Management Flows for Aquatic Ecosystems in the Fraser River

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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
External reviewer: Duncan Gray, Pattle Delamore Partners
Internal reviewer: Dave Stewart, Consultant Hydrologist, Raineffects Ltd

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Executive summary

The Earnscleugh or Fraser River is a small river which rises on the northern slopes of the Old Man Range/ Kōpūwai, Old Woman and Obelisk Ranges in Central Otago before flowing into the Clutha River/Mata-Au downstream of the Clyde Dam and opposite Alexandra.

The flows of the Fraser River are highly modified for irrigation and hydroelectric generation. Two hydro-electric power schemes operate on the Fraser River. Earnscleugh Irrigation Company augments flows in the lower Fraser River with up to 3,100 l/s from Lake Dunstan (RM18.266.01. Flow is abstracted at six locations and a residual flow of 1,000 l/s is to be maintained downstream of these takes. Thus, the hydrology of the lower half of the Fraser River is highly modified by hydro-electric generation, abstraction, and flow augmentation.

The Fraser catchment is within the Clutha Mata-Au Freshwater Management Unit (FMU) and the Roxburgh Rohe. Like many waterways within the Roxburgh Rohe, the Fraser catchment has a long history of water abstraction, with many of the water takes within the Fraser catchment historically authorised by deemed permits (also known as mining rights). These permits, originally issued for the purposes of mining but later used for irrigation, were not subject to environmental restrictions, such as minimum flows. As a consequence, catchments such as the Fraser River have not been subject to a minimum flow on the abstraction associated with those permits. As part of the development of the Land and Water Regional Plan (LWRP) minimum flows and allocation limits are to be developed for all catchments in Otago.

This report presents information to inform water management decision-making in the Fraser catchment including hydrological information (e.g. flow naturalisation and summary statistics), data on aquatic values (e.g. the distribution of indigenous fish) and application of instream habitat modelling.

A regional hydrological model developed for ORC (Friedel *et al*., 2023) estimated the mean flow in the Fraser River to be 2,332 l/s and the 7 day mean annual low (7d MALF) flow to be 598 l/s. The hydrology of the Fraser River is highly modified by Fraser Dam, hydro-electric power generation and flow augmentation.

There are nine resource consents for water takes from the Fraser catchment. Of these, there are two non-consumptive takes from the upper Fraser upstream of Fraser Dam (one for gold mining, another for run-of-the-river hydro-electric generation) and one non-consumptive take from the middle reaches of the Fraser River (hydro-electric generation). There is one consumptive take from the Hawks Burn, two consumptive takes from the Omeo Creek sub-catchment, and two consumptive takes from the Conroys Creek catchment. The consents held by Earnscleugh Irrigation Company (RM18.266), include the augmentation of the lower reaches of the Fraser River with up to 3,100 l/s from Lake Dunstan. The net allocation in the Fraser catchment (consumptive take minus augmentation) is 1,253 l/s (223.9 l/s is from Omeo Creek, 293 l/s from the Conroy's Creek, and 653 l/s from the lower Fraser River).

Limited information is currently available on periphyton communities in the Fraser River, although the invasive stalked diatom *Didymosphenia geminata* (known as Didymo) was first identified in the lower Fraser River in 2006.

Macroinvertebrate samples were collected from the Fraser River at Marshall Road between 2006 and 2010. Macroinvertebrate indices (MCI, SQMCI and ASPM) for this period were variable, but indicative of fair to good water and/or habitat quality. The lower Fraser, upstream of this site, was augmented from Lake Dunstan at this time.

Five species of indigenous freshwater fish have been recorded from the Fraser catchment – longfin eel, lamprey, upland and common bully and kōaro. Lamprey are classified as threatened – nationally vulnerable, while longfin eel and kōaro are classified as at risk – declining. Brown trout are widespread, while rainbow trout and perch have been recorded from the lower Fraser catchment. Little angler effort has been recorded in the Fraser catchment, but the upper reaches are considered to be a locally significant backcountry fishery. Brown and rainbow trout spawning in the Fraser River likely contributes to recruitment and juvenile rearing for the Clutha fishery to some degree, although the significance of this contribution is unknown.

Limited information is available on the water quality and ecological state of the lower Fraser River. MCI and SQMCI scores in the lower reaches of the Fraser River between 2006 and 2010 are in C-band while the proposed LWRP objective for the Roxburgh Rohe is B-band. Macroinvertebrate health is likely to reflect the abundance of didymo at this site over the sampling period. Water quality in the lower reaches of the Fraser River will primarily reflect the quality of augmentation water from Lake Dunstan.

Instream habitat modelling was undertaken in a reach of the Fraser River between Strode Road and Marshall Road by Waterways (2016) in the reach that is augmented with water from Lake Dunstan. Flows of 202 l/s (*Aoteapsyche*) and 501 l/s (food producing habitat) were predicted to provide 80% habitat retention (relative to naturalised flows) for macroinvertebrates. The current residual flow (1,000 l/s) retains between 123% (*Aoteapsyche*) and 163% of food producing habitat relative to the naturalised MALF.

Habitat for longfin eels (>300 mm) is predicted to increase across the modelled flow range (0-1,500 l/s), while flows of 750-850 l/s are predicted to provide optimum habitat for smaller longfin eels (<300 mm). Thus, the current augmented flows in the lower Fraser River provide close to optimal habitat for small (<300 mm) longfin eels, while enhancing habitat availability for larger longfin eels compared to naturalised 7dMALF. Upland bully have low flow requirements, with flows of 350-550 l/s predicted to offer optimum habitat in the Fraser River. Flows of 127 l/s would provide 80% habitat retention (relative to naturalised flows).

Habitat for adult brown and rainbow trout is predicted to increase with increasing flows up to 1,500 l/s, with the current residual flow predicted to enhance habitat by between 87% (rainbow trout) and 137% (brown trout) relative to modelled natural 7d MALF.

The highly modified hydrology of the middle and lower reaches of the Fraser River confounds consideration of alternative minimum/residual flows and allocation regimes. The hydrology of the lower river is affected by the presence of Fraser Dam and hydro-peaking discharges from the Fraser Hydroelectric Power Scheme as well as flow augmentation and is further complicated by the lack of hydrological monitoring in the lower catchment. The flow augmentation in the lower Fraser is a condition of the resource consent RM18.266.02 held by Earnscleugh Irrigation Company, which expires on 1 March 2044. Instream habitat modelling undertaken in the lower reaches of the Fraser River indicates that the flow augmentation in the lower reaches of the Fraser River has enhanced habitat for macroinvertebrates, longfin eels and trout.

To assist in future assessments of water allocation management in the Fraser catchment, additional hydrological information relating to the operation of the upper and lower Fraser Power Stations and Fraser Dam and hydrological monitoring in the lower river is essential. In addition, it was not possible to assess the ecological state of the lower Fraser River given the lack of water quality and ecological monitoring in the lower river.

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Glossary

Catchment	The area of land drained by a river or body of water.
Combined Suitability Index, CSI	An output from instream habitat modelling. It is a measure of average habitat quality provided at a particular flow. CSI is useful when considering the effects of changes in flow regime on periphyton where it is not the overall population response that is of interest (such as for fish), but rather the percentage cover across the riverbed (such as periphyton).
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.
Hydropeaking	The practice of generating hydro-electric power only at times when the electricity spot-price is high. Water is stored during times when the spot-price is low. This results in flows downstream of the power station that fluctuate markedly through the day.
Instream habitat modelling	A modelling approach to assess the relationship between flow, availability and quality of physical habitat for fish and invertebrates.
Irrigation	The artificial application of water to the soil, usually for assisting the growing of crops and pasture.
7-d Mean Annual Low Flow (7-d MALF)	The average of the lowest seven-day low flow for each year of record. Most 7-d MALF values reported here are calculated using flows from the irrigation season (October-April) only. This is to avoid the effect of winter low flows that may occur due to water being "locked up" in snow and ice in the upper catchment. However, if significant winter low flows do not occur, estimates of 7-d MALF calculated using data from the full hydrological year or from the irrigation season should be very similar.
Mean flow	The average flow of a watercourse (i.e. the total volume of water measured divided by the number of sampling intervals).
Minimum flow	The flow below which the holder of any resource consent to take water must cease taking water from that river.
Natural flows	The flows that occur in a river in the absence of any water takes or any other flow modification.

Naturalised flows	Synthetic (calculated) flows created to simulate the natural flows of a river by removing the effect of water takes or other flow modifications.
Reach Area Weighted Suitability, RAWS	An output from instream habitat modelling, it is a measure of the total area of suitable habitat. It is expressed as square metres per metre of river length (m^2/m).
Reach	A specific section of a stream or river.
River	A continually or intermittently flowing body of fresh water that includes a stream and modified watercourse, but does not include any artificial watercourse (such as an irrigation canal, water-supply race or canal for the supply of water for electricity power generation and farm drainage canal).
Seven-day low flow	The lowest seven-day low flow in any year is determined by calculating the average flow over seven consecutive days for every seven consecutive day period in the year and then choosing the lowest.
Taking	The taking of water is the process of abstracting water for any purpose and for any period of time.

1. Introduction

The Earnscleugh or Fraser River is a small river which rises on the northern slopes of the Old Man Range/ Kōpūwai, Old Woman and Obelisk Ranges in Central Otago before flowing into the Clutha River/Mata-Au downstream of the Clyde Dam and opposite Alexandra (Figure 1).

The flows of the Fraser River are highly modified for irrigation and hydroelectric generation. Southern Generation Limited Partnership commissioned a run-of-river power scheme in the Fraser River upstream of Fraser Dam in 2019. This scheme takes water out of the upper Fraser River into a 5 km long buried pipeline before re-entering the Fraser River upstream of Fraser Dam (Upper Fraser power scheme in Figure 1). Fraser Dam is a 35 m high concrete arch dam that was constructed as an irrigation dam and is in the middle reaches of the Fraser River. When full, the surface area of Fraser Dam is approximately 46 ha, and it impounds 5 million cubic metres of water. More recently, Fraser Dam is also used as a hydro-electric power station, releasing water to a 10 m concrete arch weir located approximately 5 km downstream, where it is taken into a 4.5 km pipeline, before flowing through steel penstocks to the Fraser River Power Station (Lower Fraser power scheme in Figure 1).

Fraser River has three main tributaries; Hawks Burn (56 km^2) flows into the true-left 2km downstream of Fraser Dam. Omeo (55 km^2) and Conroy's Creek (35 km^2) enter the on the true-right, 3.5km and 0.5km from the Fraser Clutha River confluence, respectively (Figure 1). In addition, the Earnscleugh Irrigation Company augments flows in the lower reaches with up to 3,100 l/s from Lake Dunstan.

The Fraser catchment is within the Clutha Mata-Au Freshwater Management Unit (FMU) and the Roxburgh Rohe. Like many waterways within the Roxburgh Rohe, the Fraser catchment has a long history of water abstraction, with many of the water takes within the Fraser catchment historically being authorised by deemed permits (also known as mining rights). These permits, often originally issued for the purposes of mining and later used for irrigation, were not subject to environmental restrictions, such as minimum flows. As a consequence, catchments such as the Fraser River have not been subject to a minimum flow. As part of the development of the Land and Water Regional Plan, minimum flows and allocation limits are to be developed for all catchments in Otago.

1.1. Purpose of the report

The purpose of this report is to present information to inform water management decision-making in the Fraser 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.

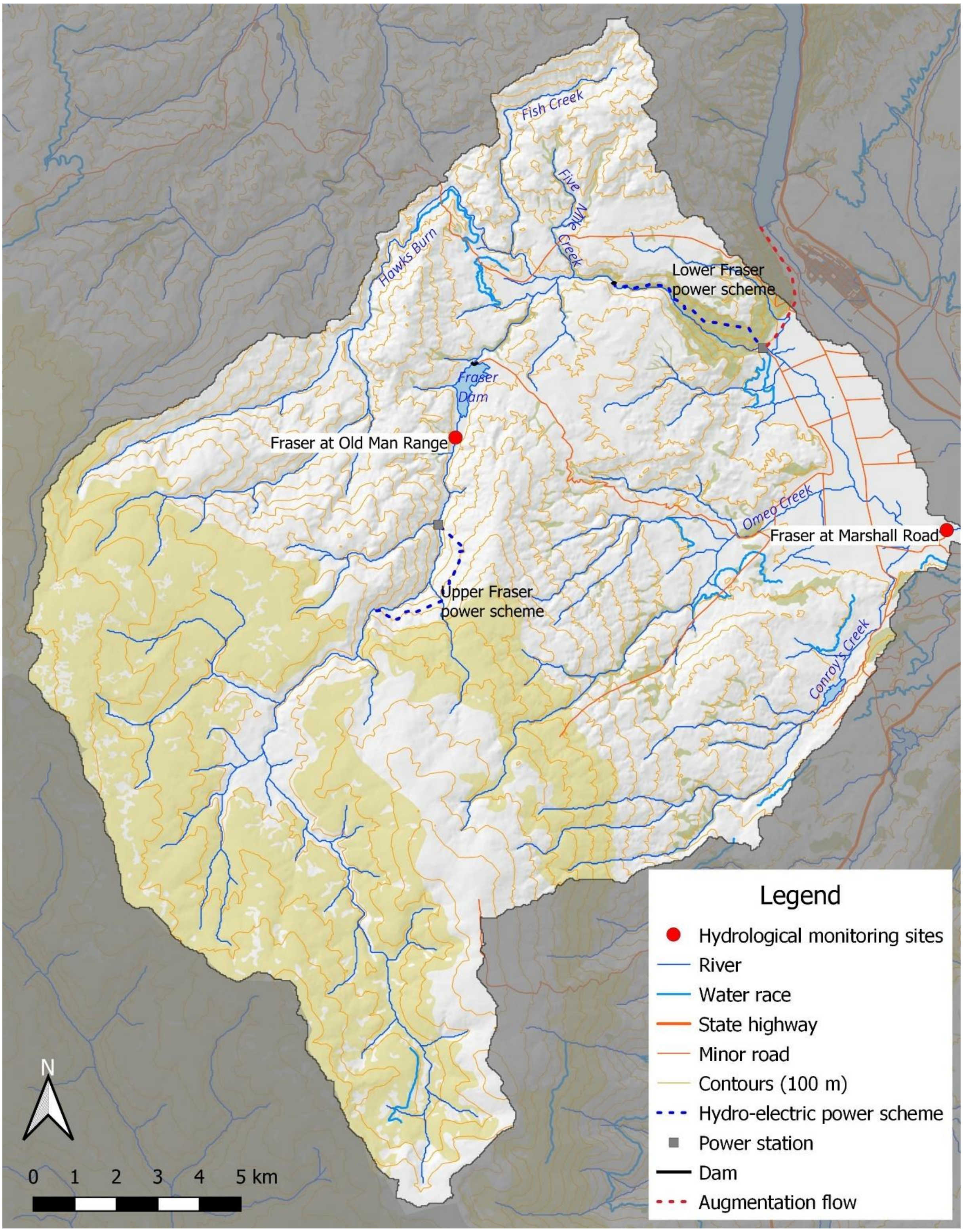

Figure 1 Map of the Fraser catchment showing flow recorder sites.

