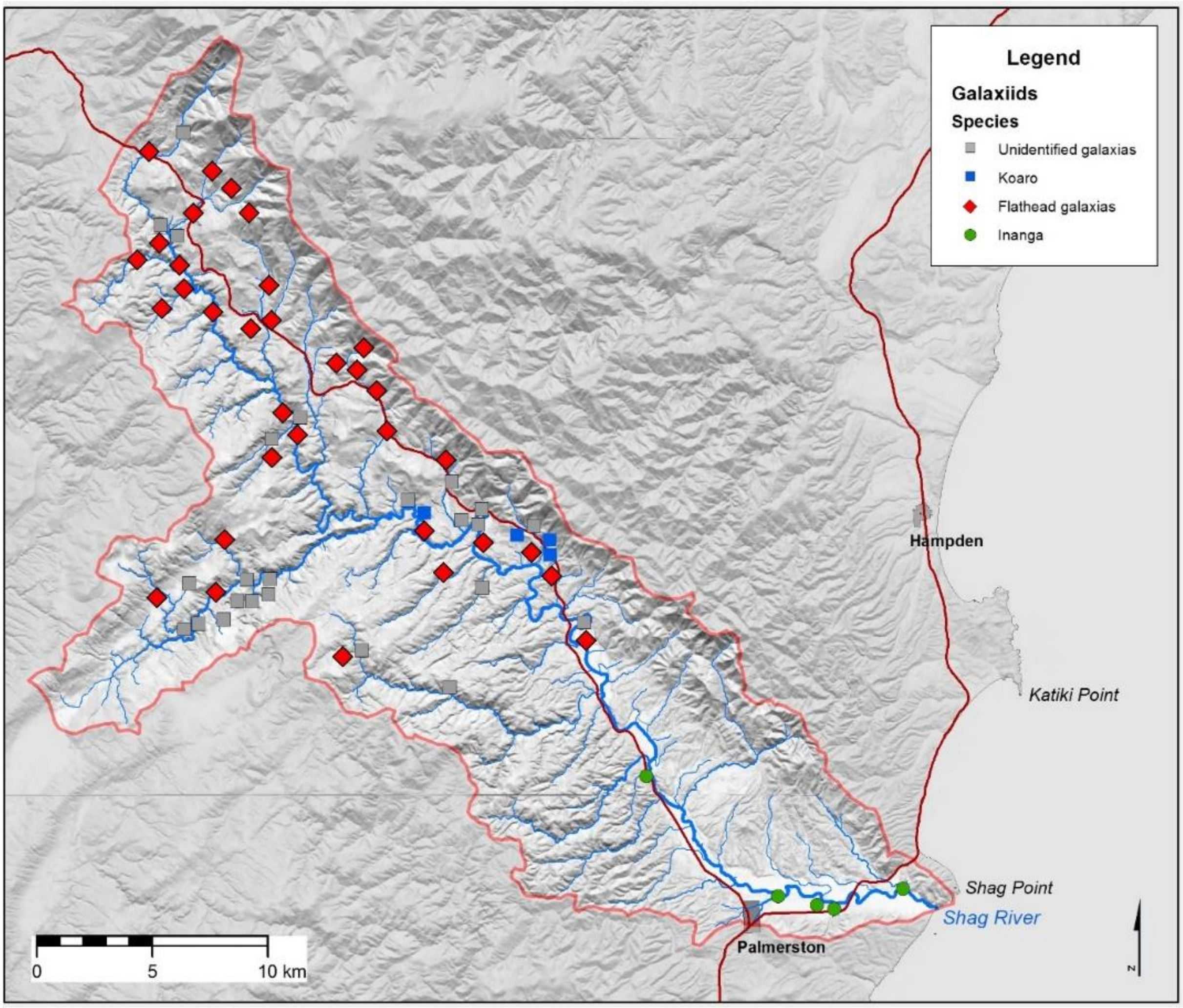

Figure 15 Distribution of galaxiid species within the Shag/Waihemo catchment.

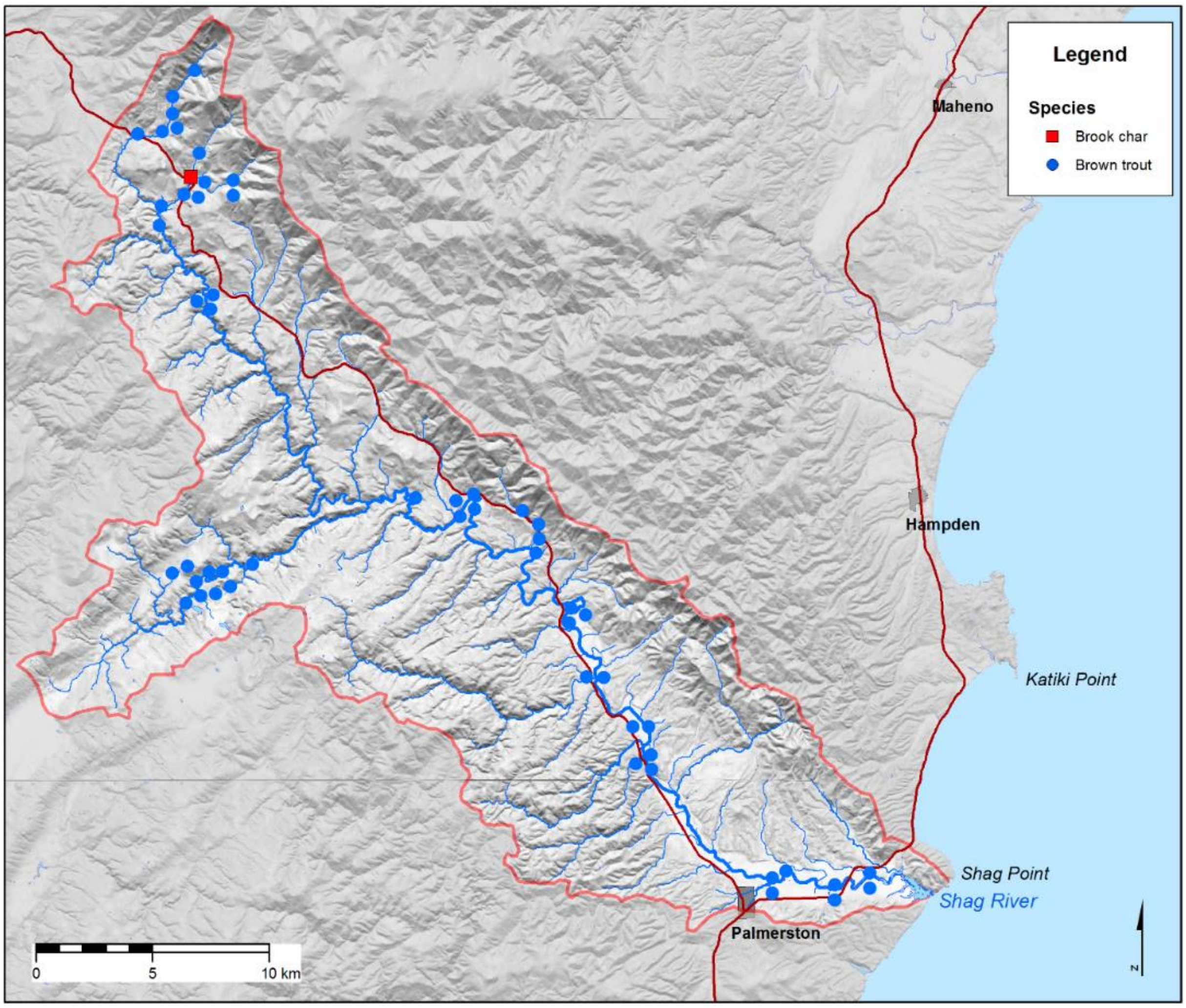

Figure 16 Distribution of sportsfish species within the Shag/Waihemo catchment.

1.10. Current ecological state

The current minimum flow and allocation in the Shag/Waihemo catchment were added to the RPW by Plan Change 1B, which was notified on 20 December 2008. Thus, the current minimum flow and allocation limit have been in effect for many years and is reflected in the current state of the Shag River/Waihemo. Therefore, comparing the current state of the Shag River/Waihemo with objectives for the North Otago FMU provide insight into whether the current minimum flow and allocation regime is consistent with the objectives proposed in the Land & Water Regional Plan.

At the time of writing, the proposed objectives for the North Otago FMU include the following narrative objectives: *"Freshwater bodies within the North Otago FMU support healthy ecosystems with thriving habitats for a range of indigenous species, and the life stages of those species, that would be expected to occur naturally"* and *"This is achieved where the target attribute state for each biophysical component (as set in table) are reached."*. The table referred to is presented in Table 9 below.

