Management flows for aquatic ecosystems in the Clutha/Mata-Au and Kawarau Rivers

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Technical summary

The Clutha River/Mata-Au is the largest river in New Zealand by flow (mean flow 614 m^3/s) and the second longest river in New Zealand (338 km), flowing from the headwaters of the three large, glacial lakes (Lakes Hāwea, Whakatipu Waimāori and Wānaka) to the Pacific Ocean 12 km south-east of Balclutha. Overall, the Clutha/Mata-Au catchment (21,135 km^2) represents two-thirds of the Otago region and spans a wide diversity of landscapes, local climates and ecosystems.

The Clutha/Mata-Au is an important source of hydro-electric power for the national grid, with two major dams at Clyde (464 MW) and Roxburgh (320 MW). A dam constructed at the outlet of Lake Hāwea in the 1950's raised the water level of Lake Hāwea by up to 20 metres, forming the largest water storage reservoir in the Clutha/Mata-Au catchment. Flows in the upper Clutha/Mata-Au down to the confluence of the Hāwea River are close to natural, while flows below the Hāwea confluence are affected by the highly modified flows in the Hāwea River resulting from the management of storage within Lake Hāwea for hydro-electric power generation in downstream power stations.

Flow statistics for several sites in the Clutha/Mata-Au are summarised in the following table:

Site	Dates		Annual		
			Mean (m^3/s)	**Median (m^3/s)**	**7-d MALF (m^3/s)**
Lake Wānaka outlet	2-Feb-1933 – 3 Aug 1955	Natural	195	180	77
	1-Jan-1933 - 29-Jun 2023	Natural	199	179	81
Lake Hāwea outlet	2-Feb-1933 – 3 Aug 1955	Natural	64	59	30
	1-Jan-1933 - 29-Jun 2023	Naturalised	64	59	32
Hāwea at Camphill Bridge	6-Mar-1968 – 6 Nov 2023	Actual	65.9	36.4	8.64
Clutha at below Cardrona confluence	1-Jan-1933 - 29-Jun 2023	Naturalised[1]	263	238	113
	10-Apr-1992 - 29-Jun 2023	Naturalised**Error! Bookmark not defined.**	267	240	117
	10-Apr-1992 - 29-Jun 2023	Actual	273	262	132
Kawarau at Chards Road	30-Jun-1967 – 30 Jun 2023	Actual	211	189	89
Clutha at Balclutha[2]	6-Jul-1954 – 30-Jun-2023	Actual	575	535	298

Water abstraction from the mainstems of the upper Clutha/Mata-Au, Kawarau and the mainstem of the Clutha/Mata-Au are currently not subject to minimum flows or allocation limits. Consented allocation in the upper Clutha/Mata-Au sub-catchment (upstream of Lake Dunstan) is 14.7 m^3/s, which represents approximately 13% of the 7-d MALF, while consented allocation in the Kawarau catchment is 5.0 m^3/s, which represents approximately 6% of the 7-d MALF. The total allocation in the Clutha/Mata-Au is 63 m^3/s, which is approximately 21% of the 7-d MALF.

[1] Based on the sum of observed (2 February 1933 – 3 August 1955) or synthetic (4 August 1955-29 June 2023) outflows from Lake Hāwea and observed outflows from Lake Wanaka)

[2] From Stewart 2023

Upper Clutha/Mata-Au - The results of instream habitat and trout bioenergetics modelling in a reach near Queensberry suggest that a reduction in flows is likely to result in increased habitat available for most species present, down to at least 80 m^3/s, although flows below 95 m^3/s may result in an elevated risk of periphyton proliferation.

The hydrological modification of flows in the upper Clutha/Mata-Au due to power generation will overshadow the current effects of run-of-the-river allocation, including the creation of a varial zone resulting from fluctuations in outflows from Lake Hāwea.

Factors other than the aquatic ecosystems will contribute to the development of flow management in the upper Clutha/Mata-Au, including (but not limited to) aesthetics and flows for recreation activities (including jetboating, rafting, and kayaking).

Kawarau River - Current abstraction from the Kawarau catchment is very low, representing 4% of the 7-d MALF at the Kawarau at Chards Road flow monitoring site. Given the current low level of abstraction pressure and the outstanding characteristics of the catchment, as recognised in the Water Conservation (Kawarau) Order, there is a strong argument for conservative management of future water abstraction from the Kawarau catchment. This could be achieved by limiting water allocation to 5% or 10% of the 7-d MALF of the Kawarau River, which is in line with the provisions of other water conservation orders.

Lower Clutha/Mata-Au - Flows in the Lower Clutha/Mata-Au are currently regulated by Contact Energy's consent requirements, which require maintenance of a minimum flow of 250 m^3/s at all times, unless the combined inflows to the Clutha/Mata-Au system are below 250 m^3/s, in which case the minimum discharge below Roxburgh Dam shall not be less than that combined daily mean flow. This permit (2001.394.V1) also requires maintenance of a stable minimum flow of 300-400 m^3/s between September-mid October. These consents expire on 25 May 2042.

The results of instream habitat modelling and NREI studies in the upper Clutha/Mata-Au have relevance to the lower Clutha/Mata-Au. It is likely that a reduction of flows will increase the suitability and extent of habitat for many species present, as high velocities, water depth, and sediment instability in the middle of the channel reduce the suitability for aquatic species.

Acceptable ecological outcomes could be achieved by a conservative allocation limit without the need for a minimum flow for the mainstem of the Clutha/Mata-Au and/or Kawarau Rivers. In such large rivers, whole-catchment allocation of ≤20% of the 7-d MALF is expected to ensure that any effects of abstraction are no more than minor, especially when the results of instream habitat modelling and NREI studies are considered.

Considerations other than the aquatic ecosystem will contribute to the development of flow management in the lower Clutha/Mata-Au, including (but not limited to) aesthetics and flows for recreation activities (e.g. jetboating). Water quality at many monitoring sites in tributaries of the lower Clutha/Mata-Au is generally poor, although in recent years there are indications of improving trends (Ozanne et al. 2023). Water quality outcomes can be affected by irrigation development and therefore may constrain future water allocation in areas such as the lower Clutha/Mata-Au.

Contents

Glossary 1

1. Introduction 1
   1.1. Objectives 2
2. The Clutha/Mata-Au catchment 3
   2.1. Climate 5
   2.1.1. Rainfall 5
   2.2. Vegetation and Land use 5
3. Water Use 11
   3.1. Hydro-electric development 11
   3.1.1. Contact Energy 11
   3.1.2. Other hydro-electric development 12
4. Regulatory setting 14
   4.1. Regional Plan: Water (RPW) 14
   4.2. Proposed Land and Water Plan 14
   4.3. National legislation and water conservation orders 16
   4.3.1. Lake Wānaka Preservation Act (1973) 16
   4.3.2. Water Conservation (Kawarau) Order 16
5. River hydrology 18
   5.1. Upper Clutha River/Mata-Au 18
   5.1.1. Outflows from Lake Wānaka 18
   5.1.2. Outflows from Lake Hāwea 18
   5.1.3. Upper Clutha/Mata-Au downstream of the Cardrona/Ōrau confluence 18
   5.2. Kawarau River 19
   5.3. Water allocation 19
6. Water temperature 21
7. Values of the Clutha/Mata-Au & Kawarau Rivers 28
   7.1. Schedule 1A of the RPW 28
   7.2. Water Conservation (Kawarau) Order 29
   7.3. Indigenous fish 29
   7.4. Sports fish 30
   7.5. Riverine birds 33
   7.6. Game birds 34
   7.7. Summary of instream values 35
8. Flow setting for the Upper Clutha/Mata-Au 36
   8.1. Habitat suitability curves 37
   8.2. Periphyton 38
   8.3. Macroinvertebrates 39
   8.4. Native fish 41
   8.5. Sports fish 42
   8.5.1. Instream habitat modelling 42
   8.5.2. NREI modelling 42
   8.6. Ecological consequences of flow fluctuations 43
   8.7. Summary of instream habitat assessments 45
   8.7.1. Applicability to the Kawarau and lower Clutha/Mata-Au 46

Otago Regional Council

9. Minimum flows and allocation limit options ... 47
9.1. Upper Clutha River/Mata-Au ... 47
9.1.1. Potential effects of climate change in the Upper Clutha/Mata-Au ... 49
9.2. Kawarau River ... 50
9.2.1. Potential effects of climate change in the Kawarau catchment ... 51
10. Lower Clutha/Mata-Au ... 52
10.1.1. Potential effects of climate change in the Lower Clutha/Mata-Au ... 54
11. Conclusions: Flow requirements for aquatic ecosystems in the Clutha/Mata-Au catchment ... 55
11.1. Upper Clutha/Mata-Au ... 55
11.2. Kawarau River ... 55
11.3. Lower Clutha/Mata-Au ... 56
12. Acknowledgements ... 57
13. References ... 57
14. Appendix A ... 59
Schedule 3 of the RMA - Water quality classes ... 59
Hāwea River - Natural MALF (1933-1955) ... 63
Upper Clutha River/Matau-Au – estimating flows for the period 1933-1955 ... 63
Estimating flows in the Hāwea River from Lake Wānaka outflows ... 64