2. Background information

2.1. Catchment description

The Fraser catchment (327 km^2) flows from the faces of the Old Man Range/ Kōpūwai, Old Woman and Obelisk Ranges and into Fraser Dam, then into a steep gorge and onto the Earnscleugh flats before entering the Clutha/Mata-Au opposite the township of Alexandra. The lower reaches of the Fraser River are adjacent to the Earnscleugh Tailings, a remnant of gold mining between the 1860s to 1963. More recently, L&M Mining Ltd mined an area of up to 255 ha on Earnscleugh Flat.

2.1.1. Climate

The climate within the Fraser catchment is classified as either 'cool-dry' (mean annual temperature <12°C, mean annual effective precipitation ≤500 mm) or 'cool-wet' (mean annual temperature <12°C, mean annual effective precipitation 500-1500 mm) (River Environment Classification, Ministry for the Environment & NIWA, 2004). There is a strong gradient in rainfall within the catchment, with more than a metre of rain falling in the higher elevation areas on the Old Man Range, while median annual rainfall in the lower catchment is as low as 350-400 mm (Figure 2). Mean annual rainfall at the nearby Alexandra climate station is 363 mm, with the greatest rainfall in summer months (13 mm in January and December) and lowest rainfall (5-6 mm) between July and September (Macara 2015).

Mean monthly air temperatures at Alexandra are 17°C in summer (December-February), with an average of seven days per year with a maximum temperature exceeding 30°C and 35 days exceeding 25°C (Macara 2015). The highest air temperature recorded in Otago was 38.7°C at Alexandra on 5 February 2005 (Macara 2015). In contrast, mean monthly air temperatures at Alexandra in winter are 3°C (June-July), with a lowest temperature recorded of -11.7°C and an average of 86 days per year with a minimum temperature of less than 0°C (Macara 2015). High summer temperatures and low rainfall results in high soil moisture deficits in the Alexandra area (Macara 2015).

Solar radiation varies markedly annually from 21.7 MJ/m^2/day in December to 4.1 MJ/m^2/day in June (Macara 2015).

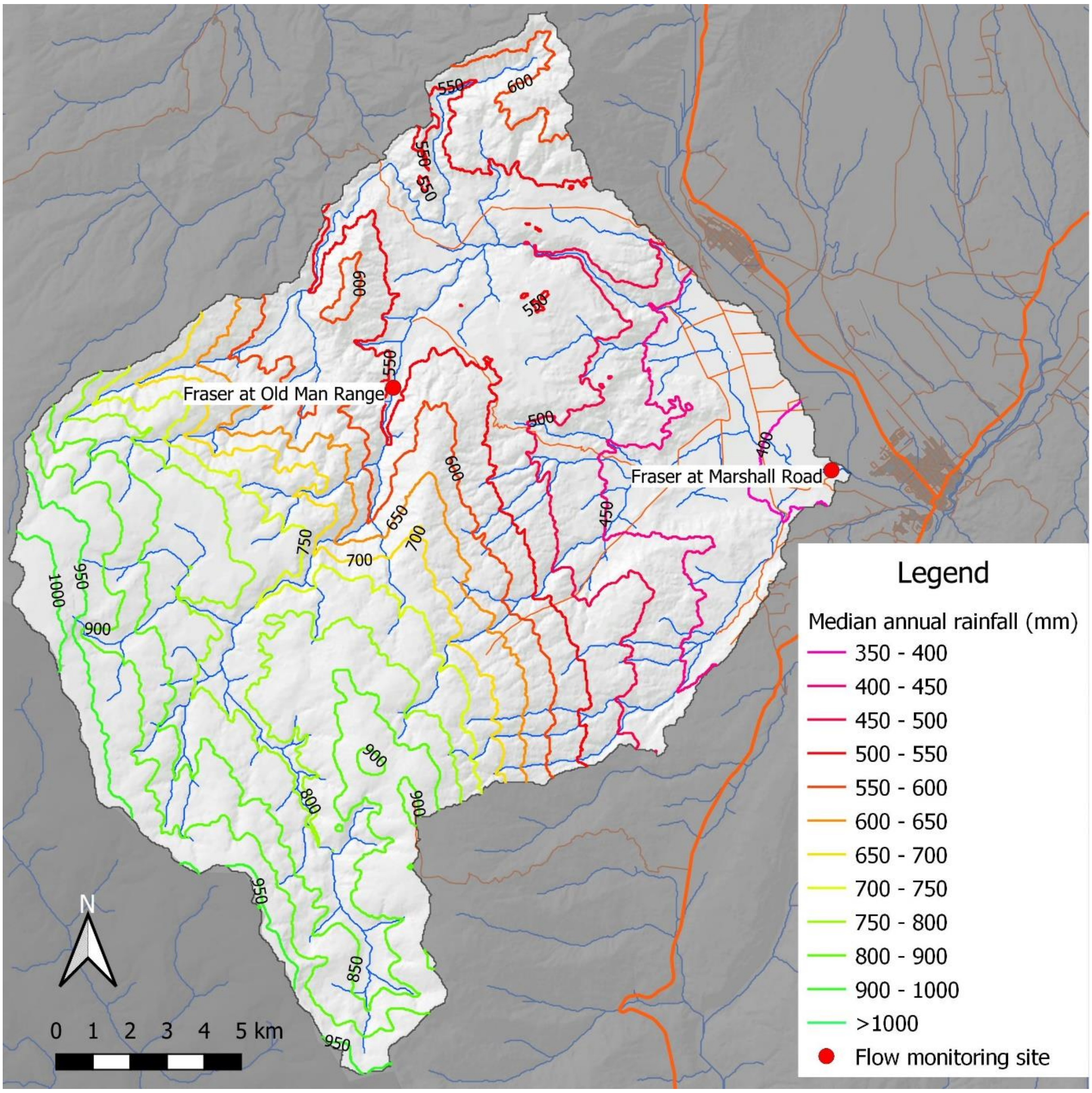

Figure 2 Distribution of rainfall (annual median rainfall) in the Fraser catchment.

2.1.2. Geological setting

Much of the Fraser catchment is underlaid by schist (both Rakaia and Caples terrane) with small pockets of mudstone (Bannockburn formation) (Turnbull 2000). The Earnscleugh Flats consist of quaternary gravels of various ages (<245,000 years ago) over conglomerate (Maniototo formation) and mudstone (Bannockburn formation) (Turnbull 2000).

2.1.3. Vegetation and land use

The vegetation of the upper Fraser catchment is mostly alpine grass and herb field, extensively grazed tussock grasslands and pasture, while land use in the lower catchment is dominated by orchards and cropping. (Figure 3).

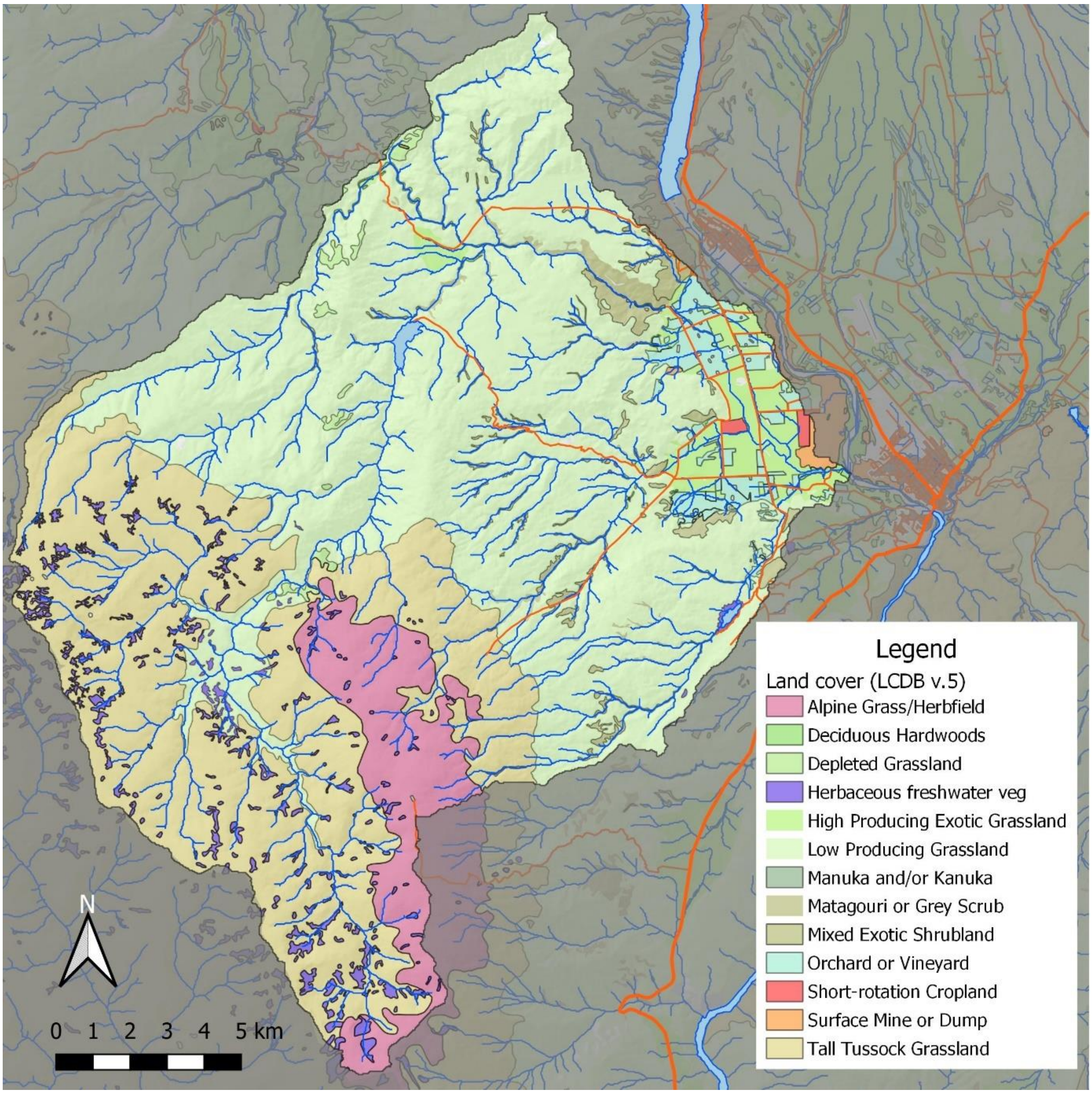

Figure 3 Land cover in the Fraser catchment based on the land cover database (version 5).

3. Regulatory setting

3.1. Regional Plan: Water (RPW)

Policy 6.4.2 of the RPW, defines the primary allocation limit as the greater of: (a) That specified in Schedule 2A, but where no limit is specified in Schedule 2A, 50% of the 7-day mean annual low flow; or (b) The sum of consented maximum instantaneous, or consented 7-day, takes of surface water and connected groundwater. Schedule 2A of the RPW does not specify a primary allocation limit for the Fraser catchment. The 7-d mean annual low flow for the Fraser River is estimated to be 598 l/s giving an allocation of 299 l/s (Section 4.3). However, net consented allocation in the Fraser catchment is 1,253 l/s[1]. Given that Policy 6.4.2 specifies the allocation limit is the greater of 50% of the 7-day mean annual low flow; or the sum of consented maximum instantaneous, or consented 7-day, takes of surface water and connected groundwater, the current allocation limit for the Fraser catchment is 1,253 l/s.

3.2. Proposed Land and Water Plan

The ORC is undertaking a full review of the RPW, and the results of this review will be incorporated into a new Land and Water Regional Plan (LWRP). As part of consultation for the LWRP, objectives have been developed for the Clutha Mata-Au Freshwater Management Unit (FMU), which is further sub-divided into 5 Rohe: Upper Lakes, Dunstan, Manuherekia, Roxburgh and Lower Clutha. The Fraser River is within the Roxburgh Rohe. The proposed objectives for the Roxburgh Rohe, valid at the time of writing, are presented in Table 1. For the sake of brevity, only objectives that apply to flowing water bodies are shown.

[1] The total of maximum take is 4,353 l/s minus the 3,100 l/s augmented from Lake Dunstan discharged into Fraser River

Table 1 Possible environmental outcomes for the values identified in the Roxburgh Rohe and their attributes and target attributes.

Value	Narrative outcome statement	Attribute	Target attribute state
Ecosystem health – (all biophysical components)	Freshwater bodies within the Roxburgh rohe support healthy ecosystems with thriving habitats for a range of indigenous species, and the life stages of those species, that would be expected to occur naturally. This is achieved where the target attribute state for each biophysical component (as set in table) are reached.		
		Periphyton - mg chl-*a*/m^2	B
		Fish - Fish index of biotic integrity (F-IBI)	B
		Macroinvertebrates - Macroinvertebrate Community Index (MCI) score; Quantitative Macroinvertebrate Community Index (QMCI) score	B
		Macroinvertebrates - Macroinvertebrate Average Score Per Metric (ASPM)	B
EH – Water quality		Ammonia (toxicity) mg NH_4-N/L (milligrams ammoniacal-nitrogen per litre)	A
		Nitrate (toxicity) - mg NO_3 – N/L (milligrams nitrate-nitrogen per litre)	A
		Suspended fine sediment - Visual clarity (metres)	B
		Dissolved oxygen - mg/L (milligrams per litre)	A
		Dissolved reactive phosphorus - DRP mg/L (milligrams per litre)	A
EH - Habitat		Deposited fine sediment - % fine sediment cover	A
EH – Ecological processes		Ecosystem metabolism (both gross primary production and ecosystem respiration) - grams of dissolved oxygen per square metre per day	B
EH – Water quantity		Under development – awaiting national guidance	Not applicable
Human contact	Water bodies within the Roxburgh rohe are clean and safe for human contact activities.	*Escherichia coli* (*E. coli*) – *E. coli*/100 mL	A
		Cyanobacteria (planktonic) - Biovolume mm^3/L	A
		E. coli (primary contact sites) – 95th percentile of *E. coli*/100 mL	A
		Phytoplankton mg chl-*a*/ m^3	B
		Suspended fine sediment - Visual clarity (metres)	A

Table 1 Possible environmental outcomes for the values identified in the Roxburgh Rohe and their attributes and target attributes.