1.10.1. Ecosystem health

In addition to the ecosystem health and human contact values identified in Table 9, the proposed objectives for fishing, animal drinking water, cultivation and production of food and beverages and fibre, commercial and industrial use, and drinking water supply are measured by the target attribute states for ecosystem health and human contact presented in Table 9. Attributes for natural form and character and threatened species within the North Otago FMU are under development, so at the time of writing, it is not possible to consider the current state of the Shag/Waihemo catchment relative to these attributes.

Table 9 presents the current attribute state for Goodwood Pump, Craig Road, and Upper Shag at SH85 culvert. It compares the current state to the proposed target attribute state for the North Otago FMU. Attributes for Ecosystem Health – Aquatic life meets the target states for macroinvertebrates and fish attributes at the Craig Road and Upper Shag at the SH85 culvert monitoring sites (Table 9). Attributes for Ecosystem Health – Aquatic life at the Goodwood Pump site meets QMCI and ASPM target states. However, periphyton biomass at Goodwood Pump exceeds the national bottom line (≤8% of values exceeding 200 mg/m^2), and the MCI score for this site (88) is also below the national bottom line (Table 9).

Periphyton biomass at a point in time reflects the balance of two opposing processes – biomass accrual and biomass loss. The rate of biomass accrual is driven by the rate of cell division, which is, in turn, affected by factors such as the supply of resources (nutrients and light) and water temperature. Biomass loss is driven by two main mechanisms: disturbance caused by high flows (resulting in increased water velocities, substrate instability and/or abrasion caused by suspended or saltating sediments) and physical removal by grazing my macroinvertebrates (Biggs 2000).

The Shag River/Waihemo flows through a dry catchment characterised by high summer temperatures and long daylight hours that experiences long periods of low flows, thereby favouring periphyton accrual processes at times. There is limited storage within the Shag/Waihemo catchment, so most of the abstraction will be run-of-the-river and is not expected to affect the magnitude and duration of high-flow events. Given the high water clarity in the Shag River/Waihemo at low flows, light availability is not expected to be affected appreciably by flow at low flows. So the main effect of water allocation on periphyton biomass is likely to be via enhanced accrual resulting from nitrogen concentrations (via reduced dilution of nitrogen-enriched groundwater in the lower reaches of the Shag River/Waihemo; Olsen 2014).

1.10.2. Water quality

Most water quality parameters considered were in A-band at the three monitoring sites (Table 9), consistent with the findings of a previous catchment water quality study (Olsen 2014). The faecal indicator bacterium *Escherichia coli (*E. coli) was the exception to this, which exceeded the target attribute state at the three monitoring sites (Table 9). The median, percentage of values exceeding 260 cfu/100 mL, and percentage of values exceeding 540 cfu/100 mL at the Upper Shag at the SH85 site were in A-band, while the 95th percentile at this site was in Band-B (Table 9). Similarly, the median and percentage of values exceeding 260 cfu/100 mL at the Craig Road site were in A-band, while the percentage of values exceeding 540 cfu/100 mL and 95th percentile at this site were in B-Band (Table 9). The median value at the Goodwood Pump site was in Band-A, the percentage of values exceeding 260 cfu/100 mL was in Band B, and the percentage of values exceeding 540 cfu/100 mL and 95th percentile at this site were in C-Band (Table 9).

Water allocation is not expected to directly affect the concentrations of *E. coli* in the Shag/Waihemo, 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 *E. coli* at times.

Table 9 Comparison of the current attribute state at two sites in the Shag River/Waihemo based on Ozanne, Borges & Levy (2023).

Value	Attribute	Target attribute state		Current attribute state	
			Goodwood Pump	Craig Road	Upper Shag at SH85 culvert
Ecosystem health – (all biophysical components)					
EH - Aquatic life:	Periphyton (trophic state) (chlorophyll *a*)	B	D 21% exceedance 372 mg/m³	-	-
	Fish index of biotic integrity	A	-	A Mean (5-y): 56	-
	Macroinvertebrate Community Index (MCI) score	C	D (88)	C (99)	B (127)
	Quantitative Macroinvertebrate Community Index (QMCI) score	C	B (5.43)	B (4.51)	A (6.58)
	Macroinvertebrate Average Score Per Metric (ASPM)	C	B (0.41)	C (0.38)	A (0.74)
EH – Water quality	Ammonia (toxicity)	A	A Median: 0.003 Max: 0.010	A Median: 0.003 Max: 0.025	A Median: 0.002 Max: 0.024
	Nitrate (toxicity)	A	A Median: 0.230 Max: 0.688	A Median: 0.110 Max: 0.493	A Median: 0.015 Max: 0.068
	Dissolved oxygen	A or B	Not able to be determined	Not able to be determined	Not able to be determined
	Suspended fine sediment - Visual clarity	A	A 4.25 m	A 4.84 m	A 8.50 m
	Dissolved reactive phosphorus	B	A Median: 0.005 Max: 0.014	A Median: 0.003 Max: 0.012	A Median: 0.002 Max: 0.004
EH - Habitat	Deposited fine sediment (% cover)	A	A Median: 0.65	-	-
EH – Ecological processes	Ecosystem metabolism (both gross primary production and ecosystem respiration)	C	Not able to be determined	Not able to be determined	Not able to be determined
Human contact	*Escherichia coli*	A	C Median: 100 95th percent: 1,074 % >260: 22 % >540: 11	B Median: 53 95th percent: 638 % >260: 9 % >540: 5	B Median: 39 95th percent: 628 % >260: 9 % >540: 4
	Escherichia coli (*E. coli*) (primary contact sites) - 95th percentile	A	C 95th percent: 1,074	B 95th percent: 638	B 95th percent: 628
	Suspended fine sediment - Visual clarity (metres)	A	A 4.25 m	A 4.84 m	A 8.50 m

Otago Regional Council

6. Instream Habitat Assessment

1.11. Instream habitat modelling in Shag River/Waihemo

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 habitat loss caused by changes in the flow regime, which helps 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 consider several other factors, including the disturbance and mortality caused by flooding and biological interactions (such as predation), which can significantly influence the distribution of aquatic species.

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

Instream habitat is defined 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), measures 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 the percentage cover across the riverbed (such as periphyton).

1.11.1. Habitat preferences and suitability curves

Habitat suitability curves (HSC) for a range of organisms present in the Shag/Waihemo catchment were modelled (Table 10) to understand the full range of potential effects of flow regime changes in the Shag River/Waihemo – from changes in the cover and type of periphyton, to changes in the availability of macroinvertebrate prey, to changes in the habitat for fish and birds.

Table 10 Habitat suitability curves used in instream habitat modelling in the Shag River/Waihemo.

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

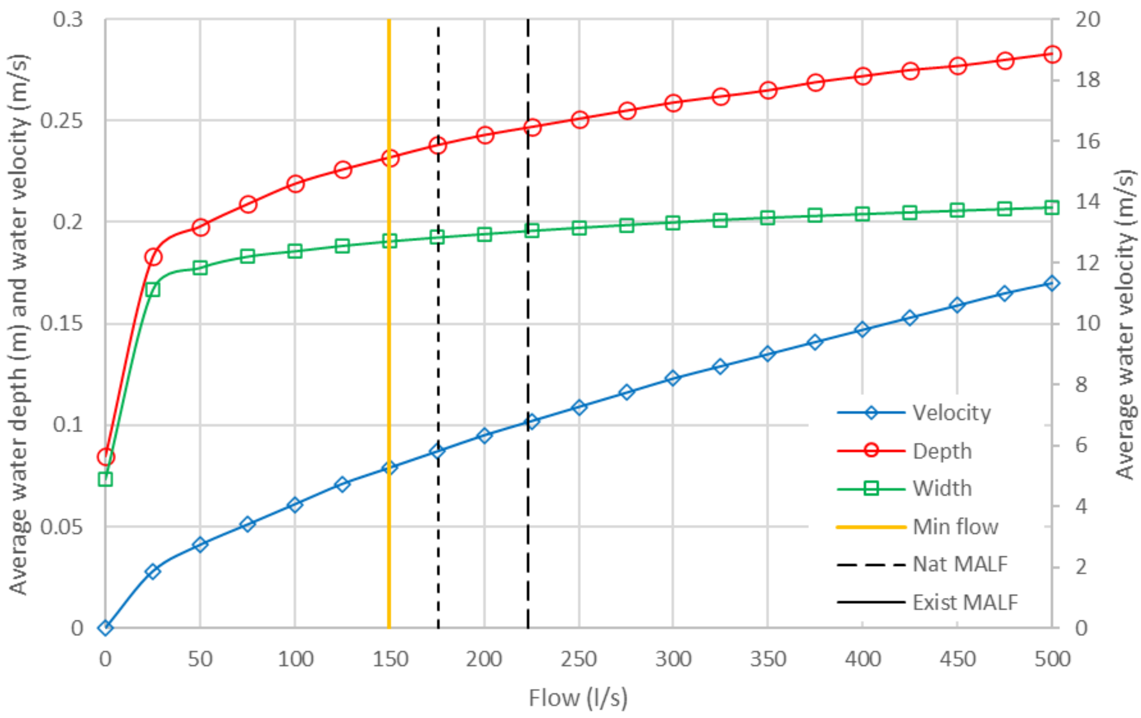

Figure 17 Variation in physical characteristics relative to flow in the survey reach of the Shag River/Waihemo.