List of figures

Figure 1 Clutha/Mata-Au catchment showing the various sub-reaches of the Clutha/Mata-Au and Kawarau River referred to in this report. 4
Figure 2 Major subcatchments of the Clutha/Mata-Au catchment 6
Figure 3 Median annual rainfall in the Clutha/Mata-Au catchment (from GrowOtago) with telemetered rainfall sites. 7
Figure 4 Seasonal rainfall distribution at rainfall sites in the upper Clutha/Mata-Au catchment. Note: The graphs for each rainfall site are were not generated using data from the same time period, so are not directly comparable. 8
Figure 5 Seasonal rainfall distribution at rainfall sites in the upper Clutha/Mata-Au catchment Note: The graphs for each rainfall site are were not generated using data from the same time period, so are not directly comparable. 9
Figure 6 Land cover in the Clutha/Mata-Au catchment based on the Land Cover Database (LCDB, version 5). 10
Figure 7 Water temperature in the Clutha at the Luggate Bridge between December 2005 and April 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. 23
Figure 8 Water temperature in the Clutha at Balclutha between September 1992 and December 1999. 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. 24
Figure 9 Water temperature in the Clutha at Balclutha between January 2000 and December 2007. 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. 25
Figure 10 Water temperature in the Clutha at Balclutha between January 2008 and December 2016. 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. 26
Figure 11 Water temperature in the Clutha at Balclutha between January 2016 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. 27
Figure 12 Hydraulic model of the 900 metre study reach in the upper Clutha River/Mata-Au near Queensberry at a flow of 209 m^3/s showing water depth (colour scale) and water velocity vectors (the length of the arrow indicates the velocity of the water). 36
Figure 13 Periphyton types a) benthic cyanobacteria (*Phormidium*), b) native diatoms, c) underwater photograph showing an extensive growth of didymo in the Hāwea River and d) long and

short filamentous algae (and cyanobacteria). 39

Figure 14 Macroinvertebrate taxa considered in these analyses: a) a nymph of the common mayfly (*Deleatidium*), b) a larva of the net-spinning caddis fly (*Aoteapsyche*) and c) nymph of the filter-feeding mayfly (*Coloburiscus*). 40

Figure 15 A larva of the net-spinning caddis fly *Hydropsyche* showing the rough retreat it makes attached to a rock (in this case, made of pieces of wood) and the silk net it uses to catch prey. 41

Figure 16 Conceptual diagram of the effect of flow on habitat for fish and macroinvertebrates in large rivers. a) low flows, b) high flows, c) variable flows. 43

Figure 17 Hydrographs showing the effects of hydro-electric power generation on a) Hāwea River at Camphill Bridge, b) Clutha at Clyde, and c) Clutha at Balclutha. Data courtesy of NIWA and data for the Hāwea and Clutha at Clyde courtesy of Contact Energy. 44

Figure 0.18 Relationship between water level in Lake Wānaka and outflow from Lake Wānaka to the upper Clutha River/Mata-Au over the period 1 January 1955-8 April 2014. A fitted quadratic function is also shown. 64

Figure 19 Linear regression of outflows from Lake Wānaka (from water levels in Lake Wānaka) with outflows from Lake Hāwea (based on water levels in Lake Hāwea prior to hydro-electric development). Based on data from 2 February 1933 to 3 August 1955. 65

Figure 20 Comparison of low flow statistics based on observed outflows from Lake Hāwea with synthetic low flow statistics for the Lake Hāwea outlet based on the linear regression presented in Figure 19. 65

Figure 21 Power regression of outflows from Lake Wānaka (from water levels in Lake Wānaka) with outflows from Lake Hāwea (based on water levels in Lake Hāwea prior to hydro-electric development). Based on data from 2 February 1933 to 3 August 1955. 66

Figure 22 Comparison of low flow statistics based on observed outflows from Lake Hāwea with synthetic low flow statistics for the Lake Hāwea outlet based on the linear regression presented in Figure 21. 66

List of tables

Table 1 Land cover types in the Clutha catchment based on LCDB v.5 5
Table 2 Proposed environmental outcomes for the values identified in the Clutha Mata-Au FMU and their attributes and target attributes. 15
Table 3 Provisions within Schedule 2 of the Water Conservation (Kawarau) Order (Waters to be Protected) that relate to the mainstem of the Kawarau River 17
Table 4 Summary of flow statistics for selected flow recorder sites in the Clutha and Kawarau catchments. All sites are operated by NIWA. 19
Table 5 Summary of consented allocation in different sub-catchments of the Clutha/Mata-Au and Kawarau Rivers. 20
Table 6 Number of exceedances of thermal criteria at monitoring sites in the Clutha River/Mata-Au. 22
Table 7 Natural values identified for the mainstem of the Clutha River/Mata-Au and Kawarau River in Schedule 1A of the Regional Plan: Water. 28
Table 8 Fish species of the Clutha/Mata-Au and Kawarau catchments, conservation threat classification, and distribution. Threat classification based on Dunn *et al.* (2018). 32
Table 9 Angler effort in the Clutha/Mata-Au and Kawarau Rivers and associated lakes (angler days ± standard error) based on the National Angler Survey (Unwin 2016). 33
Table 10 Assessment of instream habitat values at sites in the Upper Clutha/Mata-Au, Kawarau, and lower Clutha/Mata-Au with recommended levels of habitat retention (based on the approach of Jowett & Hayes, 2004). .... **Error! Bookmark not defined.**
Table 11 Habitat suitability curves used in instream habitat modelling in the upper Clutha River/Mata-Au. 37
Table 12 Assessment of instream habitat values at sites in the Upper Clutha/Mata-Au with recommended levels of habitat retention (based on the approach of Jowett & Hayes, 2004). 45
Table 13 Minimum flow and mainstem allocation limit options for the upper Clutha/Mata-Au. 48
Table 14 Potential effects of climate change on the upper Cluhta/Mata-Au based on the assessment of Macara et al. (2019) using two scenarios (RCP4.5 and RCP8.5) for the period 2031-2050. 49
Table 15 Minimum flow and mainstem allocation limit options for the Kawarau River. 50
Table 16 Potential effects of climate change on the Kawarau River based on the assessment of Macara et al. (2019) using two scenarios (RCP4.5 and RCP8.5) for the period 2031-2050. 51
Table 17 Minimum flow and mainstem allocation limit options for the lower Clutha/Mata-Au. 53
Table 18 Potential effects of climate change on the lower Clutha River based on the assessment of Macara et al. (2019) using two scenarios (RCP4.5 and RCP8.5) for the period 2031-2050. 54

Glossary

Catchment	The area of land drained by a river or body of water.
Consumptive take	A take of water where the water is used for an activity and is not returned to the source waterbody.
Existing flows	The flows observed in a river under current water usage and with current water storage and transport.
Habitat suitability curves (HSC)	Representations of the suitability of different water depths, velocities and substrate types for a particular species or life-stage of a species. Values vary from 0 (not suitable) to ideal (1). HSC are used in instream habitat modelling to predict the amount of suitable habitat for a species/life-stage.
Instream habitat modelling	An instream habitat model used to assess the relationship between flow and available physical habitat for fish and invertebrates.
Irrigation	The artificial application of water to the soil, usually for assisting the growing of crops and pasture.
7-d Mean Annual Low Flow (7-d MALF)	The average of the lowest seven-day low flow for each year of record. Most MALF values reported here are calculated using flows from the irrigation season (October-April) only. This is to avoid the effect of winter low flows that may occur due to water being “locked up” in snow and ice in the upper catchment. However, if significant winter low flows do not occur, estimates of 7-d MALF calculated using data from the full hydrological year or from the irrigation season should be very similar.
Mean flow	The average flow of a watercourse (i.e. the total volume of water measured divided by the number of sampling intervals).
Minimum flow	The flow below which the holder of any resource consent to take water must cease taking water from that river.
Natural flows	The flows that occur in a river in the absence of any water takes or any other flow modification.
Naturalised flows	Synthetic (calculated) flows created to simulate the natural flows of a river by removing the effect of water takes or other flow modifications.
Non-consumptive take	A take of water where the water is diverted from a waterbody, but is returned to the source waterbody.
Reach	A specific section of a stream or river.
Retake	The act of taking water that has already been lawfully taken and then discharged to a natural water body.
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

With its headwaters rising in the Southern Alps in the tributaries of the three large, glacial lakes: Lakes Hāwea, Whakatipu Waimāori and Wānaka, the Clutha River/Mata-Au is the largest river in New Zealand by flow (mean flow 614 m^3/s) and the second longest (338 km). Overall, its catchment (21,135 km^2) represents two-thirds of the area of the Otago region and spans a wide diversity of landscapes, local climates and ecosystems: from its alpine headwaters flowing through the steep mountainous terrain, to the braided rivers that flow into the alpine lakes, to the semi-arid landscapes of Central Otago and finally onto the fertile coastal plains where it finally discharges into the Pacific Ocean.

Unsurprisingly given its length and size and the diversity of landscapes it flows through, the Clutha/Mata-Au supports a range of significant values including significant indigenous ecosystems, habitat for a diverse range of native fish (including threatened species), trout and salmon fisheries, as well as game bird habitat. These values have been recognised and protected in legislation and regulation. The Lake Wānaka Preservation Act (1973) prevents the alteration of water levels in Lake Wānaka and the upper Clutha River (to the Hāwea River confluence) in addition to seeking to maintain or improve water quality in Lake Wānaka. Similarly, the Kawarau catchment has a national Water Conservation Order (originally gazetted in 1997) which recognises, among other things, the wild and scenic character of the Kawarau River gorge, scientific values (particularly associated with the return flow in the upper section when the Shotover River is in high flood) and the recreational values (in particular rafting, jetboating, and kayaking) that are outstanding in the Kawarau catchment.