Fishing	For parts of the Roxburgh rohe valued for fishing, the numbers of fish are sufficient and safe to eat.	Key attributes include those identified for Ecosystem Health (all biophysical components) and Human Contact	See target attribute states for ecosystem health and human contact above
Animal drinking water	Water from water bodies within the Roxburgh rohe is safe for the reasonable drinking water needs of stock and domestic animals.	Key attributes include those identified for Ecosystem Health (all biophysical components) and Human Contact	See target attribute states for ecosystem health and human contact above
Cultivation and production of food and beverages and fibre	After the health and wellbeing of water bodies and freshwater ecosystems and human health needs are provided for, water bodies within the Roxburgh rohe can provide a suitable supply of water for the cultivation and production of food, beverages and fibre.		
Commercial and industrial use	After the health and wellbeing of water bodies and freshwater ecosystems and human health needs are provided for, water bodies within the Roxburgh rohe can still provide a suitable supply of water for commercial and industrial activities.		
Drinking water supply	Source water from waterbodies within the Roxburgh rohe is safe and reliable for the drinking water supply needs of the community.	Key attributes include those identified for Ecosystem Health (all biophysical components) and Human Contact	See target attribute states for ecosystem health and human contact above
		Source water (after treatment) capable of meeting NZ Drinking water standards	
Natural form and character	Water bodies and riparian margins within the Roxburgh rohe can behave in a way that is consistent with their natural form and character.	Key attributes include those identified for Ecosystem Health (all biophysical components) and Human Contact	See target attribute states for ecosystem health and human contact above
		Other attributes under development	Not applicable

Table 1 Possible environmental outcomes for the values identified in the Roxburgh Rohe and their attributes and target attributes.

Threatened species	The Roxburgh rohe supports self-sustaining populations of threatened species.	Under development (Possible attributes based on presence, abundance, survival, recovery, habitat conditions)	Not applicable
Wetlands	Wetlands within the Roxburgh rohe are resilient and support a diversity of habitats.	Under development	Not applicable
Hydro-electric power generation	After the health and wellbeing of water bodies and freshwater ecosystems and human health needs are provided for, water bodies within the Roxburgh rohe can support low impact hydro-electric generation.		

4. Hydrology

4.1. Catchment description

The headwaters of the Fraser River arise as low-gradient streams at high altitudes (>1600 m a.s.l) on the Old Man Range/Kōpūwai before flowing into steep gorges upstream and downstream of Fraser Dam, then onto the Earnscleugh flats before entering the Clutha/Mata-Au opposite the township of Alexandra (Figure 1). Given the strong rainfall gradient in the catchment (Figure 2) and tussock vegetation cover (Figure 3), water yields in high altitude areas are expected to be much greater than in low-altitude areas.

Flows in the lower reaches of Fraser River are augmented with up to 3,100 l/s from Lake Dunstan by the Earnscleugh Irrigation Company (RM18.266.01). Resource Consent RM18.266.02 allows the abstraction of the augmented flows at six locations between the Pioneer Energy power station at Strode Road (1309581E 4987530N) and a location approximately 1 km downstream of Laing Road (1311658E 4984928N) and requires a residual flow of 1,000 l/s to be maintained downstream of all of these take points. Given that there are no surface water takes downstream of this point (1 km downstream of Laing Road), this effectively means that a flow of at least 1,000 l/s is maintained in the Fraser River to its confluence with the Clutha/Mata-Au.

4.2. Hydro-electric Power Generation

The hydrology of the mainstem of the Fraser River is modified by the operation of two hydro-electric power schemes as well as the flow augmentation from Lake Dunstan (Resource Consent RM18.266– see Section 4.3.2). The hydrology of approximately 17 km of the upper river is unmodified (40% of the total length of the mainstem) upstream of the intake to the Upper Fraser Power Station (Table 2; Figure 5). A 3.2 km long reach (8%) between the intake and outflow of the Upper Fraser Power Station is subject to a residual flow of 390 l/s, with up to 2,000 l/s diverted out of this reach before being discharged back into the river approximately 2.8 km upstream of Fraser Dam (Figure 5). The hydrology of the reach below the outflow from this scheme is expected to be close to natural.

Downstream of Fraser Dam, water is released episodically into the river to flow 4.7 km to a weir, where up to 2,000 l/s is taken into a 4.5 km pipeline, before flowing through steel penstocks to the Fraser River Power Station (Table 2; Figure 5). There is no residual flow required to be maintained downstream of Fraser Dam, and historically this section could be dry (Figure 4; Figure 5). A residual flow of 50 l/s is maintained between the Fraser Weir and the Fraser River Power Station (Figure 5). The reach downstream from the Fraser River Power Station to the confluence with the Clutha/Mata-Au is affected by hydropeaking[2] as well as being augmented with flows from Lake Dunstan (RM18.266.01 – see Section 4.3.2) (Figure 5). Therefore, the hydrology of much of the Fraser River catchment is highly modified by a combination of hydro-electric power generation and abstraction for

[2] Hydropeaking refers to the practice of generating hydro-electric power at times when the electricity spot-price is high. Thus, water is stored during times when the spot-price is low, and water is used to generate electricity when prices are high, meaning that flows downstream of the power station fluctuate markedly through the day.

irrigation (20.9 km), with only the upper reaches (19.6 km, 47% of the length of the mainstem) having relatively unmodified hydrology (Table 2).

Table 2 Description of distinct hydrological reaches in the Fraser River affected by hydro-electric power generation activities

Reach	Description	Length (km)
Upper reach	Natural	16.8
Upper Fraser Power Station residual reach	Take of up to 2,000 l/s, residual flow (390 l/s)	3.2
Upper Fraser Power Station to Fraser Dam	Downstream of Upper Fraser Power Scheme, but close to natural	2.8
FRASER DAM		1.3
Fraser Dam to intake weir	Downstream of Fraser Dam. Hydropeaking, no residual flow	4.7
Intake weir		0.3
Intake weir to lower discharge point	Downstream of intake weir, residual flow (50 l/s)	4.6
Downstream lower discharge point to Clutha confluence	Downstream of lower discharge point and augmentation, hydropeaking and 1,000 l/s residual flow	8.4

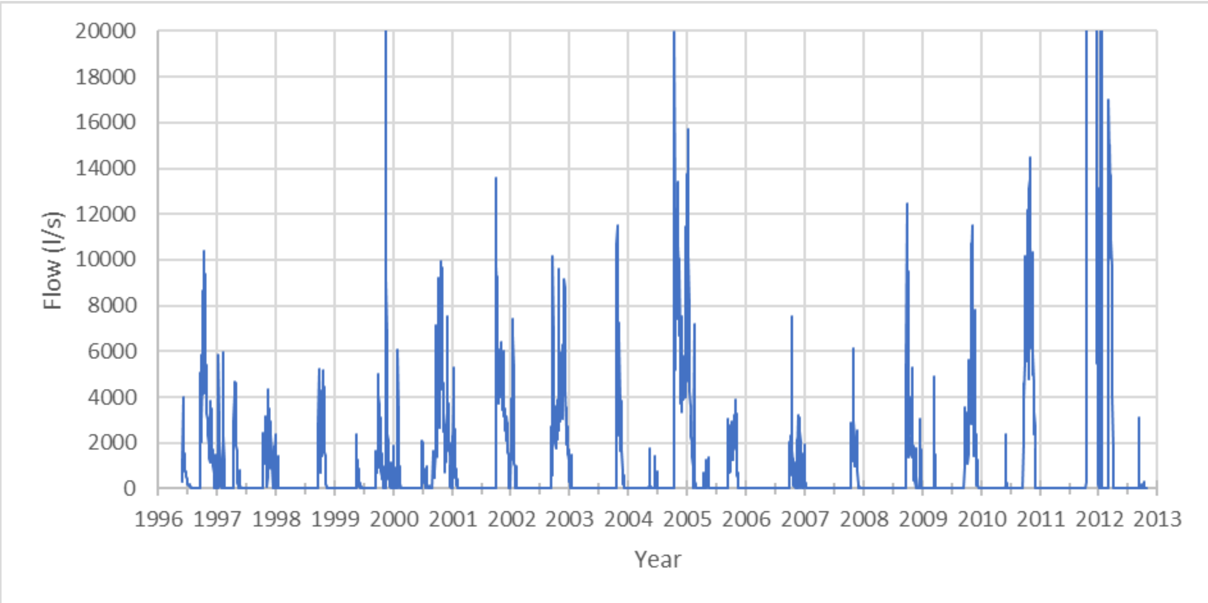

Figure 4 Observed flows immediately below the Fraser Dam between 29 May 1996 and 25 October 2012.

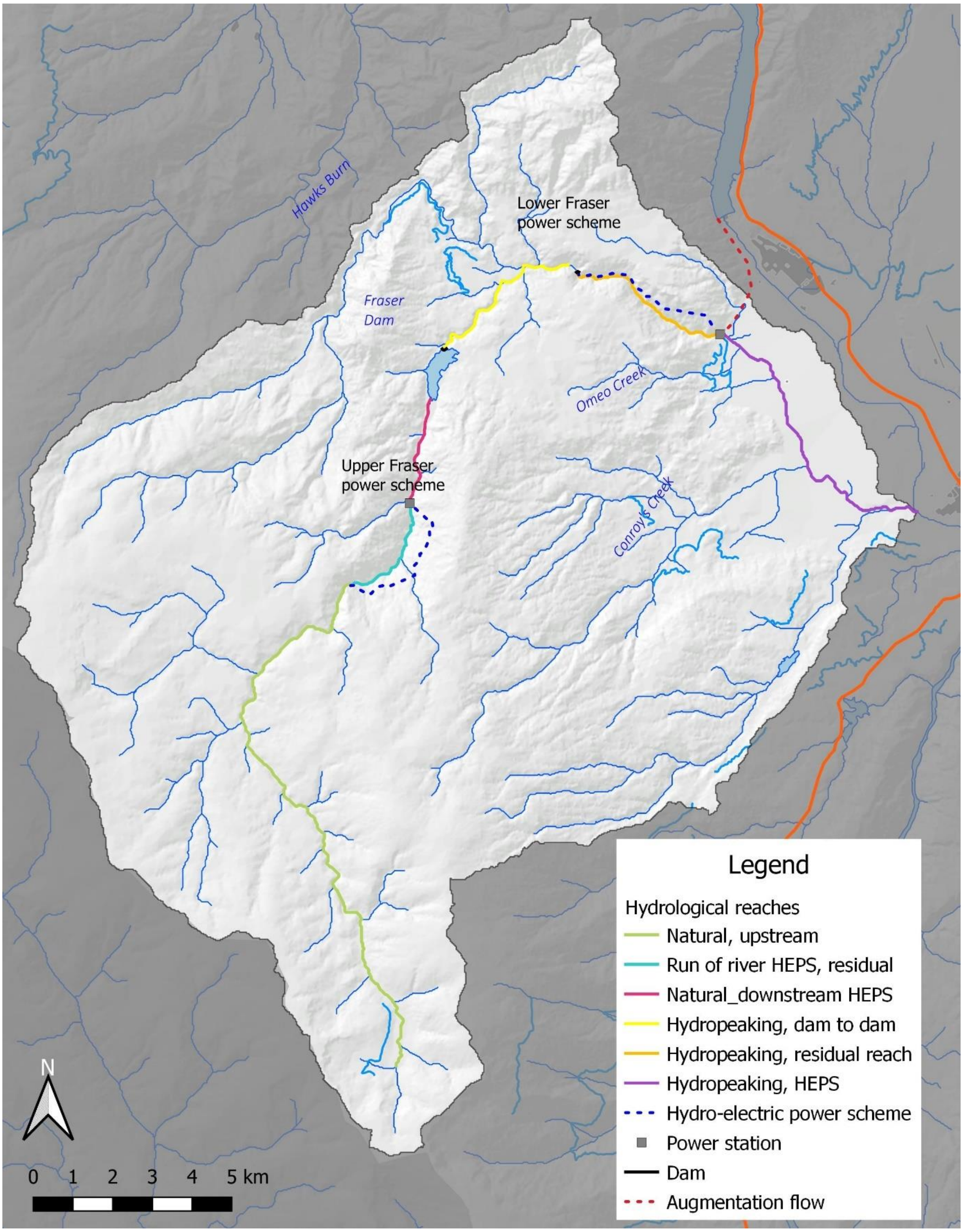

Figure 5 Hydrological reaches within the mainstem of the Fraser River showing the different effects of the operation of hydro-electric power schemes (HEPS) and flow augmentation.

4.3. Flow statistics

A continuous flow recorder was installed in the Fraser River upstream of Fraser Dam (Fraser at Old Man Range) between 1969 and 1994 and was re-established in 2016 and is still in operation at the time of writing. A site in the lower reaches of the Fraser River at Laing Road was operated by NIWA between 19 January 1984 and January 1994.

The flow statistics based on flow data collected from the upper Fraser River at Old Man Range and a regional hydrological model developed by Friedel *et al*. (2023) for the Fraser at Marshall Road are summarised in Table 3.

Table 3 Flow statistics for hydrological sites in the Fraser River from a regional hydrological model developed by Friedel *et al*. (2023).