1.12. Periphyton

The main purpose of considering periphyton is to understand how changes in flow will likely 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, the percentage of the wetted channel covered by periphyton, not the total area of suitable habitat, 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.

The flow was predicted to have little effect on habitat quality for cyanobacteria (*Phormidium*), with habitat quality predicted to increase very gradually across the modelled flow range (Figure 18). Habitat quality for native diatoms was expected to be low across the modelled flow range (Figure 18). Habitat quality for short filamentous algae was predicted to increase with increasing flows across the modelled flow. In contrast, habitat quality for long filamentous algae was expected to be highest in the absence of flow and to decline with increasing flows across the modelled flow range (Figure 18).

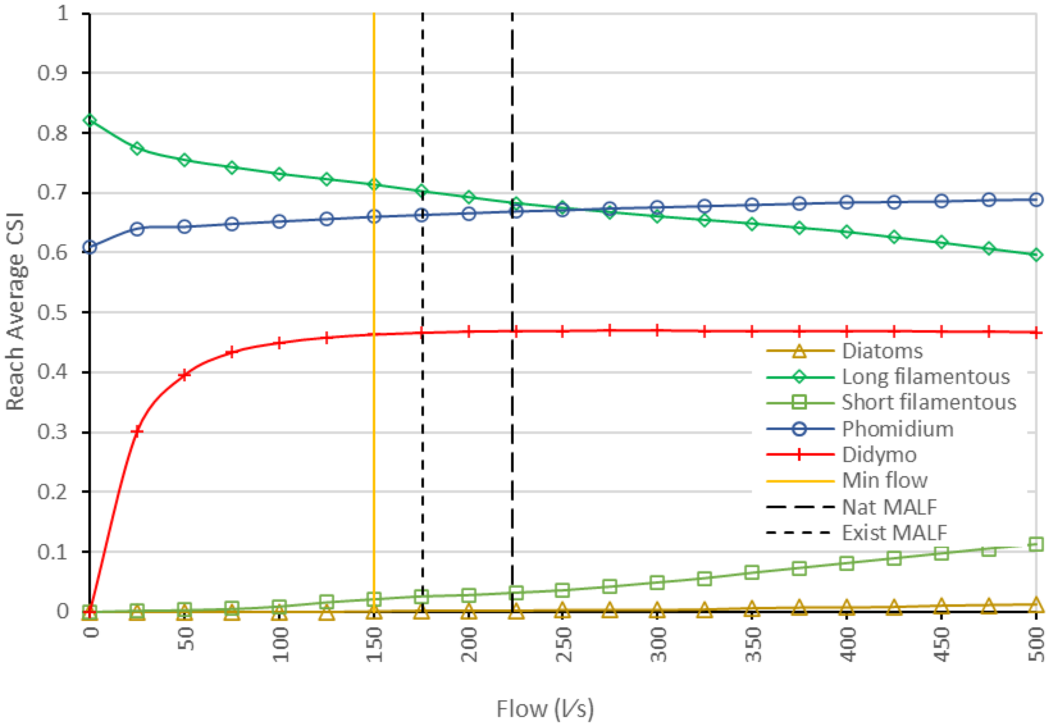

Figure 18 Variation in instream habitat quality for periphyton relative to flow in the survey reach of the Shag River/Waihemo.

Table 11 Flow requirements for periphyton habitat in the Shag River/Waihemo. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction).

Species	Optimum flow (l/s)	Flow at which % habitat retention occurs (l/s)				Habitat retention at 150 l/s (%)
		120%	150%	200%	300%	
Cyanobacteria (*Phormidium*)	>500	-	-	-	-	99
Diatoms	>500	-	-	-	-	50
Didymo	>150	-	-	-	-	99
Short filamentous	>500	-	-	-	-	66
Long filamentous	0	-	-	-	-	93

1.13. Macroinvertebrates

The food-producing habitat is an overseas HSC describing macroinvertebrates most productive habitat conditions. The mayfly *Deleatidium* is arguably the most abundant and widespread aquatic macroinvertebrate in New Zealand. It is abundant at sites in the Shag River (Section 1.8), and the habitat for *Deleatidium* was modelled for this reason. The net-spinning caddisfly *Aoteapsyche* is also widespread and can be particularly abundant in stable and productive systems (e.g. lake outlets). Habitat for *Aoteapsyche* is included here because the habitat preferences of this species mean that it is the most flow-demanding common macroinvertebrate in New Zealand and is often abundant in the Shag River/Waihemo (Section 1.8). The stony-cased caddis *Pycnocentrodes* can be amongst the most common macroinvertebrate taxa in moderate to slow-moving streams and is sometimes abundant in the Kākaunui River (Section 1.8). It is included in habitat modelling to represent taxa that prefer slower-flowing habitats.

Food-producing habitat and habitat for all macroinvertebrate taxa increased with flow across the modelled flow range (Figure 19). Flows required to achieve different habitat retention levels for each macroinvertebrate taxa are presented in Table 12.

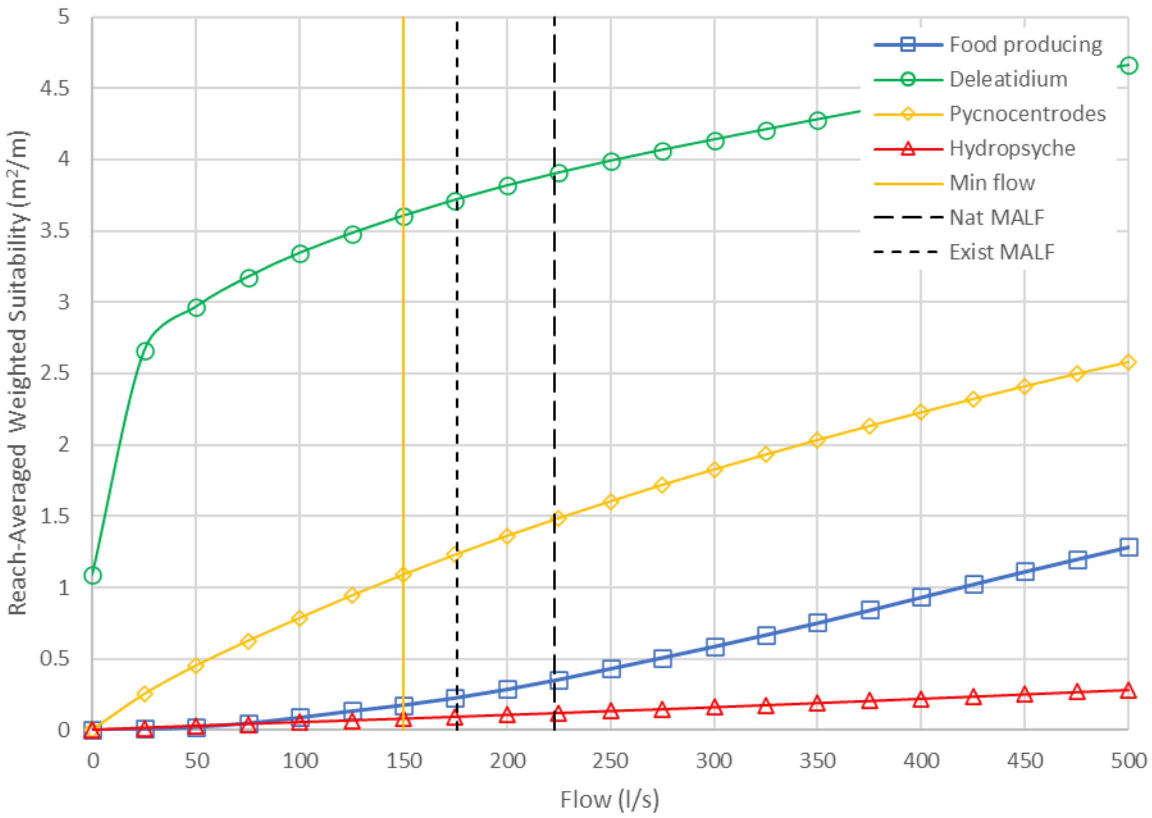

Figure 19 Variation in instream habitat for common macroinvertebrates relative to flow in the survey reach of the Shag River/Waihemo.

Table 12 Flow requirements for macroinvertebrate habitat in the Shag River/Waihemo. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction).