Several significant settlements are situated on the Clutha River/Mata-Au. These include Wānaka (permanent resident population: 10,610[34]), Cromwell (6,630[5]), Clyde (1,250), Alexandra (5,960) and Balclutha (4,110[6]). The greater Queenstown area (15,370[1,7]) is located around the shores of Lake Whakatipu and the upper Kawarau. Collectively, these districts[8] represent 19% of the total population of Otago (225,1896), and 44% of the population of Otago outside of the Dunedin City boundary.

The Clutha/Mata-Au is an important source of hydro-electric power for the national grid, with two major dams impounding its waters: Clyde (464 MW) and Roxburgh (320 MW). Combined, these two dams represent approximately 8%[9] of the total installed capacity within the New Zealand electricity sector (Ministry of Business, Innovation & Employment, 2015). A dam constructed at the outlet of Lake Hāwea in the 1950's raised the water level of Lake Hāwea by up to 20 metres, forming the largest water storage reservoir in the Clutha/Mata-Au catchment.

The Clutha/Mata-Au catchment was the site of much of the Otago gold rush, starting with the discovery of gold in 1861 at Gabriel's Gully near Lawrence, but soon spread into Central Otago with other

[3] Population estimates based on population projections from https://www.qldc.govt.nz/community/population-and-demand#projections
[4] Population estimate for Wanaka based on the combined population of Wanaka Central, Wanaka North, Wanaka Waterfront and Wanaka West.
[5] Values for 2021 from Longman A & Gonzalez B (2022).
[6] From 2018 census - https://www.stats.govt.nz/tools/2018-census-place-summaries/clutha-district
[7] Population estimate for Queenstown based on the combined populations of Sunshine Bay/Fern Hill, , Queenstown Central, Warren Park, Queenstown East, Frankton, Frankton Arm and Kelvin Heights.
[8] Queenstown Lakes District, Central Otago District and Clutha District
[9] Based on a combined output of 3,750 GWh, compared to the national output in 2015 of 44,321 GWh

discoveries. Associated with these mining activities, water rights (mining rights) were issued from the Warden's courts to supply water for gold sluicing. As the gold rush subsided and agricultural development in the upper Clutha/Mata-Au expanded, these water rights and associated water races were used to irrigate pasture. Further irrigation development was undertaken within the Clutha Mata-Au catchment by government irrigation schemes in the early 20th century. This development included the Ida Valley (1917), Galloway (1920), Manuherikia (1922), Earnscleugh (1922), Last Chance (1923), Ardgour (1923), Teviot (1924), Tarras (1925), Bengerburn (1926), Hawkdun (1929), Arrow River (1930), Conroys (1935), Omakau (1936) and Omakau Dunstan section (1938) (Lindup & Watt 1954). These schemes were divested by the government in the 1990's and are now owned by companies consisting of farmer shareholders.

1.1. Objectives

This report presents information on the main stem of the Clutha River/Mata-Au and the Kawarau River that is relevant to determining the flows required to sustain the river's aquatic habitat. This includes freshwater values, hydrology (including flow statistics), the distribution of water resources within the catchment and the results of instream habitat and trout bioenergetics modelling.

2. The Clutha/Mata-Au catchment

The Clutha/Mata-Au catchment (21,135 km^2) has been identified as one of five Freshwater Management Units (FMU) in the Otago Region, representing two-thirds of the area of the Otago region and encompassing a wide diversity of landscapes, climates and ecosystems (Figure 1). Many of the sub-catchments of the Clutha/Mata-Au (Figure 2) have distinct micro-climates, communities and values. For this reason, the Clutha FMU has been sub-divided into five Rohe: Upper Lakes, Dunstan, Manuherekia, Roxburgh and Lower Clutha.

The Clutha/Mata-Au and Kawarau were exempted from many of the water allocation provisions of the Regional Plan: Water (e.g. Policy 6.4.1) and currently do not have minimum flows and/or allocation limit(s) applied to them. These exemptions are being reviewed as part of the development of the Land & Water Regional Plan for Otago. To support this process, this report focusses on the mainstem of the Clutha River/Mata-Au and its major tributary, the Kawarau River (from Lake Whakatipu Waimaori to Lake Dunstan). For the purposes of this report, the Clutha River/Mata-Au is split into the following reaches (Figure 1):

- Upper Clutha/Mata-Au – Lake Wānaka to Lake Dunstan
- Middle Clutha/Mata-Au – Clyde Dam to Lake Roxburgh
- Lower Clutha/Mata-Au – Roxburgh Dam to the sea

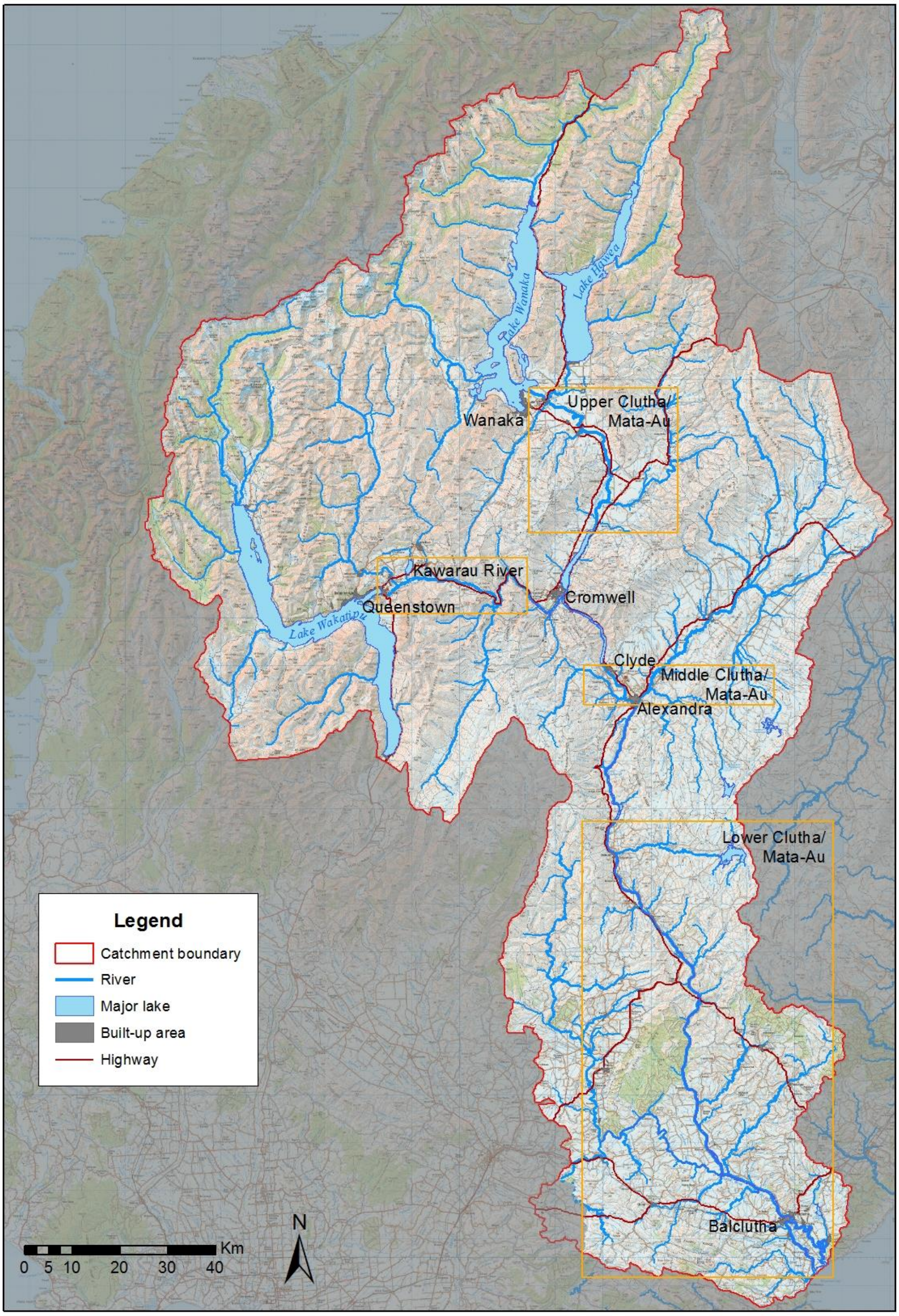

Figure 1 **Clutha/Mata-Au catchment showing the various sub-reaches of the Clutha/Mata-Au and Kawarau River referred to in this report. Orange boxes denote the variuous reaches referred to in this report.**

2.1. Climate

2.1.1. Rainfall

Rainfall in the Clutha/Mata-Au catchment ranges from 8,750 mm in alpine areas of upper catchment to less than 350 mm in parts of the Manuherikia catchment (Figure 3, Figure 4, Figure 5). This extreme gradient in rainfall results in a large proportion of the flow in the Clutha River originating in the north-western alpine part of the catchment before flowing through the semi-arid landscapes of Central Otago (Figure 3, Figure 4). Rainfall shows little seasonality at most sites in the catchment, with slightly higher average rainfall in Spring (October-November) and slightly lower average rainfall totals in Autumn (February-April) (Figure 4, Figure 5).