Site	Type	Flow statistics (l/s)		
		Mean	Median	7d MALF (Jul-Jun)
Fraser at Old Man Range	Natural flows	2,113	1,297	496
Fraser at Marshall Road	Modelled natural flows	2,332		598

Flows in the Fraser River are highest between September and December as a result of snowmelt and spring rainfall events, while lowest flows typically occur in mid-winter and late summer/autumn (Figure 6).

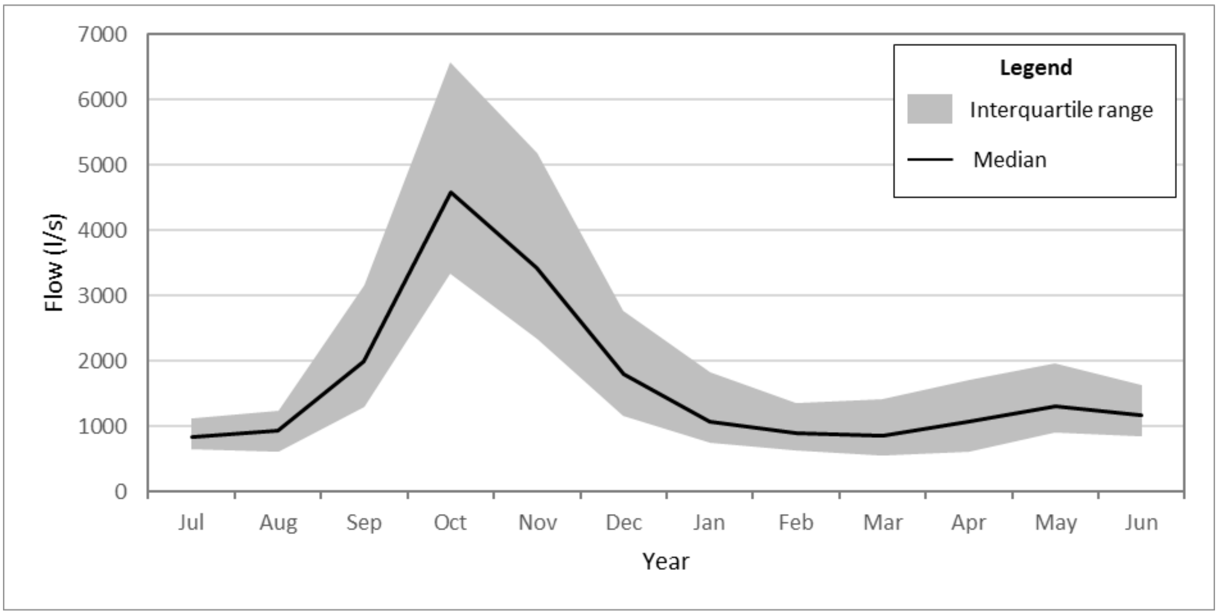

Figure 6 Seasonal variation in flows in the Fraser River at Old Man Range.

Flow events that exceed three times the median flow (FRE3) are generally considered to be large enough to reduce periphyton biomass and cover and are referred to as flushing flows. However, the presence of Fraser Dam is likely to reduce the frequency of flushing flows in the Fraser River. Approximately 38% of the Fraser catchment is upstream of Fraser Dam, which will capture flushing flows that occur when the dam is below its maximum operating level (c.545 m a.s.l.). In addition, given the high degree of hydrological modification downstream of Fraser Dam, including flow fluctuations associated with hydro-peaking and flow augmentation by Earnscleugh Irrigation Company, it is difficult to determine what flushing flows would be required to reduce periphyton biomass in the lower reaches of Fraser River.

4.3.1. Historical flows

A flow site was operated in the lower Fraser River at Laing Road between January 1984 and January 1994. Over this period, flows recorded at the Old Man Range hydrological monitoring site (natural hydrology) were markedly higher than those at the Laing Road flow monitoring site (Figure 7). The 7-d MALF (9 January 1984 – 30 June 1993) was 1 l/s at Laing Road, compared with 678 l/s at the Old Man Range site upstream. Over the same period, the maximum number of consecutive days in the irrigation season (October-April) where the measured flow in the Fraser River at Laing Road was zero ranged from zero (1985/86) to 100 days (1989/1990), although the average was 27 days. This suggests that historically, the exercise of deemed permits resulted in the lower reaches of the Fraser River drying, with this drying lasting for several weeks in dry seasons. In contrast, over this same time period, the lowest flows recorded at Fraser at Old Man Range was 231 l/s (29 March 1990).

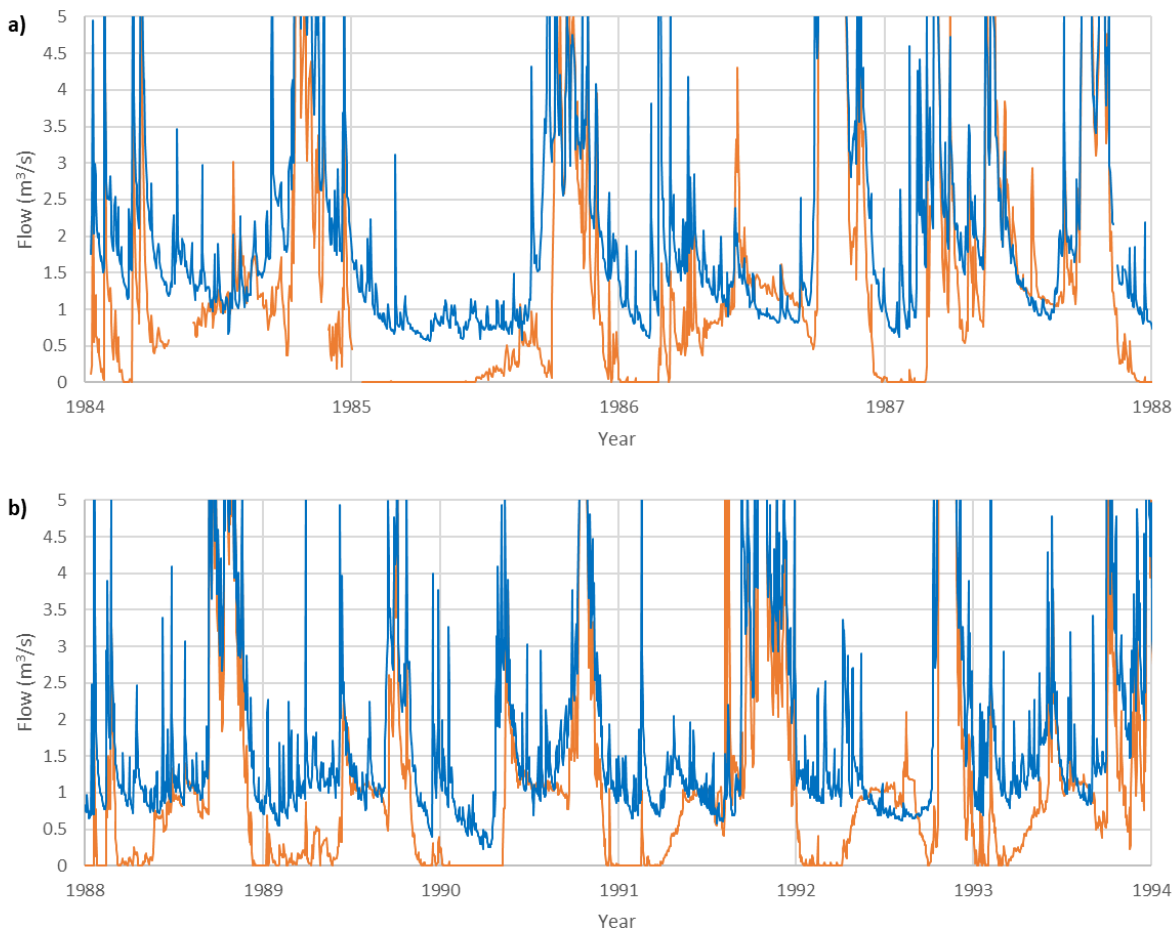

Figure 7 Observed flows in the Fraser River at Old Man Range (blue line) and Fraser River at Laing Road (orange line) between a) 1984 and 1987, and b) 1988-1993.

4.3.2. Water allocation & use

Primary allocation

There are nine resource consents for primary water takes from the Fraser catchment. Of these, there are two non-consumptive takes from the upper Fraser upstream of Fraser Dam (one for gold mining, another for run-of-the-river hydro-electric generation) and one non-consumptive take from the middle reaches of the Fraser River (hydro-electric generation) (**Error! Reference source not found.**). There is one consumptive take from the Hawks Burn, two consumptive takes from the Omeo Creek sub-catchment, and two consumptive takes from the Conroys Creek catchment (**Error! Reference source not found.**). The consents held by Earnscleugh Irrigation Company (RM18.266), include the augmentation of the lower reaches of the Fraser River with up to 3,100 l/s from Lake Dunstan (**Error! Reference source not found.**).

The net allocation in the Fraser catchment is the sum of the consumptive take (4,353 l/s) minus the augmentation flow from Lake Dunstan (3,100 l/s), which is 1,253 l/s (**Error! Reference source not found.**). Of this, 223.9 l/s is from the Omeo Creek catchment and 293 l/s is from the Conroy's Creek catchment, meaning that the net allocation from the lower Fraser River is 653 l/s (**Error! Reference source not found.**).

Table 4 Active resource consents in the Fraser catchment.

Consent #	Max. instant. Take (l/s)	Daily volume	Monthly volume	Annual Volume	Waterway	Purpose
RM12.061.03*	18	520			Upper Fraser	Gold mining
RM14.069.01*	2,000				Upper Fraser	Hydro-electric generation
RM20.084.01	83.3		216,000	2,357,816	Hawks Burn	Irrigation, stock water, orchard use, frost fighting and domestic purposes
2001.650*	2,000				Middle Fraser	Hydro-electric generation
RM18.266.02	3,753	324,259.2	6,355,914	32,133,514	Lower Fraser	Irrigation
RM21.168.01	13.9		27594	170655	Omeo (Coal Creek)	Irrigation, stock water supply and domestic use
RM19.282.01	210	18,144	6,355,914	32,133,514	Omeo (Omeo Ck)	Irrigation, frost fighting, sunburn protection and domestic purposes
RM19.281.09	28		72,000	471,407	Conroys	Irrigation, stock water, orchard use, frost fighting and domestic purposes
RM19.281.05	265		640,317	4,598,000	Conroys	Irrigation, stock water, orchard use, frost fighting, and hydroelectric power generation
RM18.266.01†	3,100				Lake Dunstan	Supplementing flows in the Fraser River

* Considered to be non-consumptive for the purposes of calculating catchment allocation

† To augment flows in the lower Fraser – this discharge off-sets the take under RM18.266.01

Available water take data for the Fraser catchment suggests that actual water use is markedly lower than the combined maximum rate of take authorised by the water permits (1,253.23 l/s), with the actual maximum instantaneous rate of take being approximately 540 l/s (Figure 8). The available water take data shows that peak demand typically occurs during between October and March (Figure 8).

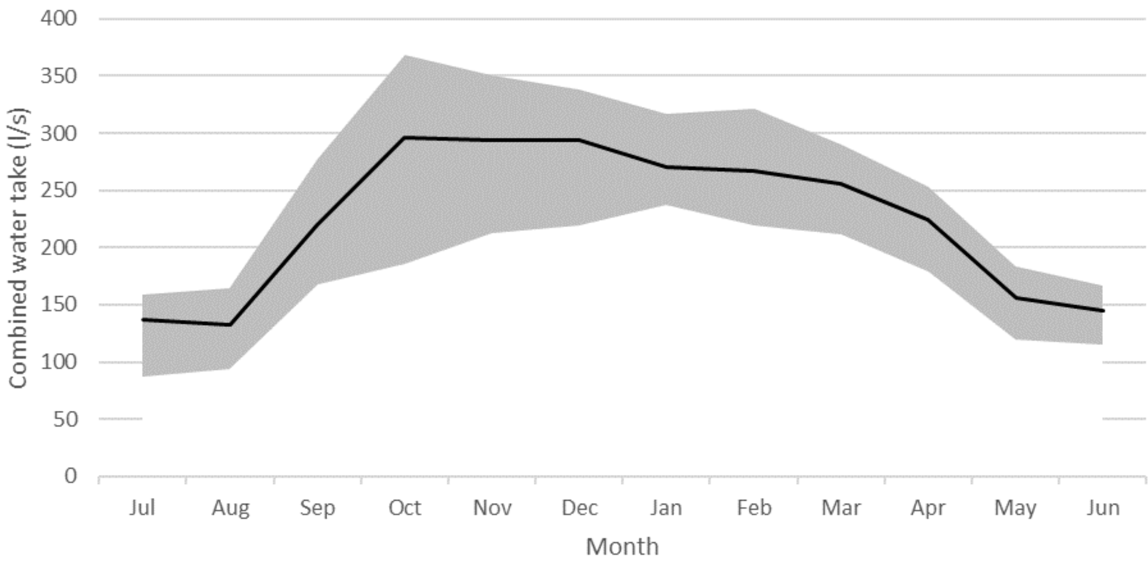

Figure 8 Combined water take in each month based on water use records (2012-2023). The grey area is the interquartile range, while the black line is the monthly median combined water take.

5. Water temperature

Water temperature is a fundamental factor affecting all aspects of stream systems. It can directly affect fish populations by influencing survival, growth, spawning, egg development and migration. It can also affect fish populations indirectly, through effects on physicochemical conditions and food supplies (Olsen et al., 2012). Of all the fish in the Fraser catchment, brown trout (*Salmo trutta*) are likely to be the most sensitive to high water temperatures. Their thermal requirements are relatively well understood, and Todd *et al*. (2008) calculated acute and chronic thermal criteria for both of these species. The objective of acute criteria is to protect species from the lethal effects of short-lived high temperatures. In this case, acute criteria are applied as the highest two-hour average water temperature measured within any 24-hour period (Todd et al., 2008). In contrast, the intent of chronic criteria is to protect species from sub-lethal effects of prolonged periods of elevated temperatures. In this study, chronic criteria are expressed as the maximum weekly average temperature (Todd et al., 2008).

Water temperature data is available for the upper Fraser River (Fraser at Old Man Range) between 5 September 2016 and 16 January 2023 (Figure 9). These data are based on data recorded by flow monitoring equipment at 5-minute intervals. In addition, water temperature is measured using a hand-held meter during monthly water quality monitoring and these handheld measurements verify the accuracy of the continuous data (linear regression: a = 0.0749, b = 0.978, R^2=0.997).