Species	Optimum flow (l/s)	Flow at which % habitat retention occurs (l/s)				Habitat retention at 150 l/s (%)
		60%	70%	80%	90%	
Food producing habitat	>500	166	183	197	210	51%
Common mayfly *Deleatidium*	>500	20	31	68	131	92%
Net-spinning caddis fly (*Aoteapsyche*)	>500	133	156	179	200	67%
Cased caddis fly (*Pycnocentrodes*)	>500	116	140	166	194	74%

1.14. Indigenous fish

Habitat for tuna/longfin eel (<300 mm and >300 mm), and large shortfin eel (>300 mm) is predicted to increase across the modelled flow range (Figure 20). Habitat for small (<300 mm) shortfin eel increased with increasing flow up to 225 l/s, before levelling out and dropping as flows increased above 400 l/s (Figure 20). Juvenile lamprey habitat increased with increasing flow up to 225 l/s, before levelling out at higher flows (Figure 20).

Habitat for bluegill bully is predicted to increase with increasing flow across the modelled range, while habitat for redfin bully is also expected to increase up to 425-450l/s before gradually declining (Figure 21). Habitat for common bully is predicted to increase with increasing flow to 400-425 l/s, before steadily declining, while habitat for upland bully is expected to increase with increasing flow to 175-200 l/s, before also declining (Figure 21).

Habitat for inanga is predicted to increase with increasing flow to 75-100 l/s and decline at higher flows (Figure 22). Habitat for juvenile flathead galaxias is expected to be highest at flows between 25 l/s and 100 l/s but dropping at higher flows. For adult flathead galaxias, habitat is predicted to increase with increasing flow to flows of 200-350 l/s before gradually dropping as flows increase further (Figure 22).

Flows required to achieve different levels of habitat retention for indigenous fish species are presented in Table 13.

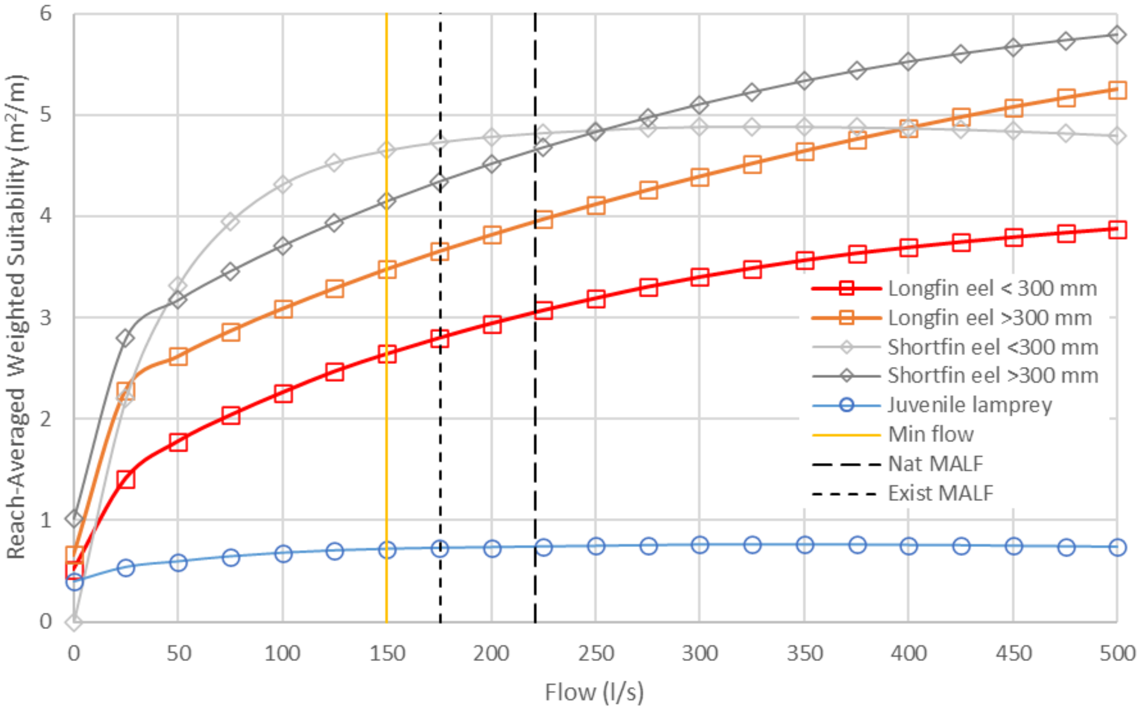

Figure 20 Variation in instream habitat for longfin and shortfin eel size-classes and lamprey relative to flow in the survey reach of the Shag River/Waihemo.

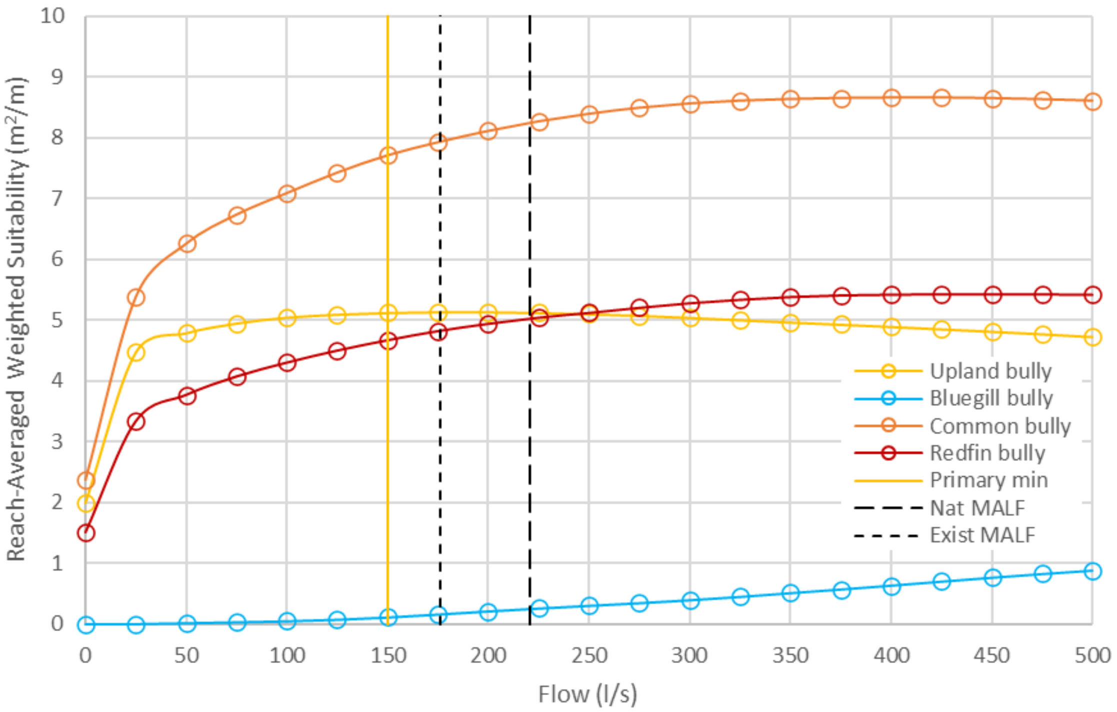

Figure 21 Variation in instream habitat for bully species size-classes relative to flow in the survey reach of the Shag River/Waihemo.

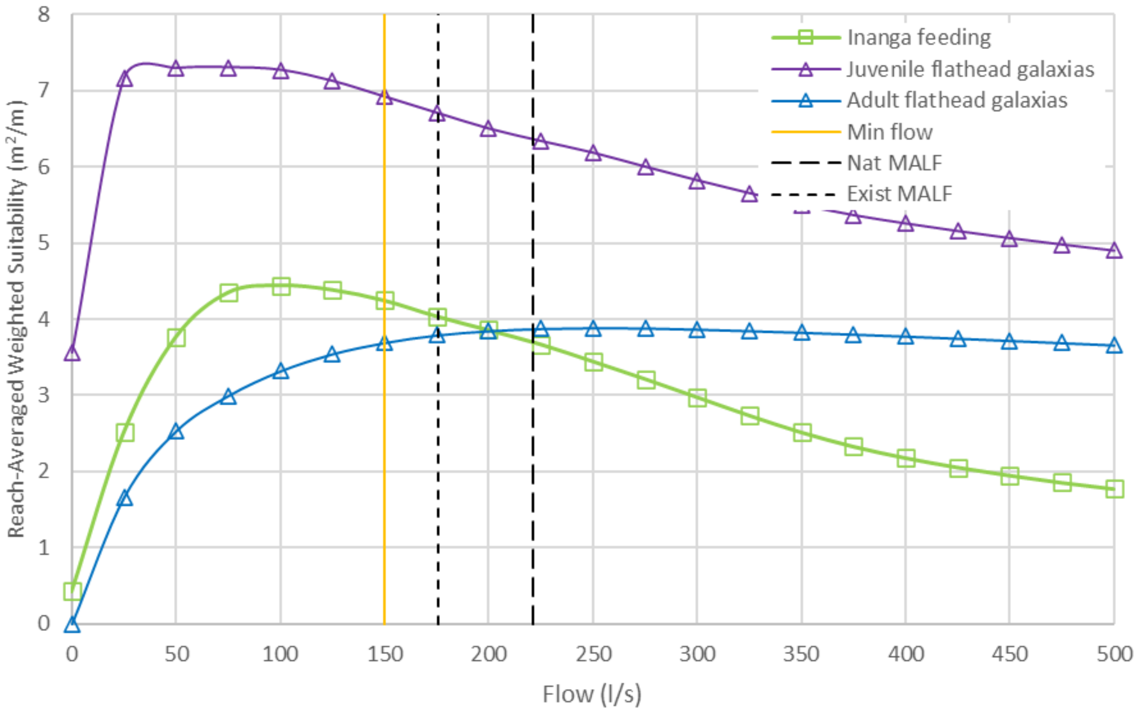

Figure 22 Variation in instream habitat for galaxiid species relative to flow in the survey reach of the Shag River/Waihemo.