2.2. Vegetation and Land use

Given the strong gradient in climate across the Clutha/Mata-Au catchment, it is not surprising that a wide range of land covers are found within the catchment (Figure 6). The predominant land cover is tall tussock (33%, Table 1), with considerable areas of high-elevation land covered by tall tussock grasslands (Figure 6). The next most widespread land covers are high producing exotic grassland (23%) and low producing grassland (20%), which dominate valley floors and the coastal plains (Figure 6). Indigenous forests are mostly found in the valleys of the tributaries of the alpine lakes and in the Blue Mountains, comprising approximately 6% of the total catchment area (Figure 6). Approximately 1% of the catchment is permanently covered by ice and/or snow, and 4% by rock or gravel (Table 1).

Table 1 **Land cover types in the Clutha catchment based on LCDB v.5**

Land cover type	Area (km^2)	Catchment cover (%)
High Producing Exotic Grassland	4,335	23%
Low Producing Grassland	3,711	20%
Depleted Grassland	137	1%
Permanent Snow and Ice	116	1%
Gravel or Rock	729	4%
Alpine Grass/Herbfield	214	1%
Sub Alpine Shrubland	276	1%
Indigenous Forest	1,233	6%
Manuka and/or Kanuka	170	1%
Tall Tussock Grassland	6,311	33%
Fernland	228	1%
Mixed Exotic Shrubland	145	1%
Exotic Forest	334	2%
Lake or Pond	707	4%
Other	349	2%

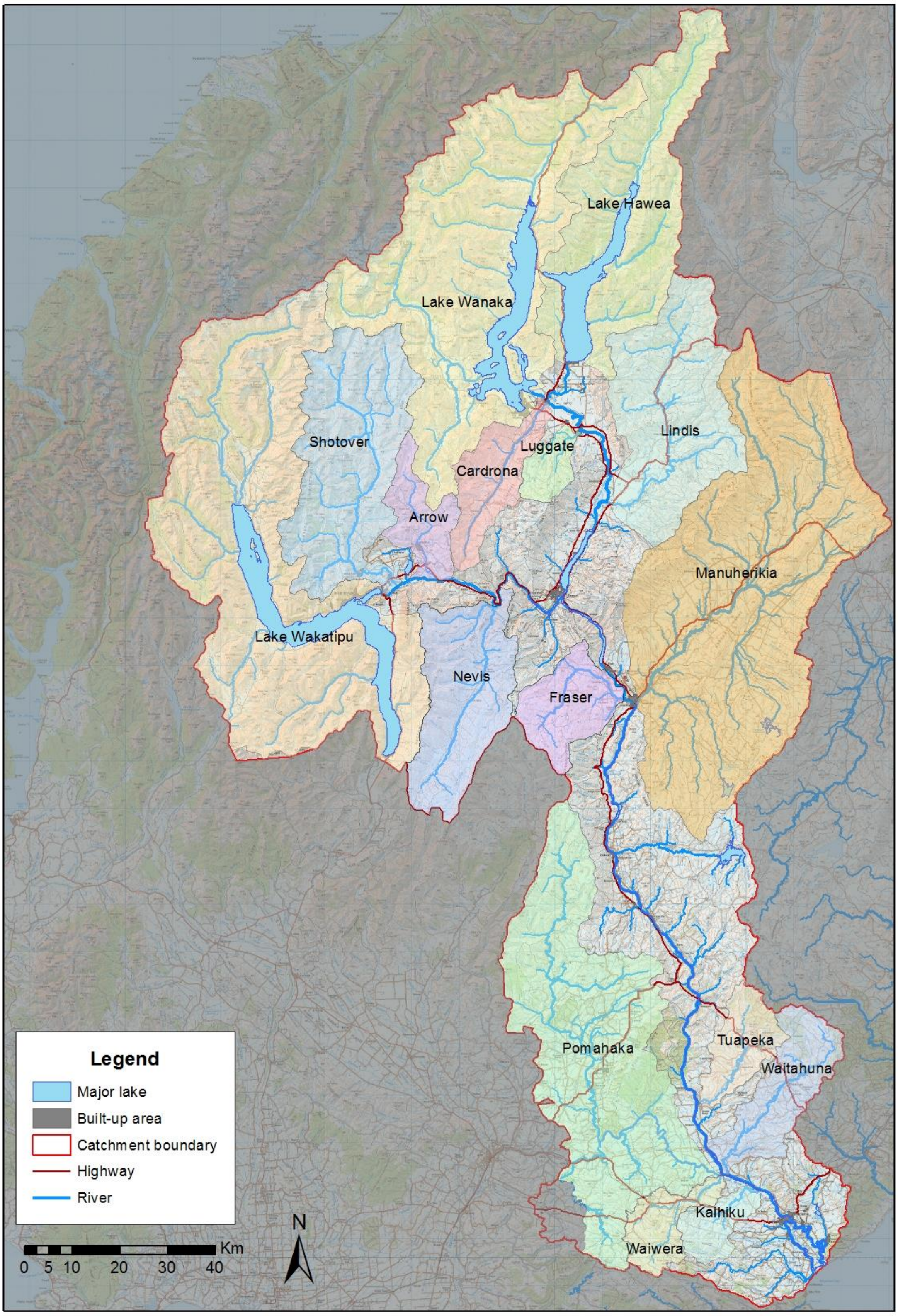

Figure 2 **Major subcatchments of the Clutha/Mata-Au catchment**

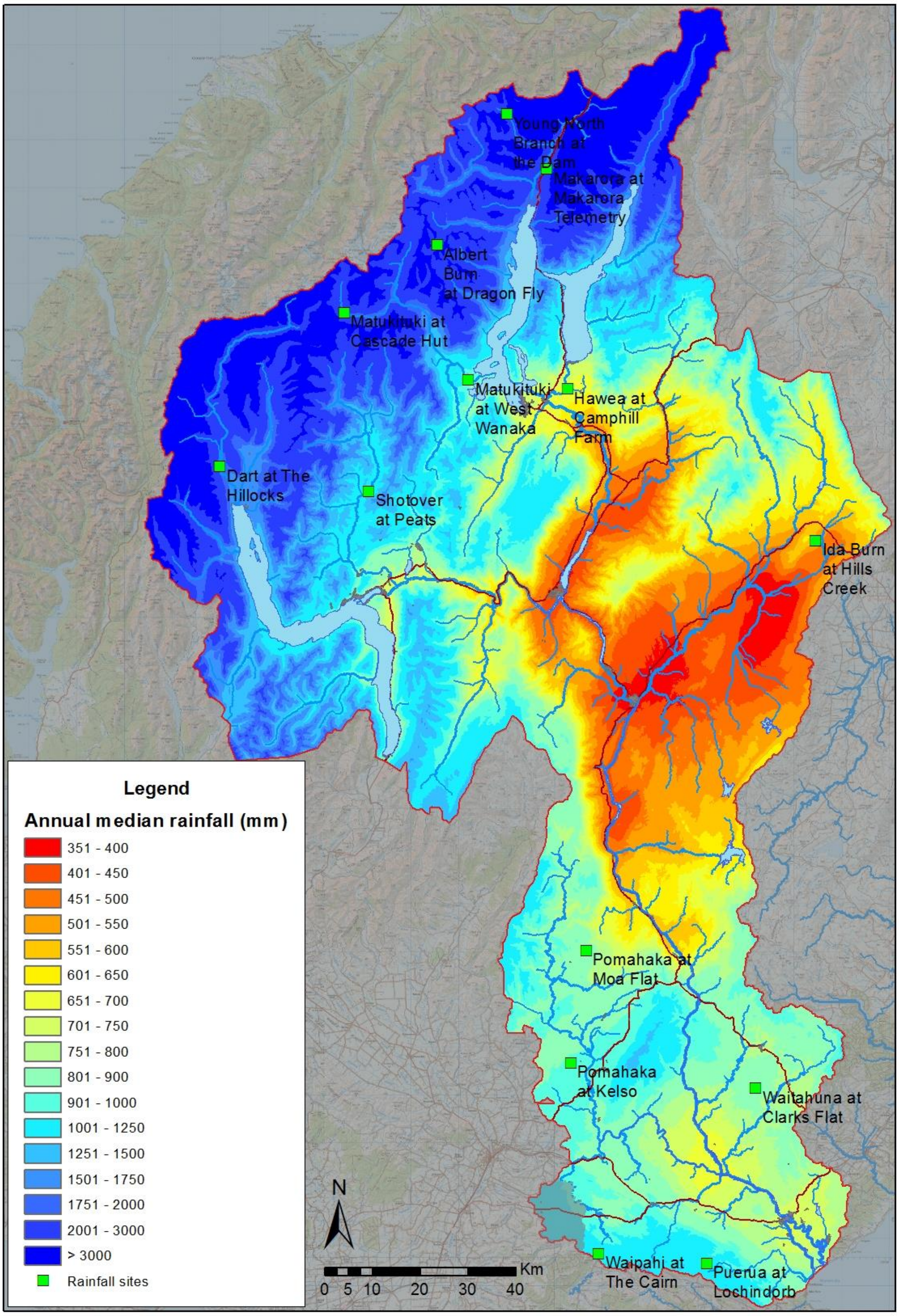

Figure 3 **Median annual rainfall in the Clutha/Mata-Au catchment (from GrowOtago) with telemetered rainfall sites.**