Water temperatures in the upper Fraser River were within acute and chronic thermal criteria for brown (Figure 9). Most indigenous fish species with available thermal tolerance data are more tolerant of high temperatures than trout (Olsen et al. 2012). Of the indigenous species present in the Fraser catchment, the common mayfly *Deleatidium* is probably the most sensitive taxon, with an interim acute criterion of 21°C (Olsen et al. 2012). However, water temperatures in the lower Fraser River were well within these criteria (Figure 9).

These data suggest that thermal environment of the upper Fraser River is suitable for all the indigenous and introduced fish species found in the catchment. Water temperature data was not available for the lower Fraser River.

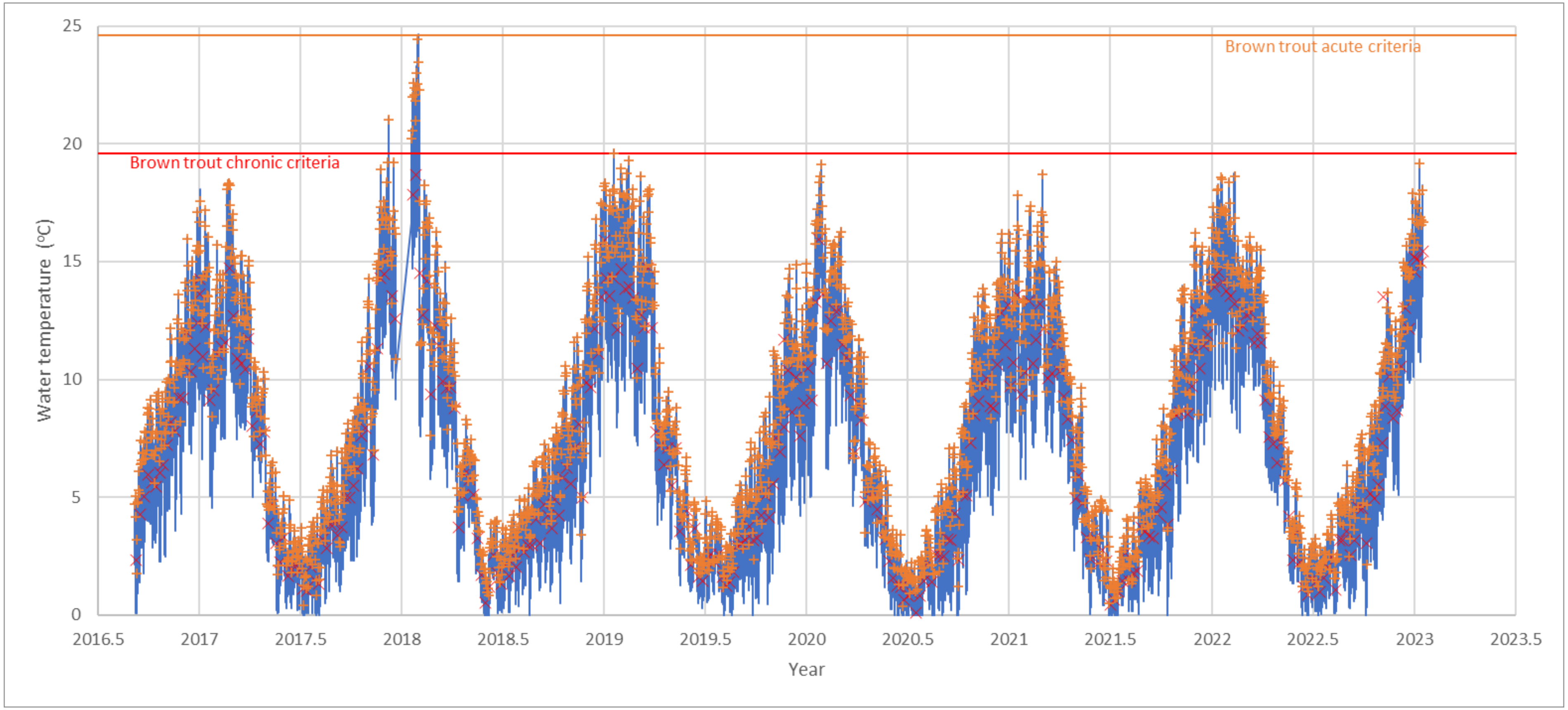

Figure 9 Water temperature in the upper Fraser River (Fraser at Old Man Range) between 2016 and January 2023. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red crosses are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.

6. The aquatic ecosystem of the Fraser catchment

6.1. Periphyton

The periphyton community forms the slimy coating on the surface of stones and other substrates in freshwaters and can include a range of different types and forms. Periphyton is an integral part of the food web of many rivers; it captures energy from the sun and converts it, via photosynthesis, to energy sources available to macroinvertebrates, which feed on it. These, in turn, are fed on by other invertebrates and fish. However, periphyton can form nuisance blooms that can detrimentally affect other instream values, such as aesthetics, biodiversity, recreation (swimming and angling), water-takes (irrigation, stock/drinking water and industrial) and water quality. Some types of cyanobacteria may produce toxins that pose a health risk to humans and animals (e.g. Hamill, 2001; Wood et al., 2007). These include toxins that affect the nervous system (neurotoxins), liver (hepatotoxins), and dermatotoxins that can cause severe irritation of the skin.

Limited information is currently available on periphyton communities in the Fraser River, although the invasive stalked diatom *Didymosphenia geminata* (known as Didymo) was first identified in the Fraser River in 2006 (Otago Regional Council 2007). Fortnightly surveys of didymo biomass and cover were undertaken at four sites in the lower Fraser River between August 2006 and January 2007 and indicated that high didymo biomasses developed during low flows and that flow variability, shading and substrate composition strongly influenced didymo biomass and the cover of other periphyton types (Otago Regional Council 2007). It is thought that Didymo was introduced to the lower Fraser River in augmentation water from Lake Dunstan discharged to the Fraser River.

6.2. Macroinvertebrates

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

Macroinvertebrate samples were collected from the Fraser River at Marshall Road between 2006 and 2010. Didymo was present in the Fraser River over this period and was likely to have affected macroinvertebrate indices calculated for this site to some degree. MCI scores for this site (Range: 97-113, mean = 104, N=5), were indicative of 'poor' to 'good' habitat/water quality based on the criteria of Stark & Maxted (2004) (Figure 10a). Similarly, SQMCI scores (Range: 3.74-6.25, mean = 5.01, N=5), ranged from 'poor' to 'excellent' habitat/water quality based on the criteria of Stark & Maxted (2004), although the mean score was indicative of 'good' habitat/water quality (Figure 10b). ASPM scores (Range: 0.32 -0.51, mean = 0.45, N=5), ranged from 'mild to moderate loss of ecological integrity' to 'moderate to severe loss of ecological integrity' although the mean score was indicative of 'mild to moderate loss of ecological integrity' (based on Table 15 of the NPSFM 2020) (Figure 10c).

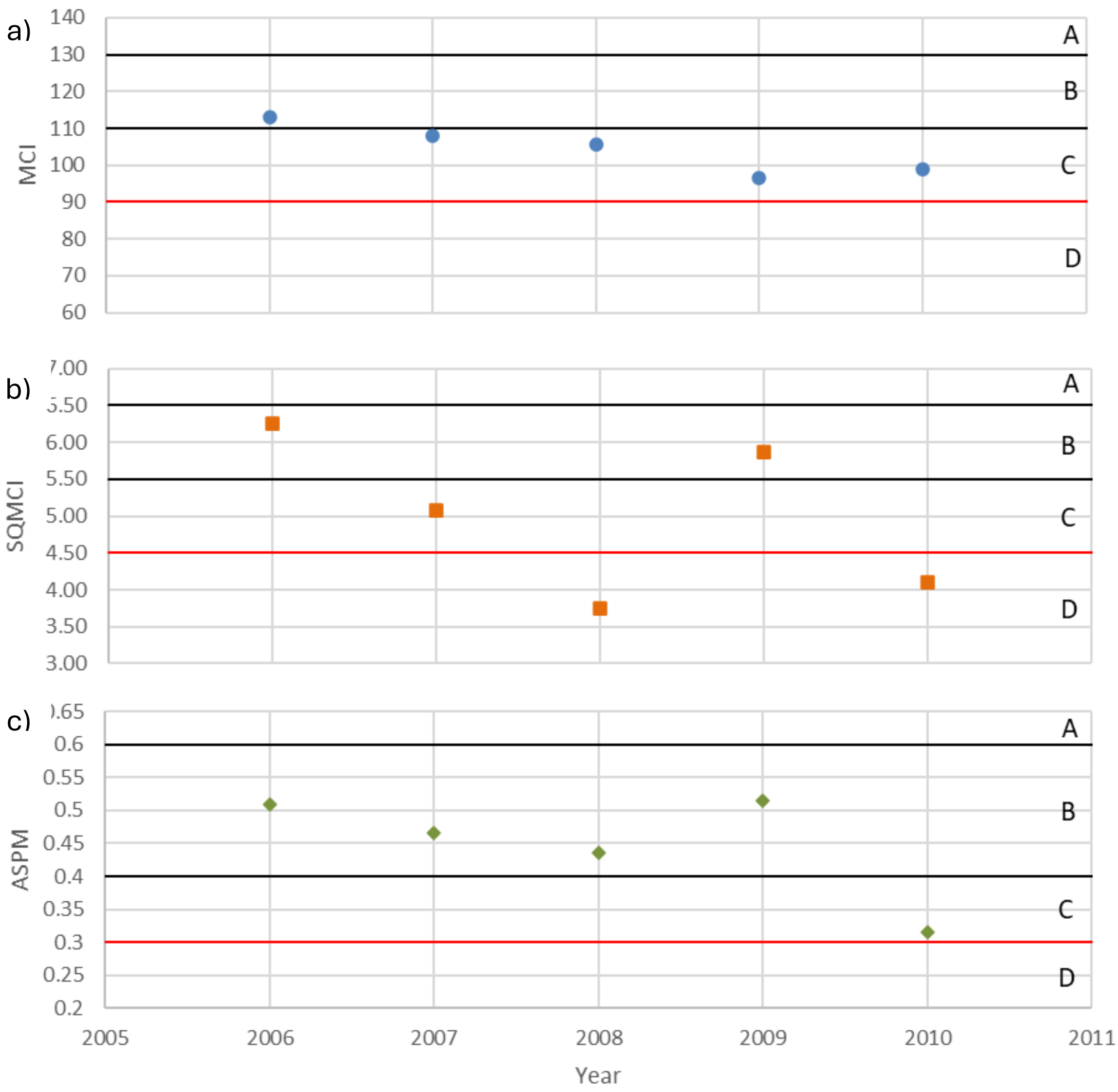

Figure 10 Macroinvertebrate indices for Fraser River at Marshall Road between 2007 and 2018. a) Macroinvertebrate community index (MCI), b) semi-quantitative MCI (SQMCI) and c) average score per metric (ASPM). Each plot includes thresholds delineated by captal letter for attribute states based on Tables 14 and 15 of the National Objectives Framework.

6.3. Fish

6.3.1. Indigenous fish

Five species of indigenous freshwater fish have been recorded from the Fraser catchment – longfin eel, lamprey, upland and common bully and kōaro (Figure 11; Table 5). Lamprey are classified as threatened – nationally vulnerable, while longfin eels and kōaro are classified as at risk – declining (Dunn et al. 2017). Upland and common bully are classified as not threatened (Dunn et al. 2017).

All five indigenous fish species have been recorded from the lower Fraser River, while common bully have also been recorded from Conroys Dam and kōaro have also been collected from Five Mile Creek (Figure 11).

6.3.2. Introduced fish

Brown trout are widespread in the Fraser catchment, including in the Conroys Creek, Fish Creek, Five Mile Creek, Hawks Burn and Omeo Creek catchment and are the only fish species recorded upstream of Fraser Dam. Rainbow trout have been recorded from the lower reaches of the Fraser River and in Omeo Creek (Figure 11). Perch have been recorded from the lower reaches of the Fraser River (Figure 11)

Little angler effort has been recorded in the Fraser catchment in the National Angler Surveys conducted in 1994/95, 2007/08 and 2014/15 (Table 6). The upper reaches are considered to be a locally significant backcountry fishery (Otago Fish & Game Council 2015). Brown and rainbow trout spawning in the lower Fraser River (below the lower Fraser Power Station) likely contributes to recruitment and juvenile rearing for the Clutha fishery to some degree, although the significance of this contribution is unknown.

Table 5 Fish species recorded from the Fraser catchment.