Table 13 Flow requirements for indigenous fish habitat in the Shag River/Waihemo. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction).

Species	Optimum flow (l/s)	Flow at which % habitat retention occurs (l/s)				Habitat retention at 150 l/s
		60%	70%	80%	90%	
Tuna/longfin eel <300 mm	>500	55	87	123	168	86%
Tuna/longfin eel >300 mm	>500	32	65	110	162	88%
Shortfin eel <300 mm	325	40	52	71	103	96%
Shortfin eel >300 mm	>500	25	58	102	157	89%
Upland bully	175-200	11	16	21	36	100%
Bluegill bully	>500	171	184	197	208	44%
Common bully	400-425	21	36	68	125	93%
Redfin bully	425-450	21	36	71	129	93%
Inanga	100	21	26	34	41	115%
Flathead galaxias juvenile	75	2	6	11	15	109%
Flathead galaxias adult	250	44	60	83	119	95%
Kanakana/lamprey ammocoetes	250	14	22	40	76	98%
Kanakana/lamprey juvenile	325-350	9	21	49	91	97%

1.15. Sports fish

Habitat for brown trout adults, juveniles and spawning is predicted to increase with flow across the modelled range (Figure 23). Flows required to achieve different levels of habitat retention for each of these species/life-stages are presented in Table 14.

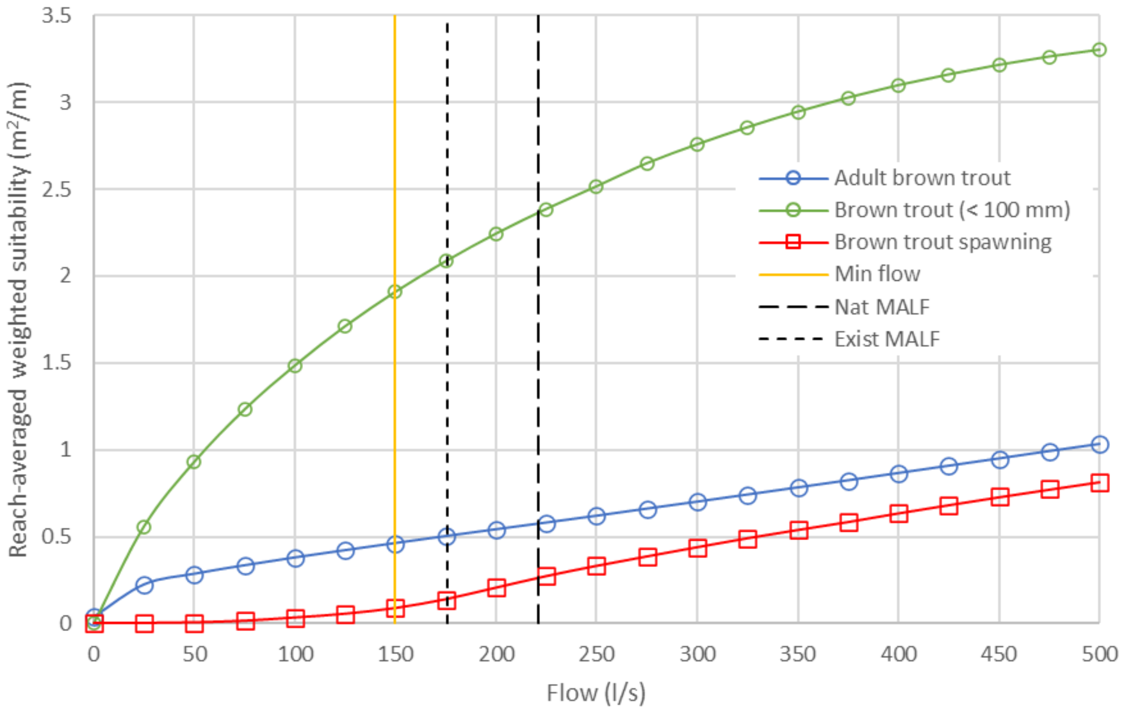

Figure 23 Variation in instream habitat for sportsfish relative to flow in the survey reach of the Shag River/Waihemo.

Table 14 Flow requirements for sportsfish habitat in the Shag River/Waihemo. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction).

Species	Optimum flow (l/s)	Flow at which % habitat retention occurs (l/s)				Habitat retention at 150 l/s
		60%	70%	80%	90%	
Brown trout adult	>500	82	115	150	186	80%
Brown trout (<100 mm)	>500	94	120	149	183	80%
Juvenile trout	>500	29	61	102	156	89%
Brown trout spawning	>500	183	193	203	213	33%

1.16. Summary of instream habitat assessments

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

Flows of 161-167 l/s are expected to retain 80% of the habitat for tuna/longfin eel available at the naturalised MALF, while flows of 101-155 l/s are predicted to retain 80% of the habitat for shortfin eel available at the naturalised MALF (Table 15). The current minimum flow retains 87-88% and 89-97% of the habitat for longfin and shortfin eels at the naturalised MALF, respectively (Table 15).

Bluegill bully are among the most flow-demanding indigenous fish species in the Shag/Waihemo catchment, and a flow of 195 l/s would provide 80% habitat retention in the Shag/Waihemo. In contrast, the current minimum flow is predicted to retain 45% of the habitat for torrentfish at the naturalised MALF (Table 15). Flows of 67 l/s, 71 l/s and 21 l/s would provide 80% habitat retention for common, redfin and upland bullies, respectively; the current minimum flow retains 94%, 93% and 100% of the habitat for these species at the naturalised MALF, respectively (Table 15).

Flows of 128-195 l/s and 67 l/s would provide 80% habitat retention for flathead galaxias and inanga, respectively; the current minimum flow retains 95-109% and 115% of the habitat for these species at the naturalised MALF, respectively (Table 15). Habitat for kanakana/lamprey was predicted to be highest at flows below the current minimum flow (>150 l/s). The current minimum flow retains 97-98% of the habitat available at the naturalised MALF (Table 15).

Flows of 195, 67, 177 and 165 l/s would provide 80% habitat retention (relative to naturalised flows) for food producing habitat, the common mayfly *Deleatidium*, net-spinning caddis fly *Aoteapsyche*, and *Pycnocentrodes*, respectively (Table 15). The current minimum flow retains 51% of food producing habitat, 93% of the habitat for *Deleatidium*, 68% of the habitat for *Aoteapsyche* and 74% of the habitat for *Pycnocentrodes*, relative to the habitat available at the naturalised MALF (Table 15).

Given that the Shag River/Waihemo supports a locally significant fishery (Otago Fish & Game Council 2015), an appropriate management objective for trout may be to maintain the existing habitat, which occurs at the current minimum flow (150 l/s), which would retain 81% of the habitat for the various life-stages of trout relative to naturalised flows (Table 15). Alternatively, a minimum flow of 113-119 l/s would retain 70% of the habitat for adult brown trout relative to the naturalised MALF (Table 15).

Table 15 Flow requirements for habitat objectives in the Shag River/Waihemo River. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction).

Value	Season	Significance	Level of habitat retention	Flow to maintain suggested level of habitat retention (l/s)	Habitat retention at 150 l/s
Food producing habitat	All year	Life-supporting capacity	80% relative to naturalised	197	51%
Common mayfly *Deleatidium*	All year	Life-supporting capacity	80% relative to naturalised	68	92%
Net-spinning caddisfly *Aoteapsyche*	All year	Life-supporting capacity	80% relative to naturalised	179	67%
Stony-cased caddisfly *Pycnocentrodes*	All year	Life-supporting capacity	80% relative to naturalised	166	74%
Tuna/longfin eel	All year	Life-supporting capacity, indigenous biodiversity, mahika kai, at risk (declining)	80% relative to naturalised	110-123	86-88%
			90% relative to naturalised	162-168	
Shortfin eel	All year	Life-supporting capacity, indigenous biodiversity, mahika kai, at risk (declining)	80% relative to naturalised	71-102	89-96%
			90% relative to naturalised	103-157	
Upland bully	All year	Life-supporting capacity, indigenous biodiversity	80% relative to naturalised	21	100%
Common bully	All year	Life-supporting capacity, indigenous biodiversity	80% relative to naturalised	68	93%
Bluegill bully	All year	Life-supporting capacity, indigenous biodiversity, at risk (declining)	80% relative to naturalised	197	44%
Redfin bully	All year	Life-supporting capacity, indigenous biodiversity, at risk (declining)	80% relative to naturalised	71	93%

Table 15 Flow requirements for habitat objectives in the Shag River/Waihemo River. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction).