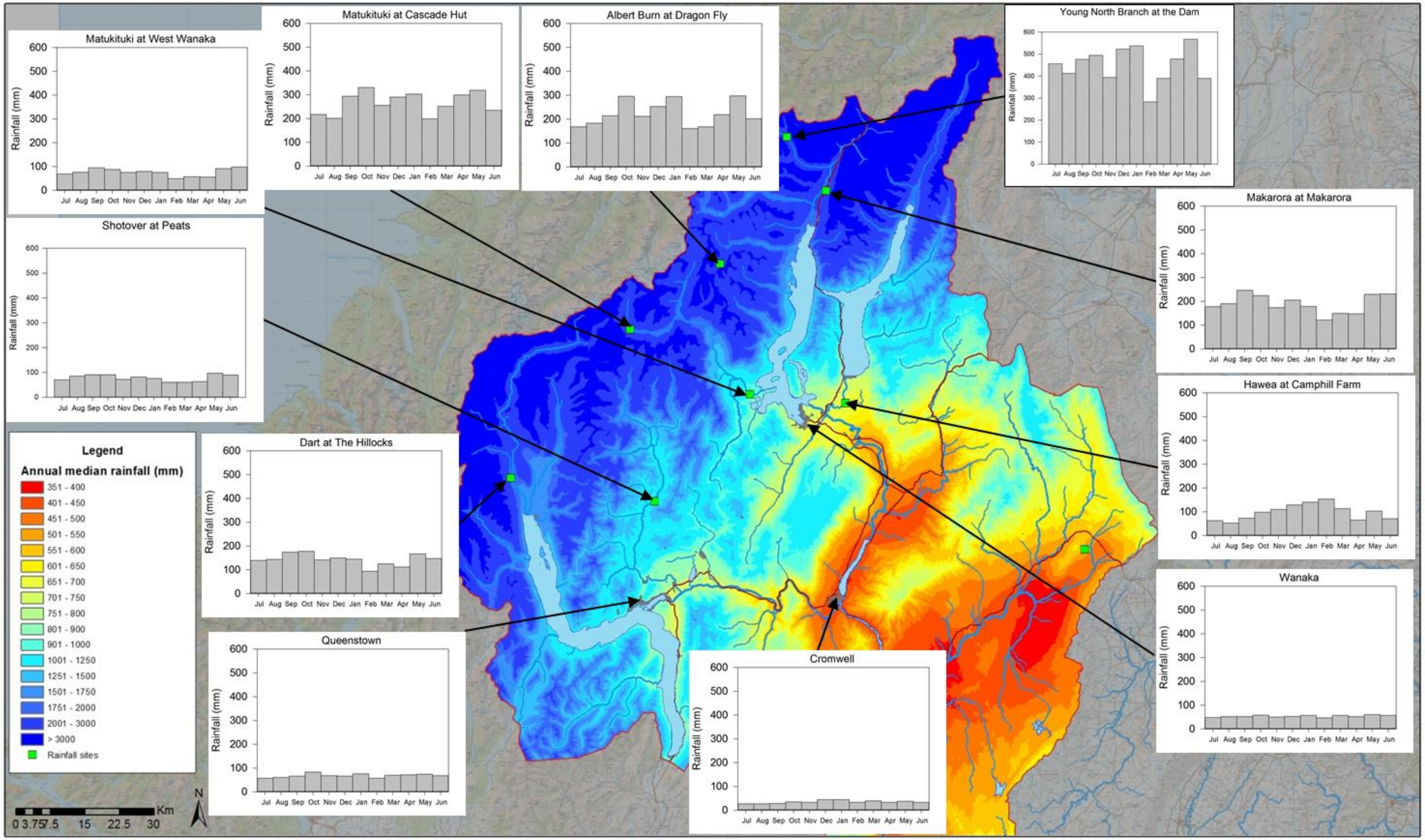

Figure 4 **Seasonal rainfall distribution at rainfall sites in the upper Clutha/Mata-Au catchment. Note: The graphs for each rainfall site are were not generated using data from the same time period, so are not directly comparable.**

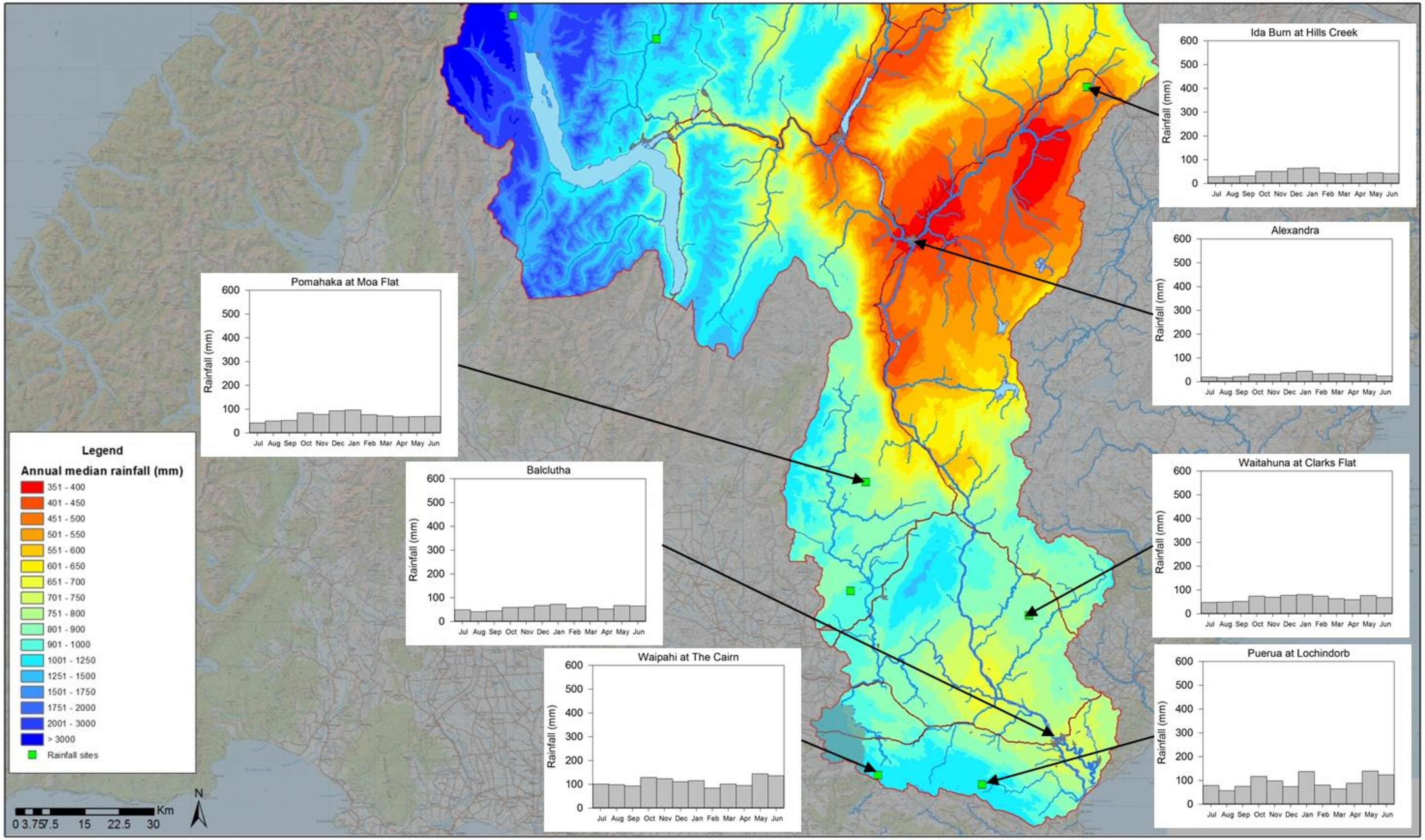

Figure 5 **Seasonal rainfall distribution at rainfall sites in the middle and lower Clutha/Mata-Au catchment Note: The graphs for each rainfall site are were not generated using data from the same time period, so are not directly comparable.**