Family	Common name	Species	Threat classification	Subcatchments
Anguillidae	Longfin eel	*Anguilla dieffenbachii*	Declining	Lower Fraser
Eleotridae	Upland bully	*Gobiomorphus breviceps*	Not threatened	Lower Fraser
	Common bully	*Gobiomorphus cotidianus*	Not threatened	Lower Fraser, Conroys Dam
Galaxiidae	Kōaro	*Galaxias brevipinnis*	Declining	Lower Fraser, Five Mile Creek
Geotriidae	Lamprey	*Geotria australis*	Nationally vulnerable	Lower Fraser
Percidae	Perch	*Perca fluviatilis*	Introduced and naturalised	Lower Fraser
Salmonidae	Brown trout	*Salmo trutta*	Introduced and naturalised	Lower Fraser, Upper Fraser, Omeo Creek, Conroys Creek, Five Mile Creek, Fish Creek, Hawks Burn
	Rainbow trout	*Oncorhynchus mykiss*	Introduced and naturalised	Lower Fraser, Omeo Creek

Table 6 Angler effort on the Fraser River and Fraser Dam based on the National Angler Survey (Unwin, 2016)

	NAS (angler days)			
Waterway	2014/15	2007/08	2001/02	1994/95
Fraser River	150 ± 110	1380 ± 520	530 ± 390	410 ± 150
Fraser Dam	30 ± 20	270 ± 170	90 ± 70	60 ± 50

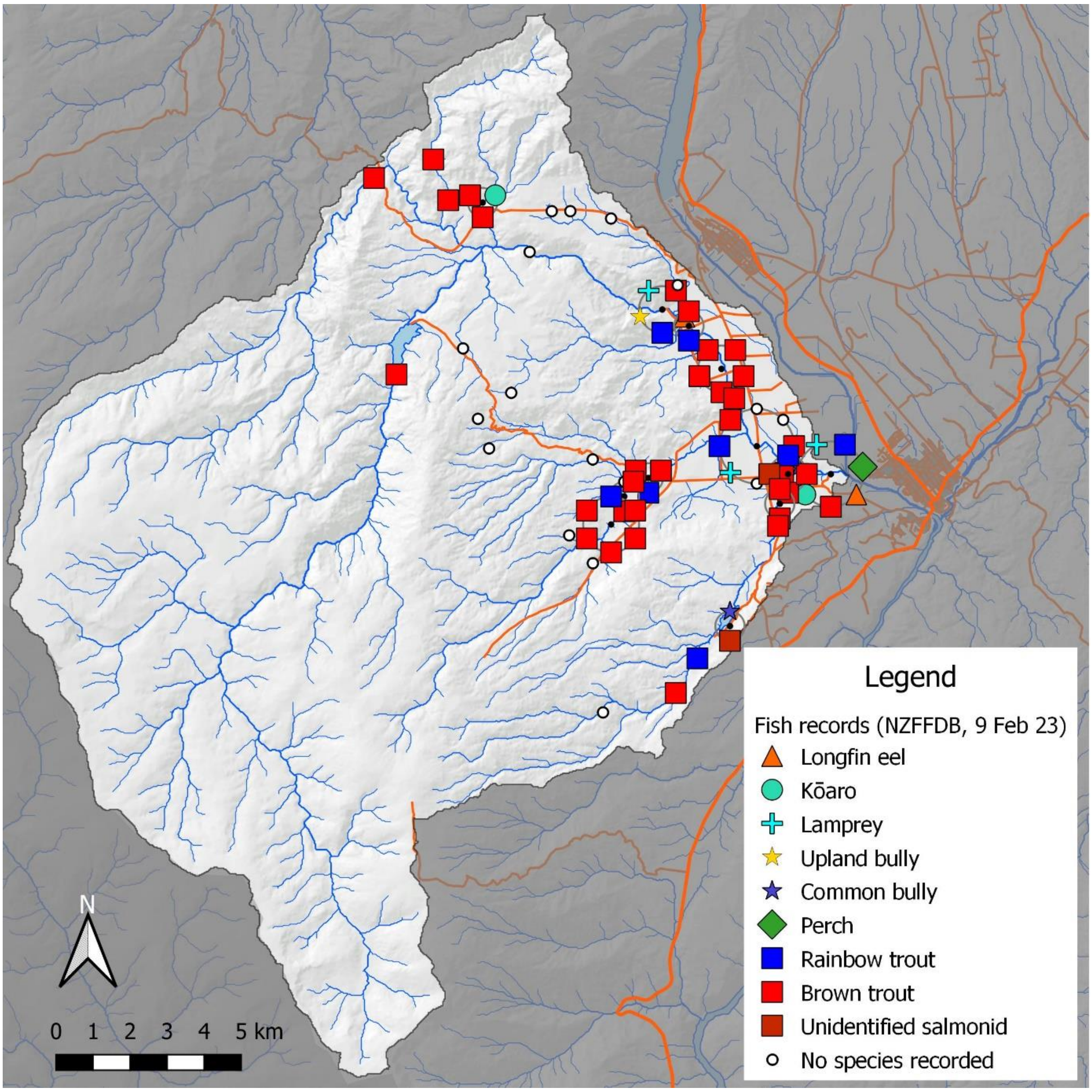

Figure 11 Fish distribution in the Fraer River/Earnscleugh catchment catchment based on records in the New Zealand Freshwater Fish Database (downloaded 9 February 2023).

6.4. Current ecological state

The current state of the Fraser River reflects the combined effects of heavy allocation pressure, hydro-electric generation and flow augmentation by Earnscleugh Irrigation Company and the presence of Didymo (see Section 6.1), all of which have been in place for many years. Comparison of the current state of the Fraser River with objectives for the Roxburgh Rohe provide insight into whether current conditions are consistent with the objectives proposed in the Land & Water Regional Plan.

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

Table 7 below.

6.4.1. Ecosystem health

In addition to the ecosystem health and human contact values identified in

Table 7, the proposed objectives for fishing, animal drinking water, cultivation and production of food and beverages and fibre, commercial and industrial use, drinking water supply are measured by the target attribute states for ecosystem health and human contact presented in

Table 7. Attributes for natural form and character and threatened species within the Roxburgh Rohe are under development, so it is not possible to consider the current state of the Fraser catchment relative to these attributes.

Table 7 presents the limited information available on the current attribute state for the Fraser River at Marshall Road and compares the current state to the proposed target attribute state for the Roxburgh Rohe. Attributes for Ecosystem Health – Aquatic life do not meet the target states for MCI and SQMCI scores (

Table 7). Macroinvertebrate community composition is affected by a range of factors including periphyton composition and biomass, predation by salmonids, water physicochemistry (e.g. water temperature, dissolved oxygen) and habitat characteristics (e.g. substrate composition, fine sediment cover). In this case, the low MCI and SQMCI scores observed in the lower reaches of the Fraser River between 2006 and 2010 are likely to reflect many factors, but the abundance of didymo at this site over the sampling period is expected to have contributed to this outcome. However, the ASPM was in B-band in most years (the exception being a score in C-band in 2010).

6.4.2. Water quality

Water quality in the upper Fraser (at the Fraser River at Old Man Range site) is very good (A-band) based on the data for the limited number of parameters available (

Table 7). Whilst water quality sampling is not currently undertaken in the lower reaches, it is expected that the water quality of the lower reaches will be heavily influenced by the water from Lake Dunstan used to augment flows in the lower reaches of the Fraser River.

Table 7 Comparison of the current attribute state in the Fraser River at Marshall Road and Old Man Range. Values at Old Man Range based on Ozanne, Borges & Levy (2023).

Value	Attribute	Target attribute state	Current attribute state	
			Fraser at Marshall Rd	Fraser at Old Man Range
Ecosystem health – (all biophysical components)				
	Periphyton - mg chl-*a*/m^2	B	Not able to be determined	-
	Fish - Fish index of biotic integrity (F-IBI)	B	Not able to be determined	-
	Macroinvertebrates - (MCI) score	B	C Mean: 104 (2006-2010)	-
	Macroinvertebrates - (QMCI) score	B	-	-
	Macroinvertebrates - (ASPM)	B	B Mean: 0.45 (2006-2010)	-
EH – Water quality	Ammonia (toxicity) mg NH_4-N/L	A	Not able to be determined	A Median: 0.005 95th percent: 0.005
	Nitrate (toxicity) - mg NO_3 – N/L	A	Not able to be determined	A Median: 0.0032 95th percent: 0.0156

	Suspended fine sediment - Visual clarity (m)	B	Not able to be determined	-
	Dissolved oxygen - mg/L	A	Not able to be determined	-
	Dissolved reactive phosphorus - DRP mg/L	A	Not able to be determined	-
EH - Habitat	Deposited fine sediment - % cover	A	Not able to be determined	-
EH – Ecological processes	Ecosystem metabolism (both gross primary production and ecosystem respiration)	B	Not able to be determined	-
Human contact	*Escherichia coli* (*E. coli*) – *E. coli*/100 mL	A	Not able to be determined	A Median: 3 95th percent: 31 % >260: 0 % >540: 0
	E. coli (primary contact sites) – 95th percentile	A	Not able to be determined	A 31
	Suspended fine sediment - Visual clarity (m)	A	Not able to be determined	-

7. Instream Habitat Assessment

Instream habitat modelling is a method that can be used to consider the effects of changes in flow on instream values, such as physical habitat, water temperature, water quality and sediment processes. The strength of instream habitat modelling lies in its ability to quantify the loss of habitat caused by changes in the flow regime, which helps to evaluate alternative flow proposals. However, it is essential to consider all factors that may affect the organism(s) of interest, such as food, shelter and living space, and to select appropriate habitat-suitability curves, for an assessment to be credible. Habitat modelling does not take a number of other factors into consideration, including the disturbance and mortality caused by flooding as well as biological interactions (such as predation), which can have a significant influence on the distribution of aquatic species.

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

Instream habitat is expressed as Reach Area Weighted Suitability (RAWS), a measure of the total area of suitable habitat per metre of stream length. It is expressed as square metres per metre (m^2/m). Another metric, the reach-averaged Combined Suitability Index (CSI) is a measure of the average habitat quality provided at a particular flow. CSI is useful when considering the effects of changes in flow regime on periphyton where it is not the overall population response that is of interest (such as for fish), but rather the percentage cover across the riverbed (such as periphyton).

7.1. Instream habitat modelling in the Fraser River

Instream habitat modelling was undertaken in a 3.5 km reach of the Fraser River between the Fraser Domain and downstream of Laing Road by Waterways (2016), with the survey flow at 1.199 l/s (19 March 2017), and calibration surveys at 0.887 l/s (2 April 2017) and 0.940 l/s (17 April 2017).

7.1.1. Habitat preferences and suitability curves

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

Table 8 Habitat suitability curves used in instream habitat modelling in the Fraser River.

Group	HSC name	HSC source
Periphyton	Cyanobacteria (*Phormidium*)	Ex Heath et al. (2013)
	Diatoms	Unpublished NIWA data
	Didymo (Waitaki)	Jowett
	Short filamentous	Unpublished NIWA data
	Long filamentous	Unpublished NIWA data
Macroinvertebrates	Food producing	Waters (1976)
	Mayfly nymph (*Deleatidium*)	Waitaki
	Net-spinning caddis fly (*Aoteapsyche*)	Jowett (1991)
	Stony-cased caddis fly (*Pycnocentrodes*)	Jowett (1991)
Indigenous fish	Longfin eel (>300 mm)	Jowett & Richardson (2008)
	Upland bully	Jowett & Richardson (2008)
	Common bully	Jowett & Richardson (2008)
Sports fish	Brown trout adult	Hayes & Jowett (1994)
	Brown trout yearling	Raleigh *et al.* (1986)
	Brown trout spawning	Shirvell & Dungey (1983)
	Juvenile trout	Wilding (2014)
	Rainbow trout (<100 mm)	Jowett & Richardson (2008)

7.2. Physical characteristics

The hydraulic component of instream habitat modelling made predictions over how water depth, channel width and water velocity will change with changes in flow (Figure 12).

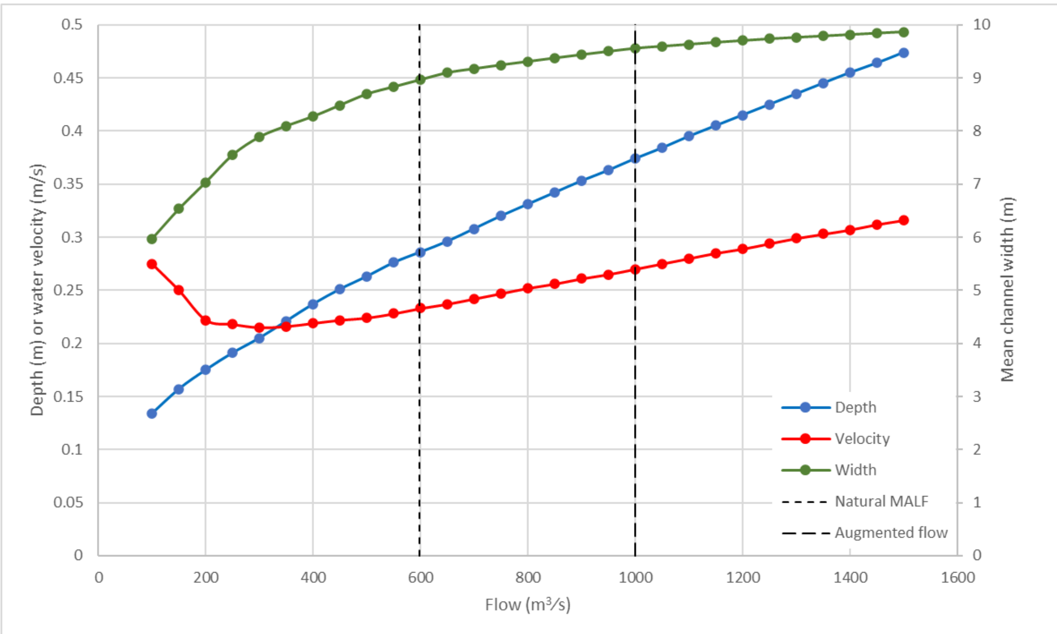

Figure 12 Changes in mean channel width, mean water depth and mean water velocity with changes in flow in the survey reach of the Fraser River.

7.3. Periphyton

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

Flow was predicted to have little effect on habitat quality for cyanobacteria (*Phormidium*) and the invasive diatom didymo, with a decline in habitat quality for both species predicted below 500 l/s (Figure 13). Habitat quality for native diatoms was predicted to be low across the modelled flow range (Figure 13). Habitat quality for short filamentous algae was predicted to increase with increasing flows to 1,400 l/s before declining at higher flows while habitat quality for long filamentous algae was predicted to be highest in the absence of flow and to decline across the modelled flow range (Figure 13).

This analysis suggests that flows below the modelled natural 7-d MALF would increase the risk of long filamentous proliferation (Table 9), with a flow of 496 l/s predicted to increase habitat suitability by 20% compared to the 7-d MALF (Figure 13).