Value	Season	Significance	Level of habitat retention	Flow to maintain suggested level of habitat retention (l/s)	Habitat retention at 150 l/s
Flathead galaxias	All year	Life-supporting capacity, indigenous biodiversity	80% relative to naturalised	128-195	95-109%
Inanga	All year	Life-supporting capacity, indigenous biodiversity, at risk (declining), mahika kai	80% relative to naturalised	67	115%
Kanakana/lamprey	All year	Threatened (nationally vulnerable), life-supporting capacity, indigenous biodiversity, mahika kai	80% relative to naturalised	Juvenile: <150 Adult: <150	97-98%
			90% relative to naturalised	Juvenile: <150 Adult: <150	
Brown trout adult	All year	Locally significant fishery	70% relative to naturalised	115	80%
			80% relative to naturalised	150	
Juvenile trout	All year	Locally significant fishery	70% relative to naturalised	120	81%
			80% relative to naturalised	149	
			Maintain existing	150	
Trout spawning	Winter	Locally significant fishery	70% relative to naturalised	193	33%
			80% relative to naturalised	203	
			Maintain existing	150	

1.17. Consideration of the Shag/Waihemo Estuary

Minimum flows in both the Shag River/Waihemo have the potential to interact with water quality in the Shag/Waihemo Estuary; an increase in the minimum flow and/or reduction in abstraction from the Shag/Waihemo may be beneficial for water quality outcomes in the Shag/Waihemo Estuary. However, addressing water quality issues in the Shag/Waihemo Estuary will require an integrated approach targeting nutrient loads and any potential changes to the minimum flow/allocation regime in the Shag/Waihemo catchment.

The hydrological analysis summarised in Table 2 estimated the naturalised 7-d MALF at Goodwood is 223 l/s, while the observed 7-d MALF is 176 l/s. The reduction in flows from naturalised to those observed may reduce the dilution of inputs of nitrogen-enriched groundwater.

Minimum flows typically apply for a relatively short proportion of the irrigation season - observed flows in the Shag/Waihemo have dropped to 150 l/s on about 7 % of occasions. Raising the minimum flow would increase the length of time that the river was at the minimum flow: minimum flows of 175 l/s and 200 l/s would be reached at approximately 9% and 12% of occasions[5]. This illustrates the limited impact a change to the minimum flow alone would have on nitrogen concentrations entering the Shag/Waihemo Estuary. In comparison, reducing the allocation from the Shag/Waihemo catchment will increase flows in the lower catchment and should reduce nitrogen concentrations whenever significant abstraction occurs.

[5] Based on observed flows in the Shag/Waihemo at Craig Road between 1 July 2011 and 21 June 2023

7. Assessment of alternative minimum flows & allocation in the Waihemo/Shag catchment

1.18. Consideration of existing minimum flows

Three minimum flows were considered, representing different proportions of the 7-day MALF, and four allocation limits in addition to the current Schedule 2A minimum flow/allocation limit (Table 16). Simulations were run from 1 July 2011 to 20 March 2023 to consider the hydrological effects of the various combinations of minimum flow/allocation. The simulations used naturalised flows estimated by adding measured water take (based on water metering data for water users in the catchment upstream of the Craig Road flow monitoring site) back onto the observed flows in the Shag/Waihemo River at Craig Road. For each simulation, a supplementary allocation block of 100 l/s was included, with a minimum flow of 311 l/s, 411 l/s and 511 l/s and a fourth supplementary block of 33 l/s (current allocation) with a minimum flow of 611 l/s.

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

Minimum flow		Allocation limit		Description
Option	% 7-d MALF	Option	% 7-d MALF	
150 l/s primary, 650 l/s first supplementary	68%	280 l/s	127%	Current minimum flow (68% of MALF), current actual allocation (127% MALF)
		220 l/s	100%	Current minimum flow (68% of MALF), allocation at 100% MALF
		180 l/s	81%	Current minimum flow (68% of MALF), allocation at 81% MALF
		145 l/s	66%	Current minimum flow (68% of MALF), allocation at 66% MALF
		110 l/s	50%	Current minimum flow (68% of MALF), allocation at 50% MALF
175 l/s primary	79%	220 l/s	100%	175 l/s minimum flow (79% of MALF), allocation at 100% MALF
		180 l/s	81%	175 l/s minimum flow (79% of MALF), allocation at 79% MALF
		145 l/s	66%	175 l/s minimum flow (79% of MALF), allocation at 66% MALF
		110 l/s	50%	175 l/s minimum flow (79% of MALF), allocation at 50% MALF
200 l/s primary	90%	220 l/s	100%	200 l/s minimum flow (90% of MALF), allocation at 100% MALF
		180 l/s	81%	200 l/s minimum flow (90% of MALF), allocation at 81% MALF
		145 l/s	66%	200 l/s minimum flow (90% of MALF), allocation at 66% MALF
		110 l/s	50%	200 l/s minimum flow (90% of MALF), allocation at 50% MALF

The degree of hydrological alteration from each minimum flow/allocation scenario was assessed using the Dundee Hydrological Regime Assessment Method (DHRAM) (Black et al. 2005). This method involves the calculation of 32 parameters relating to the seasonality of flows, magnitude and duration of annual extremes (high and low flow events), timing of annual extremes, frequency and duration of high and low pulses and the rate and frequency of change in flow (Black et al. 2005). The results of these simulations are presented in Table 18.

Table 17 DHRAM classes used in the assessment of alternative minimum flow/allocation

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

Observed flows in the Shag River/Waihemo at Craig Road are unimpacted relative to naturalised flows (Table 18). Scenarios with a minimum flow of 150 l/s and allocation of 280 l/s or 220 l/s, a minimum flow of 175 l/s and allocation of 80 l/s and a minimum flow of 200 l/s and allocation of 280 or 220 l/s were assessed as having a low risk of impact. Other scenarios considered are evaluated to result in an unimpacted hydrograph relative to naturalised flows (Table 18; Figure 24, Figure 25 and Figure 26).

Table 18 Comparison of the hydrological effects of different minimum flow/allocation limit combinations in the Shag River/Waihemo.

Min flow	Allocation	Monthly		Min/max means		Date/timing		Pulse count /duration		Rate of change		Risk grade
		CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	
Observed flows		0	0	0	0	0	0	0	0	0	0	Unimpacted
150	280	0	0	0	0	0	0	3	1	0	0	Low risk
	220	0	0	0	0	0	0	1	0	0	0	Low risk
	180	0	0	0	0	0	0	0	0	0	0	Unimpacted
	145	0	0	0	0	0	0	0	0	0	0	Unimpacted
	110	0	0	0	0	0	0	0	0	0	0	Unimpacted
175	280	0	0	0	0	0	0	3	1	0	0	Low risk
	220	0	0	0	0	0	0	0	0	0	0	Unimpacted
	180	0	0	0	0	0	0	0	0	0	0	Unimpacted
	145	0	0	0	0	0	0	0	0	0	0	Unimpacted
	110	0	0	0	0	0	0	0	0	0	0	Unimpacted
200	280	0	0	0	0	0	0	1	1	0	0	Low risk
	220	0	0	0	0	0	0	1	1	0	0	Low risk
	180	0	0	0	0	0	0	0	0	0	0	Unimpacted
	145	0	0	0	0	0	0	0	0	0	0	Unimpacted
	110	0	0	0	0	0	0	0	0	0	0	Unimpacted