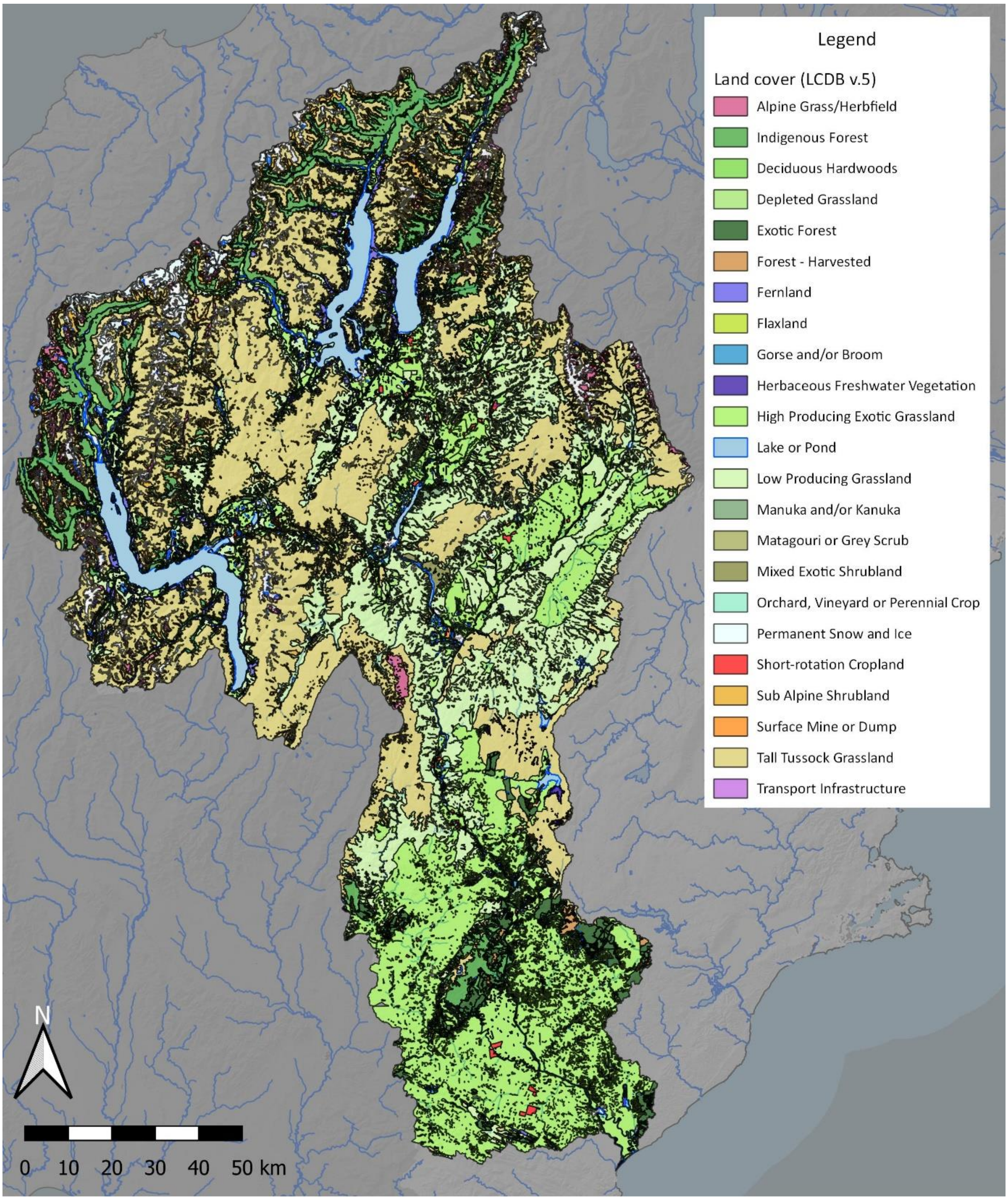

Figure 6 **Land cover in the Clutha/Mata-Au catchment based on the Land Cover Database (LCDB, version 5).**

3. Water Use

3.1. Hydro-electric development

Two large hydroelectric dams are present on the Clutha River/Mata-Au, both of which are currently operated by Contact Energy. Combined, these two dams represent approximately 8%[10] of the total installed capacity within the total New Zealand electricity sector (Ministry of Business, Innovation & Employment, 2015).

Construction of Roxburgh Dam (320 MW) was started in 1952 and was commissioned in 1956. As part of the Clutha power development, a dam was formed at the outlet of Lake Hāwea and was commissioned in 1958, raising the water level of Lake Hāwea by up to 20 metres (8 m operating range). Construction of Clyde Dam (432 MW) was started in 1982, and it was commissioned in 1992, forming Lake Dunstan. From 1987, both dams were owned by the Electricity Corporation of New Zealand (ECNZ), a state-owned enterprise until 1996, when ECNZ was split into two entities and the two dams were transferred to the newly formed state-owned enterprise, Contact Energy. Contact Energy became a private company in 1999.

3.1.1. Contact Energy

The operation of the dam at the outlet of Lake Hāwea, Clyde Dam and Roxburgh Dam are subject to a number of resource consents held by Contact Energy. These consents expire on 25 May 2042 and have conditions relating to a wide range of matters including flood management, discharge rates from structures (including minimum discharge, or residual flows), ramping rates (rate of change in flow with time), recreational flows, riverbank stability, safety warnings, river mouth maintenance, coastal erosion, archaeological sites, fish habitat enhancement, native fish management, sports fish management, sediment management, landscape and visual amenity management, monitoring (water level, flow, biological), and reporting.

Key consent conditions relating to residual flows include:

- Discharge Permit 2001.392.V5 requires:
    - A minimum discharge of 10 m^3/s below the Hāwea Dam at all times (Condition 8a),
    - A maximum discharge of 200 m^3/s below the Hāwea Dam, except during flood conditions (Condition 8b),
    - Discharge from the Hāwea River is to be managed such that the flow of the Clutha River at the Cardrona Confluence flow site does not exceed 800 m^3/s, except during flood conditions (Condition 8c),
    - Condition 8d of this consent requires the consent holder to use "reasonable endeavours to maintain a stable minimum flow regime in the Hāwea River between 10 and 60 cumecs between 1 September in any year and 31 January the following year

[10] Based on a combined output of 3,750 GWh, compared to the national output in 2015 of 44,321 GWh

to provide for rainbow trout spawning and rearing and angling" and that a flow of 60 m^3/s is not to be exceeded during this period except when flows in the Hāwea River are being managed to minimise the risk of high lake levels, recreational flows are provided for other recreational users, electrical supply and demand considerations require, or plant maintenance requires.

  - Condition 9 outlines maximum rates of increase in discharge (condition 9a) and decrease in discharge (condition 9b).

- Discharge Permit 2001.394.V1 requires a minimum flow of 250 m^3/s be maintained in the lower Clutha River/Mata-Au below the Roxburgh Dam, except when the combined mean daily flow of:

  i. Clutha/Mata-Au at Cardrona plus 10 m^3/s, less the mean Hāwea River flow (at Camp Hill bridge),

  ii. Kawarau at Chards Road,

  iii. Nevis at Wentworth, and

  iv. Manuherikia at Ophir

is less than 250 m^3/s, then the minimum discharge below Roxburgh Dam shall not be less than that combined daily mean flow.

- Discharge Permit 2001.394.V1 also requires the consent holder to use "reasonable endeavours to maintain a stable minimum flow regime between 300 and 400 cumecs from Roxburgh Dam for a period from the beginning of September to mid-October each year to limit the dewatering of salmon redds when eggs are hatching…"

The presence of Roxburgh and Clyde Dams impedes fish passage to the upper Clutha catchment for several migratory fish species, including lamprey, eels and salmon. These impacts are recognised and addressed by conditions 16a(vi) and 17 of Resource Consent 2001.394.V1.

3.1.2. Other hydro-electric development

In addition to the large power stations in the Clutha/Mata-Au catchment, Pioneer Energy Ltd. operates several power schemes within the Clutha/Mata-Au catchment:

- Oxburn Power Scheme, Rees Valley, Glenorchy (2.5 GWh),
- Wye Creek Station, Queenstown-Kingston Highway (9 GWh),
- Roaring Meg Hydro Scheme, Kawarau Gorge (28 GWh).
- Upper Fraser Hydro Scheme, Earnscleugh (33 GWh),
- Fraser Dam (no installed generation, but storage for downstream schemes and irrigation)

- Fraser Station, Earnscleugh (20 GWh),
- Falls Dam, upper Manuherekia River (8 GWh),
- Onslow Dam (no installed generation, but storage for downstream scheme and irrigation),
- Horseshoe Bend Hydro Scheme, Teviot River (4.3 MW),
- Kowhai Power Station, Teviot River (2 MW, 7 GWh)
- Michelle Hydro Scheme, Teviot River (1.6 MW, 12 GWh),
- George Hydro Scheme, Roxburgh (1 MW, 7 GWh),
- Ellis and Bridge Hydro Schemes, Roxburgh (6.8 MW and 1.125 MW respectively; 3 GWh).

Other small-scale hydro-electric power schemes are present in tributaries of Lake Wānaka (Alpha Burn, Niger Stream, Rough Burn, Waterfall Creek), Lake Whakatipu Waimaori (Georges Creek, Short Burn, and an unnamed tributary), tributaries of the Lindis River (McKenzies Creek, Station Creek and Waiwera Creek), unnamed tributary of Long Spur Creek), Lake Dunstan (Quartz Reef Creek), Butchers Dam (Butchers Creek, Chapmans Gully, Link Race Dam, Pagets Dam), and the Talla Burn.

4. Regulatory setting

4.1. Regional Plan: Water (RPW)

The Clutha/Mata-Au and Kawarau rivers were exempted from many of the water allocation provisions of the Regional Plan: Water (RPW, e.g. Policy 6.4.1). Therefore, the Clutha/Mata-Au and Kawarau rivers currently do not have minimum flows and/or allocation limit(s) applied to them.

Furthermore, the RPW provides for water to be taken from the Clutha/Mata-Au or Kawarau Rivers, or Lakes Wānaka, Hāwea, Whakatipu, Dunstan or Roxburgh as a permitted activity as long as the instantaneous rate of take does not exceed 100 l/s and no more than 1,000,000 litres is taken in any single day (Rule 12.1.2.2 of the RPW).