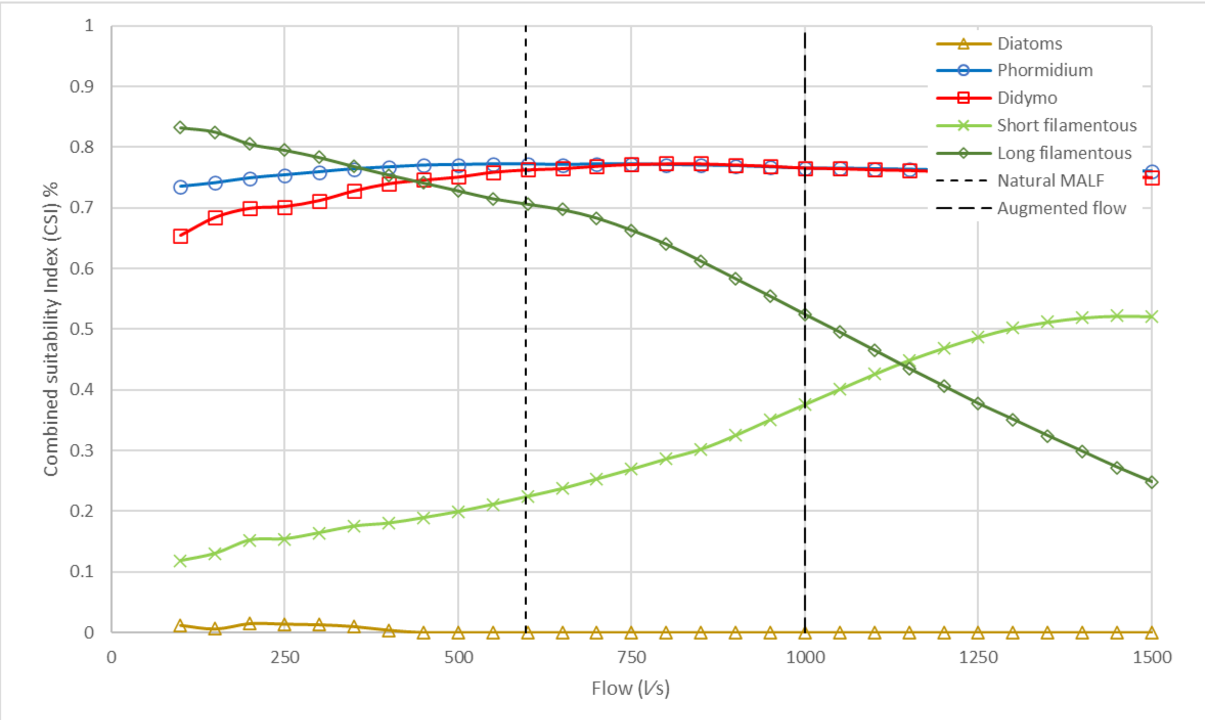

Figure 13 Variation in instream habitat quality for periphyton relative to flow in the survey reach of the Fraser River.

Table 9 Flow requirements for periphyton habitat in the Fraser River. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction).

Species	Optimum flow (l/s)	Flow at which % habitat suitability occurs (l/s)				Habitat retention at 1,000 l/s (%)
		120%	150%	200%	300%	
Cyanobacteria (*Phormidium*)	550-750	-	-	-	-	99
Diatoms	200	-	-	-	-	-
Didymo	800-850	-	-	-	-	100
Short filamentous	1,450	-	-	-	-	103
Long filamentous	<100	496	-	-	-	86

7.4. Macroinvertebrates

Food producing habitat is an overseas HSC that describes the most productive habitat conditions for macroinvertebrates. The mayfly *Deleatidium* is arguably the most abundant and widespread aquatic macroinvertebrate in New Zealand, and has been among the most abundant macroinvertebrate taxa in the lower Fraser River and habitat for *Deleatidium* was modelled for this reason. The net-spinning caddisfly *Aoteapsyche* is also widespread and can be particularly abundant in stable and productive systems (e.g. lake outlets) and has been among the most abundant macroinvertebrate taxa in the lower Fraser River. Habitat for *Aoteapsyche* is included here because the habitat preferences of this species means that it is the most flow-demanding common macroinvertebrates in New Zealand and is also a preferred food for trout. The stony-cased caddis *Pycnocentrodes* can be amongst the most common macroinvertebrate taxa in moderate to slow-moving streams and can be abundant in the Fraser River at times. It is included in habitat modelling to represent taxa that prefer slower-flowing habitats.

Food producing habitat and habitat for the common mayfly *Deleatidium* and stony-cased caddis *Pycnocentrodes* increased with flow across the modelled flow range (Figure 14). Habitat for the net-spinning caddisfly *Aoteapsyche* increased with flow up to 300 l/s, dropped between 400 l/s and 500 l/s before rising at flows above 500 l/s (Figure 14). Flows required to achieve different levels of habitat retention for each of the macroinvertebrate taxa are presented in Table 10.

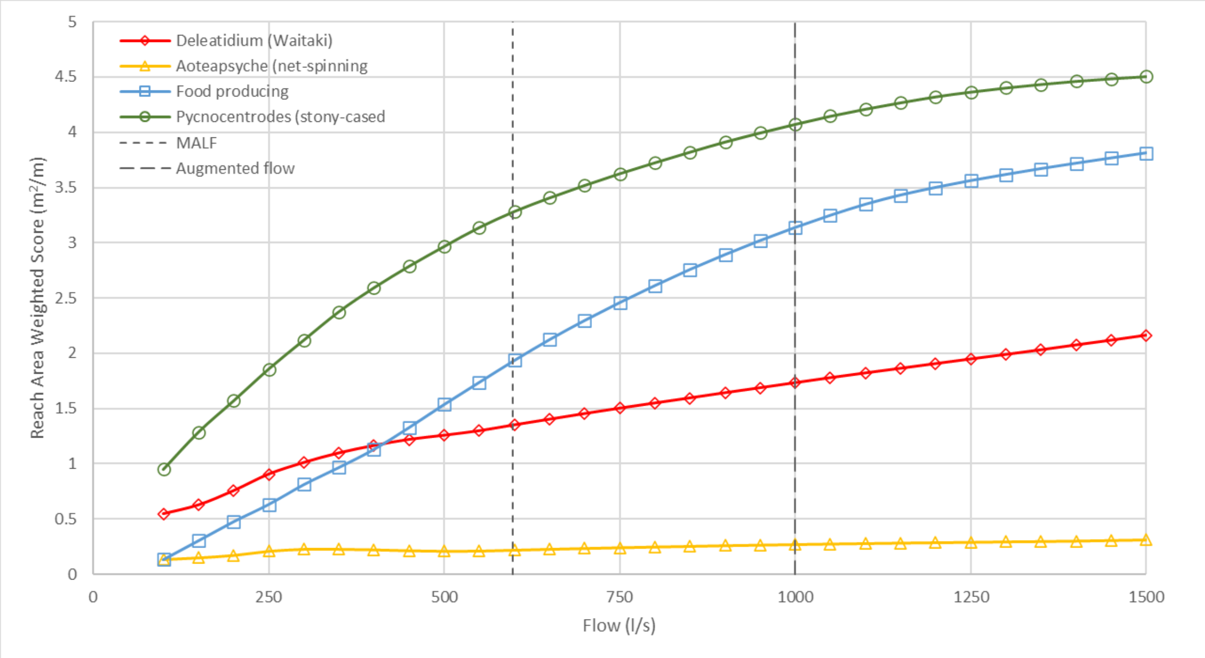

Figure 14 Variation in instream habitat for common macroinvertebrates relative to flow in the survey reach of the Fraser River.

Table 10 Flow requirements for macroinvertebrate habitat in the Fraser River. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction).

Species	Optimum flow (l/s)	Flow at which % habitat retention occurs (l/s)				Habitat retention at 1000 l/s (%)
		60%	70%	80%	90%	
Food producing habitat	>1,500	406	455	501	549	163
Common mayfly *Deleatidium*	>1,500	218	269	340	445	128
Net-spinning caddis fly (*Aoteapsyche*)	>1,500	87	154	202	233	123
Cased caddis fly (*Pycnocentrodes*)	>1,500	271	334	408	495	124

7.5. Indigenous fish

Habitat for large longfin eel (>300 mm) is predicted to increase across the modelled flow range, while habitat for small longfin eel (<300 mm) increases up to 800 l/s, before slowly declining at higher flows (Figure 14). Habitat for upland bully is predicted to be optimum at 450 l/s, while habitat declines as flows increase above this range (Figure 14). Flows required to achieve different levels of habitat retention for indigenous fish species are presented in Table 11.

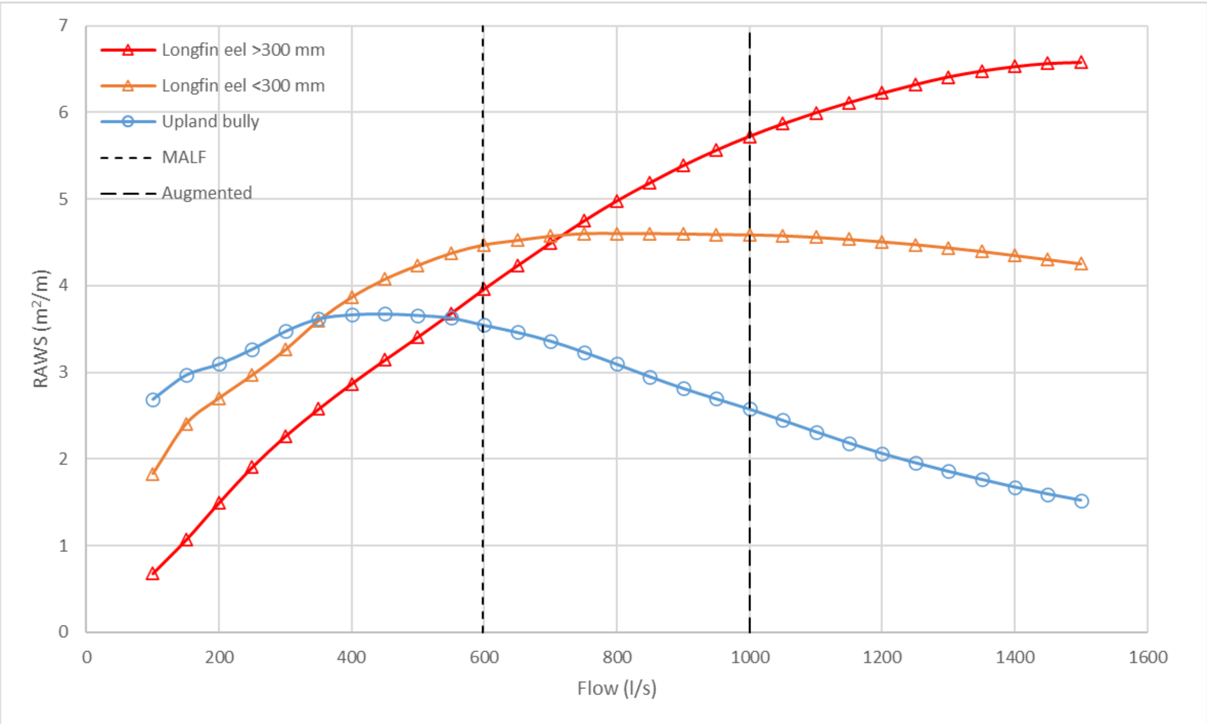

Figure 15 Variation in instream habitat for indigenous fish relative to flow in the survey reach of the Fraser River.

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

Species	Optimum flow (l/s)	Flow at which % habitat retention occurs (l/s)				Habitat retention at 1000 l/s (%)
		60%	70%	80%	90%	
Longfin eel >300 mm	>1,500	317	382	454	527	145%
Longfin eel <300 mm	750-900	196	277	347	437	103%
Upland bully	450	<100	63	127	228	73%

7.6. Sports fish

Habitat for brown trout adults and yearlings, and rainbow trout feeding habitat increased with flow across the modelled range (Figure 14). In contrast, brown trout spawning habitat increased with flow up to 950 l/s but declined at higher flows, while habitat for brown trout fry increased with flow up to 1050 l/s but declined at higher flows (Figure 14). Rainbow trout spawning habitat increased with flow to 1450 l/s (Figure 14). Habitat for rainbow trout <100 mm increased with flow up to 350 l/s but declined at higher flows (Figure 14). Flows required to achieve different levels of habitat retention for each of these species/life-stages are presented in Table 12.

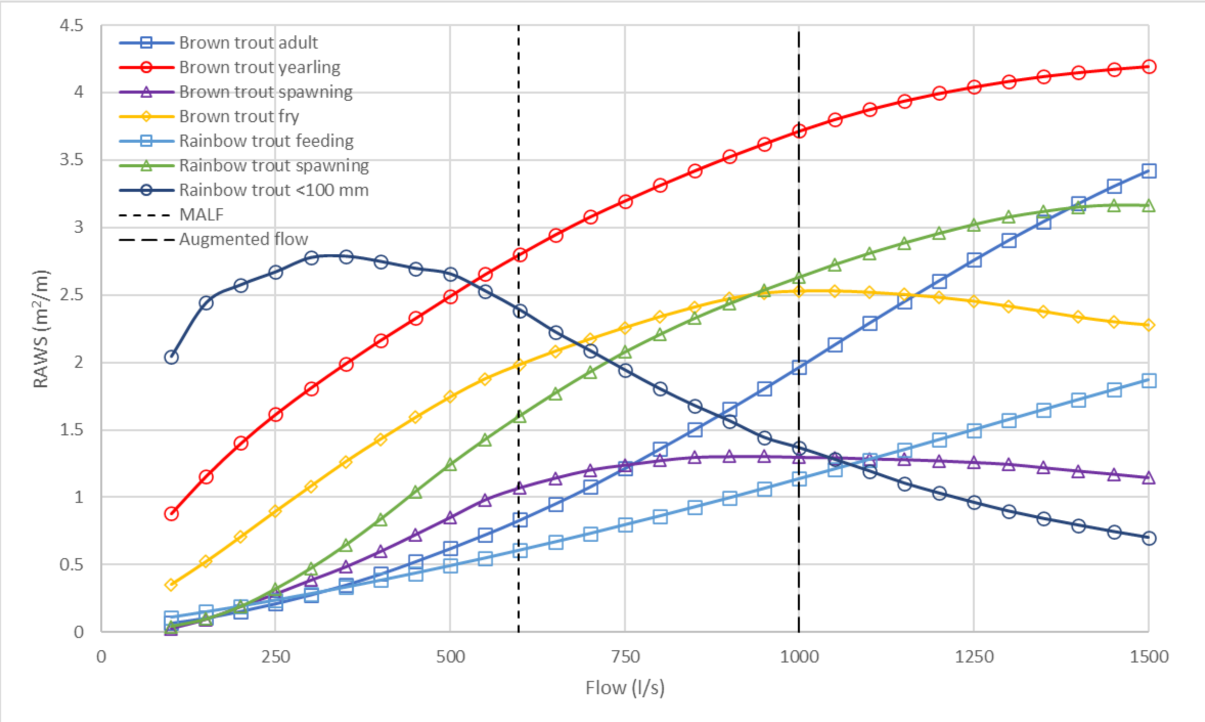

Figure 16 Variation in instream habitat for sportsfish relative to flow in the survey reach of the Fraser River.