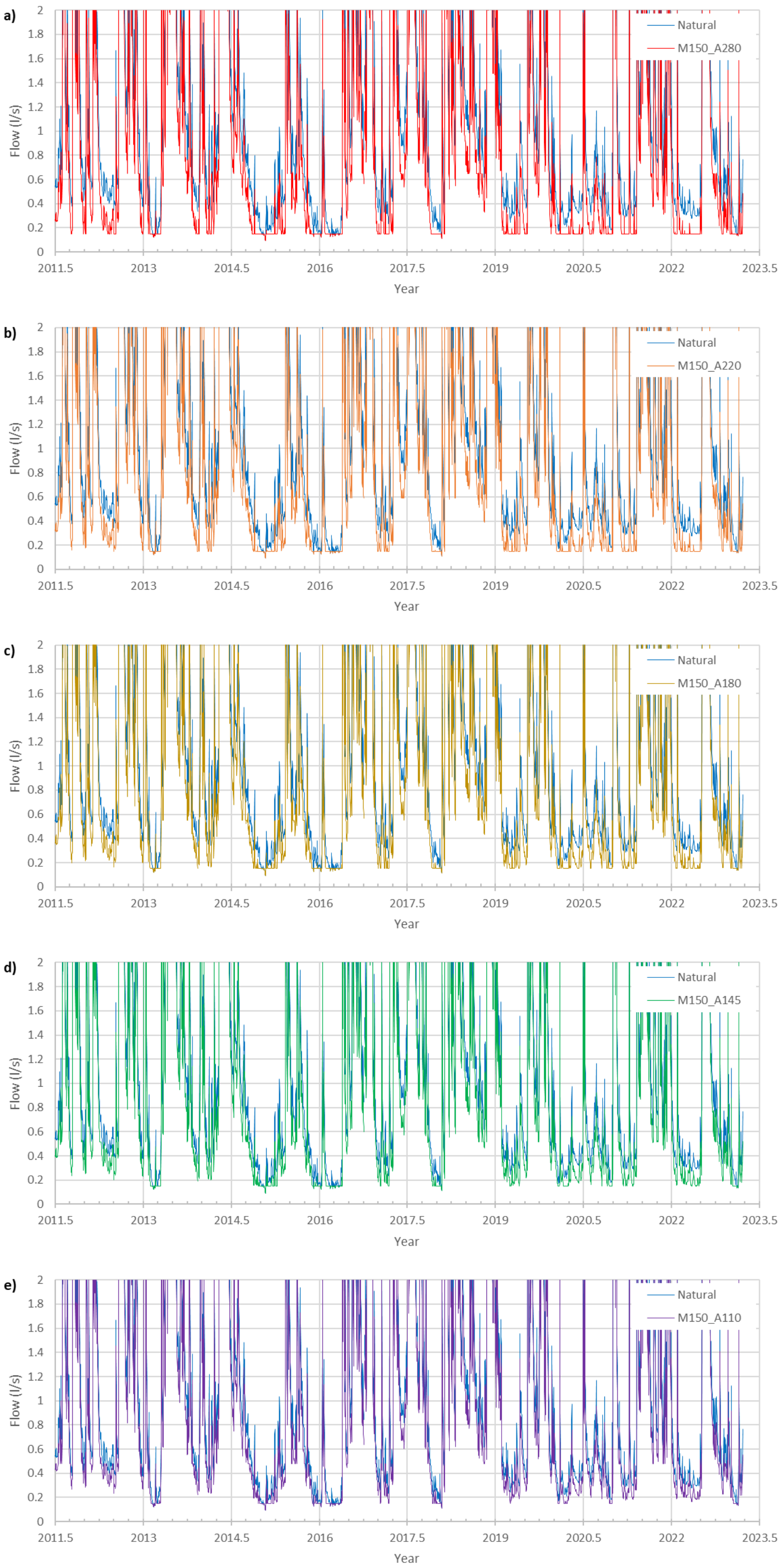

Figure 24 Hydrographs of allocation scenarios with a minimum flow of 200 l/s. a) Current allocation limit 190 l/s, b) allocation limit of 160 l/s, c) allocation limit of 120 l/s, d) allocation limit of 80 l/s.

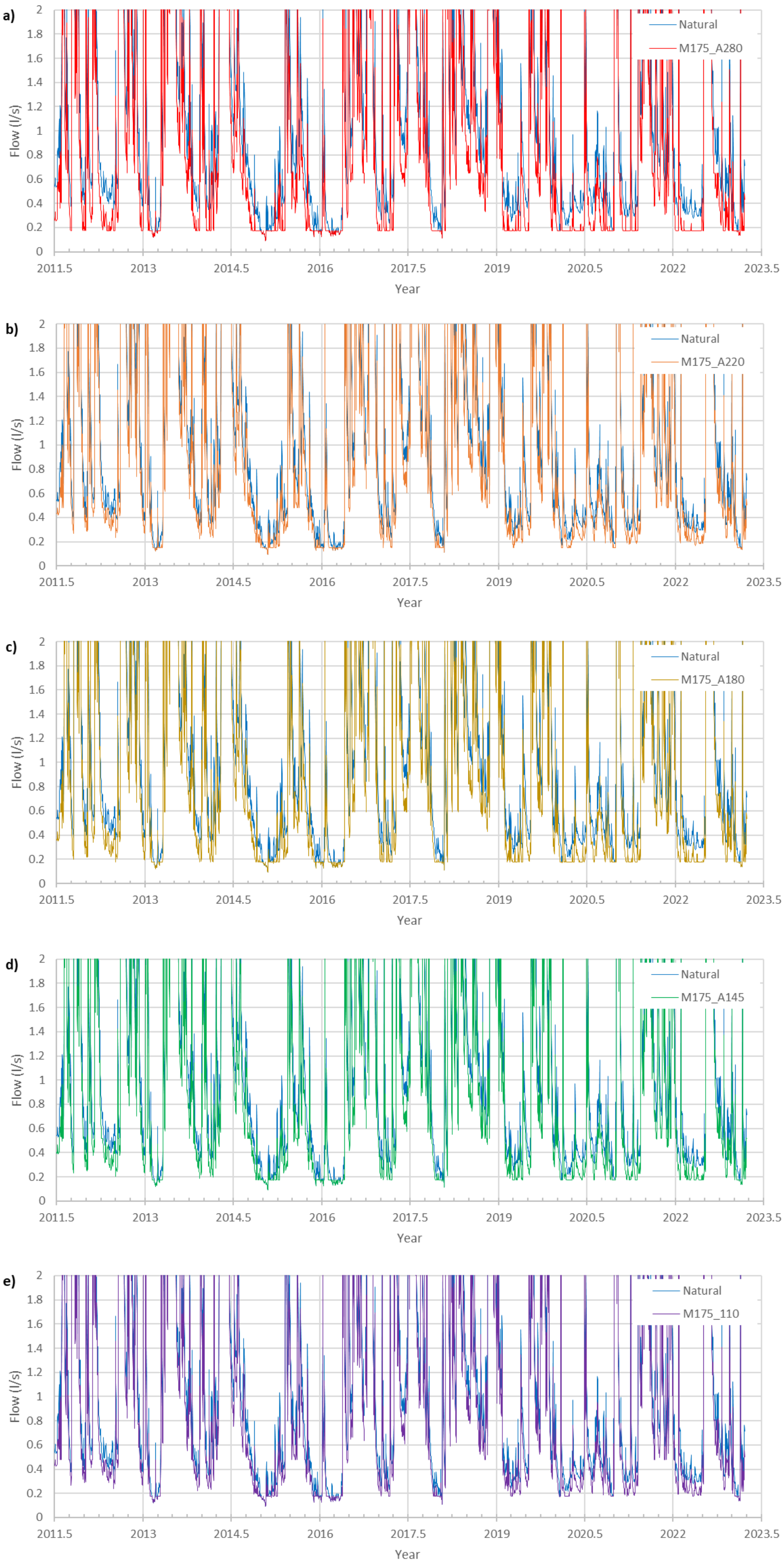

Figure 25 Hydrographs of allocation scenarios with a minimum flow of 230 l/s. a) Current allocation limit 190 l/s, b) allocation limit of 160 l/s, c) allocation limit of 120 l/s, d) allocation limit of 80 l/s.