4.2. 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 proposed objectives for the Dunstan, Roxburgh and Lower Clutha Rohes, valid at the time of writing, are presented in Table 2.

The objectives set out in Table 2 apply to sites on the mainstems of the Clutha/Mata-Au and Kawarau Rivers. For the sake of brevity, only objectives that apply to flowing water bodies are shown in Table 2.

Table 2 **Proposed environmental outcomes for the values identified in the Clutha Mata-Au FMU and their attributes and target attributes.**

Rohe	Dunstan Rohe						Roxburgh Rohe		Lower Clutha Rohe	
	Clutha @ Luggate Br			Kawarau @ Chards Rd			Clutha at Millers Flat		Clutha at Balclutha	
Variables	Baseline State	Interim Target	Target 2030	Baseline State	Interim Target	Target 2030	Baseline State	Target 2050	Baseline State	Target 2050
Periphyton Biomass										
Periphyton TN	B		B	C (C - B)		C	B	B	B	B
Periphyton TP	C (C - A)		B	C		B	A (A - B)	B	C	B
Ammonia - median	A		A	A		A	A	A	A	A
Ammonia - 95th Percentile	A		A	A		A	A	A	A	A
E. coli 260	A		A	B (B - A)		B	A	A	A	A
E. coli 540	B (B - A)		B	C (C - A)		B	A	A	B	B
E. coli median	A		A	D (D - A)	C	B	A	A	A	A
E.Coli Q95	B (B - A)		B	D (D - A)	C	B	A	A	D (B - D)	C
DRP-median	B (A - B)		B	A		A	A	A	A	A
DRP Q95	B (A - B)		B	A		A	A	A	A	A
MCI										
ASPM										
FISH IBI										
Suspended fine sediment	D (D - A)	C	B	Exempt		Exempt	Exempt	Exempt	Exempt	Exempt
NNN - median	A		A	A		A	A	A	A	A
NNN - 95th percentile	A		A	A		A	A	A	A	A

Otago Regional Council

4.3. National legislation and water conservation orders

Several waterways within the Clutha/Mata-Au catchment are protected by an Act of Parliament or by National Water Conservation Order. This section provides an overview of each of these regulations, the values they recognise and the implications they have for the management of aquatic ecosystems in the mainstem of the Clutha River/Mata-Au and Kawarau Rivers.

4.3.1. Lake Wānaka Preservation Act (1973)

The purposes outlined in the Lake Wānaka Preservation Act (1973)[11] are:

(a) to prevent the water in the body of the lake from being impounded or controlled by, or, as far as possible, obstructed by, any works except in an emergency;

(b) to prevent the natural rate of flow of lake water between the outlet of the lake which forms the source of the Clutha River and the confluence of that river and the Cardrona River from being varied or controlled by any works except in an emergency;

(c) to preserve, as far as possible, the water levels of the lake and its shoreline in their natural state;

(d) to maintain and, as far as possible, to improve the quality of water in the lake.

For the purposes of this report, the key provisions of the Act are the maintenance of natural flows and lake levels and prohibition of damming of Lake Wānaka or the upper Clutha River/Mata-Au to the Cardrona confluence.

4.3.2. Water Conservation (Kawarau) Order

The Water Conservation (Kawarau) Order[12] was originally gazetted on 20 March 1997. It was amended on 14 November 2011 for an exemption for flood protection works in the lower Shotover River (from the state highway bridge to the confluence with the Kawarau) and on 11 November 2013 in respect of the Nevis River. The WCO (Kawarau) sets out those waterways in the Kawarau catchment that are to be preserved in natural state (Schedule 1) and the characteristics to be protected in those waterways that are no longer in their natural state (Schedule 2). Each of these schedules outlines the outstanding amenity and intrinsic values present in the listed waterways (see Table 3 for those relating to the Kawarau River and Lake Whakatipu).

For the purposes of this report, the key provisions of the Water Conservation (Kawarau) Order are the prohibition of damming of the Kawarau River and the water quality classes these water bodies are to be managed to (Table 3).

[11] https://www.legislation.govt.nz/act/public/1973/0107/latest/DLM411131.html
[12] https://www.legislation.govt.nz/regulation/public/1997/0038/latest/DLM227675.html

Table 3 **Provisions within Schedule 2 of the Water Conservation (Kawarau) Order (Waters to be Protected) that relate to the mainstem of the Kawarau River**

Waters	Outstanding characteristics	Restrictions and prohibitions
Kawarau River mainstem from Scrubby Stream to Lake Whakatipu control gates (S133: 940715 to S132: 615707)	(c) wild and scenic characteristics; (c) natural characteristics, in particular the return flow in the upper section when the Shotover River is in high flood; (d) scientific values, in particular the return flow in the upper section when the Shotover River is in high flood; (e) recreational purposes, in particular rafting, jetboating, and kayaking.	(i) no damming allowed; (ii) water quality to be managed to Class CR[13] standard.
Lake Whakatipu (from outlet at control gates (S132:615707) to confluences of Dart River (at or about S122: 291916) and Rees River (at or about S123: 301915) and including whole lake)	(b) fishery; (c) scenic characteristics; (d) scientific value, in particular water clarity, and bryophyte community; (e) recreational purposes, in particular boating (g) significance in accordance with tikanga Maori, in particular sites at the head of the lake, and the legend of the lake itself.	(i) fish passage to be maintained; (ii) water quality to be managed to Class AE[13], Class CR[13], Class F[13], and Class FS[13] standards.

[13] See Appendix A

5. River hydrology

5.1. Upper Clutha River/Mata-Au

5.1.1. Outflows from Lake Wānaka

A long-term record of water level is available for Lake Wānaka (1 February 1933-29 June 2023), and this record was used to estimate outflows from Lake Wānaka since 1954. The rating for this site has been very stable (Pete Stevenson, *pers. comm.*), and for the purposes of this analysis, it has been retrospectively applied to the full period of record (for full analysis see Appendix B).

Long-term average outflows from Lake Wānaka were 199 m^3/s, while median flows were 179 m^3/s and 7-d MALF was estimated to be 81.1 m^3/s (Table 4).

5.1.2. Outflows from Lake Hāwea

Water level in Lake Hāwea was monitored since 10 July 1930, with records from 1930 to 1955 being of natural water levels in the lake, prior to the construction and commissioning of the outlet control structure in 1958. Flow data for this site is available from 1 January 1933 to 30 June 1955, representing 23 years of actual natural flow data for this site (Table 4). The 7-d MALF obtained for this period was 30.1 m^3/s (Table 4).

Synthetic flows for the outlet of Lake Hāwea were calculated for the period 1 January 1933 to 29 June 2023) based on the relationship of flows from this site with outflows from Lake Wānaka over the period 1 January 1933-30 June 1955 (Table 4). The method used to estimate naturalised outflows from Lake Hāwea is outlined in Appendix B. The 7-d MALF obtained for this period was 32.2 m^3/s (Table 4).

5.1.3. Upper Clutha/Mata-Au downstream of the Cardrona/Ōrau confluence

Naturalised mean flows for the upper Clutha/Mata-Au downstream of the Cardrona/Ōrau confluence were calculated as the sum of outflows from Lake Wānaka and Lake Hāwea and flows in the Cardrona River.

Naturalised flows accord closely with the mean based on observed flows (Table 4). The median flow based on observed flows was higher than the naturalised median flow, which is to be expected given that Lake Hāwea operates to store water for electricity generation and therefore expected to decrease the magnitude of peak flows and supplement flows during periods of low flow. Estimates of the 7-day MALF at this site based on naturalised and observed flows suggest that observed low flows are higher than that expected to occur naturally (Table 4).

5.2. Kawarau River

Flows in the Kawarau River are measured at the Chards Road flow recorder, which is downstream of the confluence of the Shotover River with the Kawarau. It was determined that flows at this site were little affected by water abstraction (which mostly occurs in tributary streams), so for the purposes of this report, flows in the Kawarau at Chards Road were treated as very close to the natural flow.

Table 4 **Summary of flow statistics for selected flow recorder sites in the Clutha and Kawarau catchments. All sites are operated by NIWA.**

			Annual		
Site	**Dates**		**Mean (m³/s)**	**Median (m³/s)**	**7-d MALF (m³/s)**
Lake Wānaka outlet	2-Feb-1933 – 3 Aug 1955	Natural (pre- Hāwea Dam)	195	180	77
	1-Jan-1933 - 29-Jun 2023	Natural (full record)	199	179	81
Lake Hāwea outlet	2-Feb-1933 – 3 Aug 1955	Natural (pre- Hāwea Dam)	64	59	30
	1-Jan-1933 - 29-Jun 2023	Naturalised	64	59	32
Hāwea at Camphill Bridge	6-Mar-1968 – 6 Nov 2023	Actual	65.9	36.4	8.64
Clutha at below Cardrona confluence	1-Jan-1933 - 29-Jun 2023	Naturalised*	263	238	113
	10-Apr-1992 - 29-Jun 2023	Naturalised*	267	240	117
	10-Apr-1992 - 29-Jun 2023	Actual	273	262	132
Kawarau at Chards Road	30-Jun-1967 – 30 Jun 2023	Actual†	211	189	89
Clutha at Balclutha‡	6-Jul-1954 – 30-Jun-2023	Actual	575	535	298

* Based on the sum of observed (2 February 1933 – 3 August 1955) or synthetic (4 August 1955-29 June 2023) outflows from Lake Hāwea and observed outflows from Lake Wanaka)

† Actual allocation upstream of this site is ~6% of the 7-d MALF, so the flow statistics presented approximate natural flows.