Table 12 Flow requirements for sportsfish habitat in the Fraser 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 1000 l/s (%)
		60%	70%	80%	90%	
Brown trout adult	>1,500	435	479	520	560	237
Brown trout yearling	>1,500	266	341	423	508	133
Brown trout spawning	950	417	460	501	542	121
Brown trout fry to 15cm	1,050	329	387	448	514	128
Rainbow trout adult feeding	>1,500	379	437	493	546	187
Rainbow trout spawning	1,450	430	469	509	552	165

7.7. 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 Dunstan Rohe outlined in Table 1.

Flows of 501, 340, 202 and 408 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 residual flow retains 163% of food producing habitat, 128% of habitat for *Deleatidium*, 123% of habitat for *Aoteapsyche* and 124% of the habitat for *Pycnocentrodes*, relative to habitat available at the naturalised MALF (Table 15).

Habitat for longfin eels (>300 mm) is predicted to increase across the modelled flow range, while flows of 750-850 l/s are predicted to provide optimum habitat for smaller longfin eels (<300 mm). Thus, the current augmented flows in the lower Fraser River provide close to optimal habitat for small (<300 mm) longfin eels, while enhancing habitat availability for larger longfin eels compared to the modelled natural MALF. Upland bully have low flow requirements, with flows of 350-550 l/s predicted to offer optimum habitat in the Fraser River (Table 13). Flows of 127 l/s would provide 80% habitat retention (relative to naturalised flows) (Table 13).

Habitat for adult brown and rainbow trout is predicted to increase with increasing flows up to 1,500 l/s, with the current residual flow predicted to enhance habitat by between an 87% increase (rainbow trout) and 137% (brown trout).

Table 13 Flow requirements for habitat objectives in the Fraser 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 1,000 l/s residual flow
Food producing habitat	All year	Life-supporting capacity	80% relative to naturalised	501	163%
Common mayfly *Deleatidium*	All year	Life-supporting capacity	80% relative to naturalised	340	128%
Net-spinning caddisfly *Aoteapsyche*	All year	Life-supporting capacity	80% relative to naturalised	202	123%
Stony-cased caddisfly *Pycnocentrodes*	All year	Life-supporting capacity	80% relative to naturalised	408	124%
Longfin eel	All year	Life-supporting capacity, Indigenous biodiversity, mahika kai	80% relative to naturalised	347-454	103-145%
			90% relative to naturalised	437-527	
Upland bully	All year	Life-supporting capacity, biodiversity	80% relative to naturalised	127	73%
Adult brown trout	All year	Sports fish, recruitment to Clutha/Mata-Au	80% relative to naturalised	520	237%
Juvenile brown trout	All year	Sports fish, recruitment to Clutha/Mata-Au	80% relative to naturalised	423-448	128-133%
Brown trout spawning	Winter	Sports fish, recruitment to Clutha/Mata-Au	Maintain or enhance	501	121%
			Optimum	950	
Adult rainbow trout	All year	Sports fish, recruitment to Clutha/Mata-Au	80% relative to naturalised	493	187%
Rainbow trout spawning	Winter	Sports fish, recruitment to Clutha/Mata-Au	Maintain or enhance	509	165%
			Optimum	1,450	

8. Assessment of alternative minimum flows and allocation limits

The highly modified hydrology of the middle and lower reaches of the Fraser River confounds consideration of alternative minimum/residual flows and allocation regimes. The hydrology of the lower river is affected by the presence of Fraser Dam and hydro-peaking discharges from the Fraser Hydroelectric Power Scheme as well as flow augmentation. This is further complicated by the lack of hydrological monitoring in the lower catchment. The flow augmentation in the lower Fraser is a condition of the resource consent RM18.266.02 held by Earnscleugh Irrigation Company, which expires on 1 March 2044.

Continuous flow monitoring site in the lower river would provide a time-series of modified flows and would provide a basis for comparison with modelled natural flows. The long-term flow site in the upper Fraser River (upstream of Fraser Dam (Fraser at Old Man Range) operated between 1969 and 1994 and was re-established in 2016 and is still in operation at the time of writing. This site represents 36% of the catchment area of the Fraser River, including a large proportion of the high-yielding, high-altitude portion of the catchment. As a consequence, the Fraser at Old Man Range site is expected to represent many attributes of the natural hydrograph of the lower Fraser River, including the frequency and approximate magnitude of high flows and timing and duration of low flows. To develop a time-series of naturalised flows in the lower Fraser river would require further hydrological investigations in major tributaries, such as the Hawk Burn, Omeo Creek and Conroys Creek.

8.1. Potential effects of climate change in the Fraser catchment

The potential effects of future climate change are subject to considerable variation depending on future emission scenarios. This assessment is based on the assessment of Macara et al. (2019) using two scenarios (RCP4.5 and RCP8.5) for the period 2031-2050.

The probability, magnitude and duration of low flow events in the Fraser catchment is expected to be similar to, or slightly less than what is currently experienced (Table 14). Climate change is not expected to reduce habitat suitability for sensitive species (via increased water temperatures) in the upper Fraser River by 2040 given that current temperatures are well within the tolerances of the most sensitive species present in the catchment (see Section 0).

The predicted changes in the hydrology of the Fraser River resulting from climate change include slightly higher mean annual flow and higher flood magnitudes, which may enhance flushing of fine sediments and periphyton (Table 14), which is expected to be a positive ecological effect, particularly on the macroinvertebrate community of the Fraser River.

Natural cycles, such as the El Niño Southern Oscillation (ENSO), Interdecadal Pacific Oscillation (IPO) account for some of the variability observed in the climate and hydrology of catchments in Otago. The variability associated with these cycles may exceed the predicted effect of climate change, particularly over the period 2031-2050. However, the effect of climate change is in addition to, and therefore may exacerbate the variability associated with such cycles.

Table 14 Potential effects of climate change on the Fraser 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 Fraser River	Potential ecological consequences
Temperature	• Increased mean temperatures (0.8-0.9°C) • Increased annual mean maximum temperature (1.1-1.2°C) • Increase in number of hot days (>30°C) (increase by 17.2-17.3 days per annum) • Reduced frost days (-15 - -18 days per year) fewer frost days per annum)	• Increased evapotranspiration • Faster flow recession • Increased irrigation demand	• Higher water temperatures, reduced suitability for sensitive species • Faster accrual of periphyton biomass
Rainfall	• Increase in annual mean rainfall (6-7%) • Increase in summer mean rainfall (8-9%) • Increased winter rainfall (7%) • Similar risk of low rainfall events • Little change in heavy rain days (>25 mm; +0.7- +0.9 days per annum) • Increase in peak rainfall intensity	• Similar or slightly reduced likelihood and/or magnitude of low flow events • Potential increase in magnitude of high flow events	• Enhanced flushing of sediment and periphyton
Snow	• Reduction in snow days, especially in upper catchment (-1 - -5 days)	• Reduced snowpack • Earlier and/or shorter spring snowmelt • Larger winter floods	• Enhanced flushing of sediment and periphyton
Hydrology	• Little change in Q95 flow (-5- +5%) • Increase in mean flow (up to 5-10% increase) • Increased mean annual flood	• Low flows similar magnitude to existing • Irrigation demand may slightly decrease • Increased frequency and/or magnitude of flushing flows • Reliability for irrigators similar or slightly higher than present	• Enhanced flushing of sediment and periphyton

9. Conclusions

The Earnscleugh or Fraser River is a small river which rises on the northern slopes of the Old Man Range/ Kōpūwai, Old Woman and Obelisk Ranges in Central Otago before flowing into the Clutha River/Mata-Au downstream of the Clyde Dam and opposite Alexandra.

The flows of the Fraser River are highly modified for irrigation and hydroelectric generation. Two hydro-electric power schemes operate on Fraser River: a run-of-river power scheme in the Fraser River upstream of Fraser Dam and Fraser Dam is also used as a hydro-electric power station, releasing water to a 10 m concrete arch weir located approximately 5 km downstream, where it is taken into a 4.5 km pipeline, before flowing through steel penstocks to the Fraser River Power Station. In addition, Earnscleugh Irrigation Company augments flows in the lower Fraser River with up to 3,100 l/s from Lake Dunstan (RM18.266.01), with flows abstracted at six locations, but a residual flow of 1,000 l/s to be maintained downstream of these takes. Thus, the hydrology of the lower half of the Fraser River is highly modified by hydro-electric generation, and flow augmentation.

The Fraser catchment is within the Clutha Mata-Au Freshwater Management Unit (FMU) and the Roxburgh Rohe. Like many waterways within the Roxburgh Rohe, the Fraser catchment has a long history of water abstraction, with many of the water takes within the Fraser catchment historically authorised by deemed permits (also known as mining rights). These permits, often originally issued for the purposes of mining and later used for irrigation, were not subject environmental restrictions, such as minimum flows. As a consequence, catchments such as the Fraser River have not been subject to a minimum flow and historically, water abstraction has resulted in the lower reaches of the Fraser River going dry. As part of the development of the Land and Water Regional Plan, minimum flows and allocation limits are to be developed for all catchments in Otago.

Flow statistics for hydrological sites in the Fraser River:

Site	Type	Flow statistics (l/s)		
		Median	Mean	7d MALF (Jul-Jun)
Fraser at Old Man Range	Natural flows	2,113	1,297	496
Fraser at Marshall Road	Modelled flows	2,332	-	598

There are nine resource consents for primary water takes from the Fraser catchment. Of these, there are two non-consumptive takes from the upper Fraser upstream of Fraser Dam (one for gold mining, another for run-of-the-river hydro-electric generation) and one non-consumptive take from the middle reaches of the Fraser River (hydro-electric generation). There is one consumptive take from the Hawks Burn, two consumptive takes from the Omeo Creek sub-catchment, and two consumptive takes from the Conroys Creek catchment. The consents held by Earnscleugh Irrigation Company (RM18.266), include the augmentation of the lower reaches of the Fraser River with up to 3,100 l/s from Lake Dunstan. The net allocation in the Fraser catchment (consumptive take minus augmentation) is 1,253 l/s (223.9 l/s is from Omeo Creek, 223.9 l/s from the Conroy's Creek, and 653 l/s from the lower Fraser River).

Limited information is currently available on periphyton communities in the Fraser River, although the invasive stalked diatom *Didymosphenia geminata* (known as Didymo) was first identified in the Fraser River in 2006.

Macroinvertebrate samples were collected from the Fraser River at Marshall Road between 2006 and 2010. Macroinvertebrate indices (MCI, SQMCI and ASPM) for this period were variable, but were indicative of fair to good water and/or habitat quality.

Five species of indigenous freshwater fish have been recorded from the Fraser catchment – longfin eel, lamprey, upland and common bully and kōaro (Figure 11; Table 5). Lamprey are classified as threatened – nationally vulnerable, while longfin eels and kōaro are classified as at risk – declining. Brown trout are widespread, while rainbow trout and perch have been recorded from the lower Fraser catchment. Little angler effort has been recorded in the Fraser catchment, but the upper reaches are considered to be a locally significant backcountry fishery (Otago Fish & Game Council 2015). Brown and rainbow trout spawning in the Fraser River likely contributes to recruitment and juvenile rearing for the Clutha fishery to some degree, although the significance of this contribution is unknown.

Limited information is available on the water quality and ecological state of the lower Fraser River. MCI and SQMCI scores in the lower reaches of the Fraser River between 2006 and 2010 are in C-band (the proposed LWRP objective for the Roxburgh Rohe is B-band). However, likely to reflect the abundance of didymo at this site over the sampling period. Whilst water quality sampling is not currently undertaken in the lower reaches of the Fraser River, it is expected that the water quality of the lower reaches will be heavily influenced by the water from Lake Dunstan used to augment flows in the lower reaches of the Fraser River.

Instream habitat modelling was undertaken in a reach of the Fraser River between Strode Road and Marshall Road by Waterways (2016). Flows of 202 (*Aoteapsyche*) and 501 l/s (food producing habitat) would provide 80% habitat retention (relative to naturalised flows) for macroinvertebrates. The current residual flow retains between 123% (*Aoteapsyche*) and 163% of food producing habitat relative to the naturalised MALF.

Habitat for longfin eels (>300 mm) is predicted to increase across the modelled flow range, while flows of 750-850 l/s are predicted to provide optimum habitat for smaller longfin eels (<300 mm). Thus, the current augmented flows in the lower Fraser River provide close to optimal habitat for small (<300 mm) longfin eels, while enhancing habitat availability for larger longfin eels compared to natural MALF. Upland bully have low flow requirements, with flows of 350-550 l/s predicted to offer optimum habitat in the Fraser River (Table 13). Flows of 127 l/s would provide 80% habitat retention (relative to naturalised flows) (Table 13).

Habitat for adult brown and rainbow trout is predicted to increase with increasing flows up to 1,500 l/s, with the current residual flow predicted to enhance habitat by between 87% (rainbow trout) and 137% (brown trout).

The highly modified hydrology of the middle and lower reaches of the Fraser River confounds consideration of alternative minimum/residual flows and allocation regimes. The hydrology of the lower river is affected by the presence of Fraser Dam and hydro-peaking discharges from the Fraser Hydroelectric Power Scheme as well as flow augmentation and is further complicated by the lack of hydrological monitoring in the lower catchment. The flow augmentation in the lower Fraser is a condition of the resource consent RM18.266.02 held by Earnscleugh Irrigation Company, which expires on 1 March 2044. Instream habitat modelling undertaken in the lower reaches of the Fraser River indicates that the flow augmentation in the lower reaches of the Fraser River has enhanced habitat for macroinvertebrates, longfin eels and trout.

To assist in future assessments of water allocation management in the Fraser catchment, additional hydrological information relating to the operation of the upper and lower Fraser Power Stations and Fraser Dam and hydrological monitoring in the lower river is essential. In addition, it was not possible to assess the ecological state of the lower Fraser River given the lack of water quality and ecological monitoring in the lower river.

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