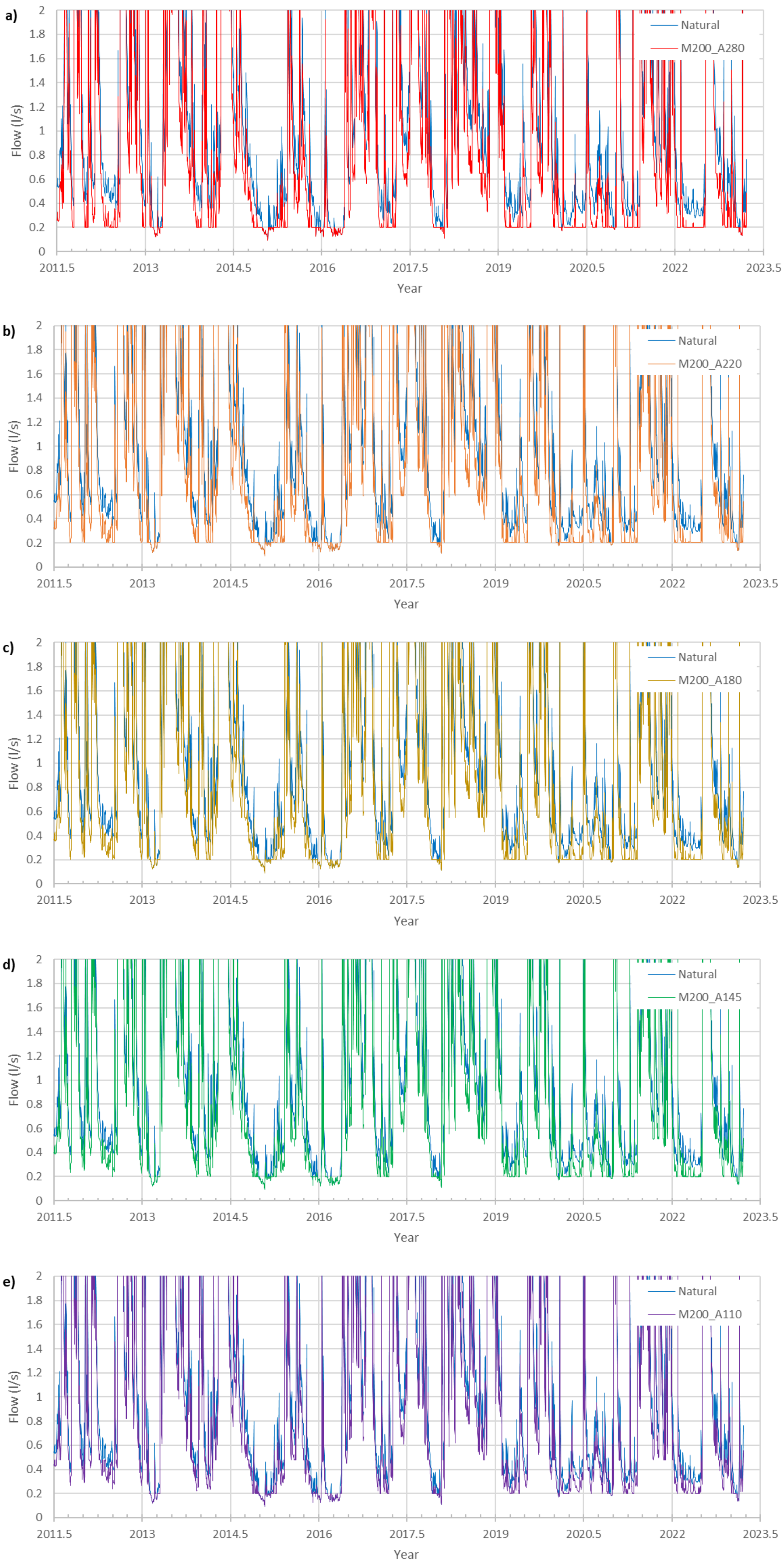

Figure 26 Hydrographs of allocation scenarios with a minimum flow of 200 l/s. a) Current allocation limit 190 l/s, b) allocation limit of 160 l/s, c) allocation limit of 120 l/s, d) allocation limit of 80 l/s.

1.19. Consideration of existing minimum flows & allocation

The minimum flow is the flow below which any resource consent holder must cease taking water from that river, and the allocation limit is the maximum rate (or volume) of water abstraction. Schedule 2A of the RPW specifies minimum flows of 150 l/s for primary allocation, and the primary allocation in the Shag River/Waihemo is 280 l/s.

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

Most macroinvertebrate indices meet the target attribute state proposed in the LWRP. However, MCI scores for the Goodwood Pump monitoring site are in D-band (88), which is just below the national bottom line set out in the NPS-FM. This is likely to reflect, at least in part, the high chlorophyll *a* concentrations observed at this site.

1.20. Potential effects of climate change in the Waihemo/Shag catchment

The potential effects of future climate change vary considerably depending on future emission scenarios. This assessment is based on the evaluation of Macara et al. (2019) using two scenarios (RCP4.5 and RCP8.5) for 2031-2050.

The projected effects of climate change, such as reduced snowpack, higher temperatures (and therefore evapotranspiration), and reduced summer rainfall, are expected to increase the probability, magnitude and duration of low flow events in the Waihemo/Shag catchment (Table 19). Climate change may reduce habitat suitability for sensitive species (via increased water temperatures, reduced flows) and increase the risk of periphyton proliferations (through increased water temperatures, longer accrual periods). This may affect the baseline state for periphyton biomass (i.e. the periphyton biomass that would be achievable under natural conditions). Given that periphyton biomass exceeds the target attribute state in the Waihemo/Shag catchment at the Goodwood Pump monitoring site, such changes may reduce the achievability of periphyton objectives in the Waihemo/Shag catchment.

Table 19 Potential effects of climate change on the Waihemo/Shag catchment based on the assessment of Macara et al. (2019) using two scenarios (RCP4.5 and RCP8.5) for the period 2031-2050.

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

8. Conclusions

The Shag River/Waihemo[6] is a medium-sized river that rises in the Horse Range/Pakihiwitahi[2] and Kakanui Range/Pokohiwitahi[2] in North Otago, entering the Pacific Ocean near Shag Point/Matakaea[2]. Landcover in the upper Shag /Waihemo catchment is dominated by tall tussock grassland and low-producing grassland. In contrast, much of the lower part of the Shag/Waihemo catchment and most of the flat land in the valley floor consists of high-producing grasslands, with cropping areas in the lower catchment.

Schedule 2A of the RPW specifies minimum flows for primary allocation at Craig Road (150 l/s) and Goodwood Pump (28 l/s). The primary allocation limit set for the Shag/Waihemo catchment in Schedule 2A is 280 l/s. The primary allocation at the time of writing is 264.1 l/s.

This report presents information to assist water management decision-making in the Shag/Waihemo catchment, including hydrological details, information on aquatic values, application of instream habitat modelling to guide flow-setting processes, and consideration of the current state of the Shag River/Waihemo compared to the proposed objectives for the North Otago FMU set out in the proposed Otago Land and Water Regional Plan.

In the lower Shag/Waihemo, the river interacts with the underlying aquifer with losing and gaining reaches identified by Mourot *et al.* (2022). Losing reaches between Munro Road and Switchback Road and between Blacks Road and Horse Range Road can dry during particularly low flows (as observed in 2015).

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

		Flow statistics (l/s)		
		Mean	**Median**	**7d MALF (Jul-Jun)**
Craig Road	Naturalised flows	2,388	825	223
	Observed flows	2,367	814	176
Goodwood Pump	Naturalised flows	2,650	-	235

There are 14 resource consents for primary water takes from the Shag River/Waihemo, with a total primary allocation of 264.1 l/s. Oceana Gold (New Zealand) Ltd. has six resource consents for water takes (including non-consumptive takes) as part of their operations at the Macraes gold mine. There are three resource consents in the first supplementary allocation block (combined maximum take 102.5 l/s). Other supplementary takes in the Shag/Waihemo catchment include a take of up to 200 l/s from Deepdell North Stage III Pit for dewatering and dust suppression and a small take from an

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

unnamed ephemeral tributary of the Shag River for lime kiln exhaust gas scrubbing and hydrated lime manufacture.

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

The macroinvertebrate community at the Goodwood Pump site was dominated by the cased caddis fly *Pycnocentrodes*, common mayfly *Deleatidium*, and mudsnail *Potamopyrgus*. However, the net-spinning caddis *Hydropsyche* and riffle beetle larvae are sometimes among the most abundant taxa. MCI scores for Goodwood Pump are in D-band, SQMCI scores are in C-band, and ASPM scores are in B-band. The Goodwood Pump site is in the lower reaches of the catchment, just upstream of tidal influence, and is likely to be affected by high periphyton biomasses, which may account for the low scores observed at these sites.

In comparison, macroinvertebrate samples collected from the Craig Road site (2007-2022) were typically dominated by the common mayfly *Deleatidium*, mudsnail *Potamopyrgus* and/or the net-spinning caddis fly *Hydropsyche*. MCI and SQMCI scores for Craig Road would put this site in C-band of the NOF, while ASPM scores put this site in B-band of the NOF.

The Shag River supports a highly diverse community of indigenous fish with thirteen indigenous fish species recorded, including several species that are at risk or threatened – longfin eel (at risk – declining), torrentfish (at risk – declining), bluegill bully (at risk – declining), kōaro (at risk – declining), inanga (at risk – declining), while lamprey and Taieri flathead galaxias are classified as threatened – nationally vulnerable). Brown trout are the only introduced fish species that have been collected from the Shag/Waihemo catchment. The Shag River/Waihemo supports a locally important sport fishery with low angler usage.

An instream habitat model developed for the mainstem of the Shag River/Waihemo below Craig Road has been applied to consider the effects of different flows on the physical characteristics of the Shag River/Waihemo and habitat for periphyton, macroinvertebrates and fish.

The current minimum flow in the Shag River/Waihemo catchment (150 l/s) is predicted to maintain between 51% (food-producing habitat) and 92% (the common mayfly *Deleatidium*) of habitat for macroinvertebrates at the naturalised 7-d MALF. It is predicted to maintain 44% of the bluegill bully habitat compared to the naturalised 7-d MALF. The current minimum flow is predicted to achieve >86% habitat retention for other indigenous species considered and between 80-89% habitat retention for the various brown trout life-stages considered.

Flows of 110-123 l/s are predicted to retain 80% of the habitat for tuna/longfin eel available at the naturalised MALF. Bluegill bully are among the most flow-demanding indigenous fish species in the Shag River/Waihemo catchment, and a flow of 197 l/s is expected to provide 80% habitat retention in the Shag River/Waihemo. Flows of 11 l/s and 83 l/s are predicted to provide 80% habitat retention for juvenile and adult flathead galaxias. Habitat for kanakana/lamprey was predicted to be highest at low flows.

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

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