‡ From Stewart 2023

5.3. Water allocation

Consented allocation in the upper Clutha/Mata-Au sub-catchment is 14.7 m³/s, with almost 1 m³/s from the Lake Wānaka sub-catchment (lake and tributaries), and 3 m³/s from the Lake Hāwea catchment. Other large volumes are allocated from the Lindis (1.489 m³/s), Cardrona (0.958 m³/s), Basin Burn catchments (1.557 m³/s), and 4.4 m³/s from the unnamed tributaries and the Clutha River itself (Table 5). The allocation estimate includes permits that are non-consumptive (e.g. hydro-electric generation or snow-making activities[14]), so it likely over-estimates the actual water allocation pressure in the upper Clutha/Mata-Au sub-catchment.

[14] Water abstraction for snow making typically occurs outside of the irrigation season, and water is released from the snow-pack during snow-melt.

In the Kawarau sub-catchment, 1.412 m^3/s is allocated from Lake Whakatipu and its tributaries, 1.619 m^3/s from the Roaring Meg, 0.922 m^3/s from the Arrow sub-catchment, and 0.451 m^3/s from the Shotover catchment (Table 5). These amounts include permits that are non-consumptive (including 1.541 m^3/s of the 1.619 m^3/s in the Roaring Meg), so likely over-estimates the water allocation pressure in the Kawarau sub-catchment.

An additional allocation of 2 m^3/s is allocated from Lake Dunstan and its tributaries, 26.7 m^3/s from the Clutha catchment between Clyde and Roxburgh Dams (including 4 m^3/s from the Fraser River, and 18.4 m^3/s from the Manuherekia catchment). Further downstream 14.6 m^3/s is allocated from the lower Clutha/Mata-Au below the Roxburgh Dam (including 2.3 m^3/s from the Beaumont River, 6.7 m^3/s from the Teviot River, 1.3 m^3/s from the Poumāhaka[15] catchment and 3.7 m^3/s from the mainstem and unnamed tributaries) (Table 5). This value appears to include permits that are non-consumptive or retakes and so likely over-estimate the water allocation pressure in this part of the Clutha/Mata-Au catchment.

Overall allocation in the Clutha/Mata-Au is approximately 63 m^3/s, although as noted above, this value is likely to over-estimate the actual consumptive take. This represents 21% of the estimated 7-d MALF for the lower Clutha/Mata-Au (Table 5).

Table 5 **Summary of consented allocation in different sub-catchments of the Clutha/Mata-Au and Kawarau Rivers.**

Sub-catchment	Consented allocation (m^3/s)	7-d MALF (m^3/s)	Allocation (% 7-d MALF)
Upper Clutha/Mata-Au (upstream Lake Dunstan)	14.7	115.9	13%
Kawarau River	5.0	88.5	6%
Clutha/Mata-Au (Clyde Dam to sea)	43.3		
Clutha/Mata-Au catchment total	**63.0**	**298.0**	**21%**

[15] https://kahurumanu.co.nz/atlas

6. 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 Clutha/Mata-Au catchment, brown trout (*Salmo trutta*) are likely to be among 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 temperatures in the Clutha River/Mata-Au at Luggate Bridge between 15 December 2015 and 1 April 2009 are presented in Figure 7. Water temperatures in the Clutha River/Mata-Au at Luggate Bridge over this period were well within acute and chronic thermal criteria for the indigenous species present, as well as brown and rainbow trout (Table 6). These data suggest that the thermal environment of the upper Clutha/Mata-Au is suitable for several of the indigenous and introduced fish species found in the river.

Water temperatures in the Clutha River/Mata-Au at Balclutha between 15 September 1992 and 27 June 2023 are presented in Figure 8 - Figure 11. Water temperatures in the lower Clutha River/Mata-Au at Balclutha over this period were well within acute criteria for brown and rainbow trout, but have exceeded acute criteria for several of the indigenous species on occasion (including the common mayfly *Deleatidium*, common bully, longfin eels, the amphipod *Paracalliope* and the sand-cased caddis fly *Pycnocentria*) (Table 6). Temperatures in the lower Clutha River/Mata-Au at Balclutha exceeded chronic thermal criteria for brown in some years and rainbow trout in most years considered (Table 6). These data suggest that the thermal environment of the lower Clutha/Mata-Au may be unsuitable for several of the indigenous species (including the common mayfly *Deleatidium*, common bully, longfin eels, the amphipod *Paracalliope* and the sand-cased caddis fly *Pycnocentria*) and introduced fish species (brown and rainbow trout) found in the river at times.

Table 6 Number of exceedances of thermal criteria at monitoring sites in the Clutha River/Mata-Au.

Site	Thermal criteria	Number of exceedances		Years with no exceedances	Total number of years
		Mean	Max		
Clutha at Luggate Bridge (15 December2005 – 1 April 2009)	Brown trout acute (>24.6°C)	0	0	4	4
	Rainbow trout acute (>23.8°C)	0	0	4	4
	Deleatidium acute (21°C)	0	0	4	4
	Common bully, *Paracalliope* acute (22°C)	0	0	4	4
	Longfin eel, *Pycnocentria* acute (23°C)	0	0	4	4
	Brown trout chronic (>19.6°C)	0	0	4	4
	Rainbow trout chronic (>18.2°C)	0	0	4	4
Clutha at Balclutha (15 September 1992 – 27 June 2023)	Brown trout acute (>24.6°C)	0	0	31	31
	Rainbow trout acute (>23.8°C)	0	0	31	31
	Deleatidium acute (21°C)	1.2	17	28	31
	Common bully, *Paracalliope* acute (22°C)	0.3	7	29	31
	Longfin eel, *Pycnocentria* acute (23°C)	0.1	3	30	31
	Brown trout chronic (>19.6°C)	2.1	23	28	31
	Rainbow trout chronic (>18.2°C)	16.3	72	5	31

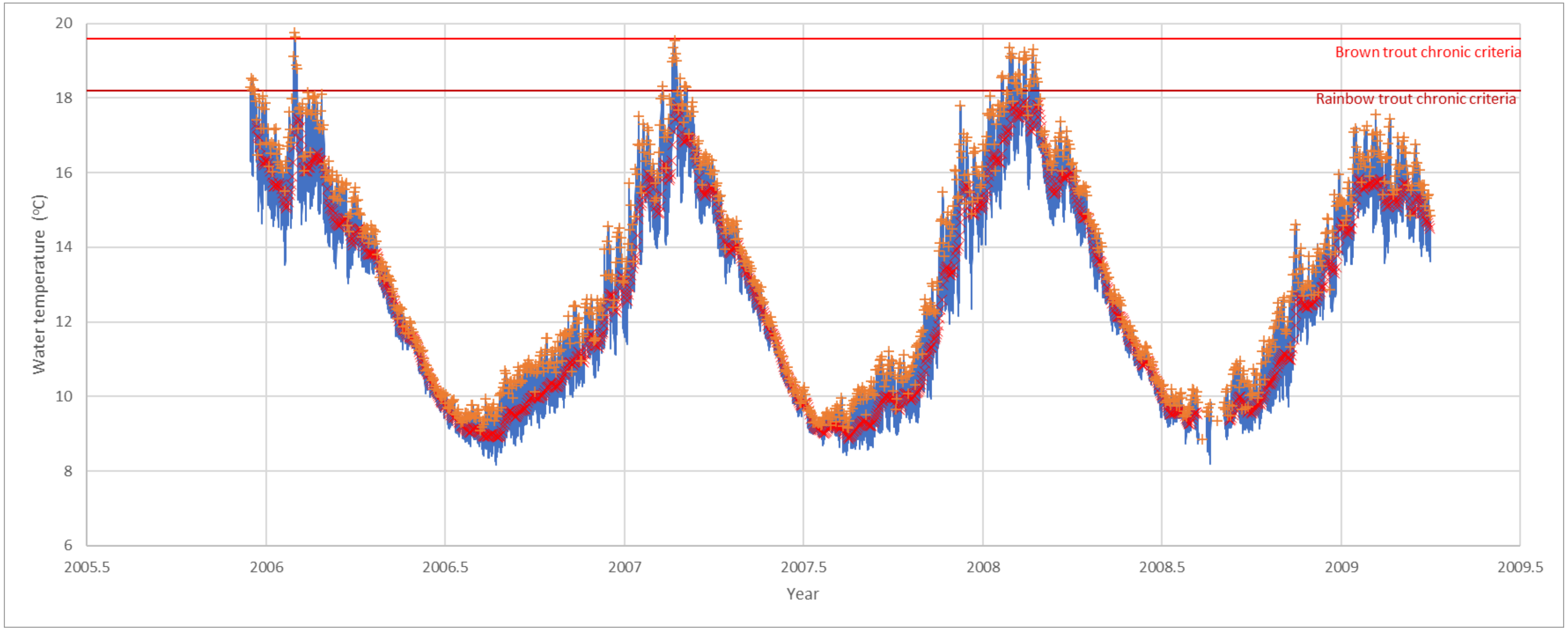

Figure 7 **Water temperature in the Clutha at the Luggate Bridge between December 2005 and April 2009. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red circles are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.**

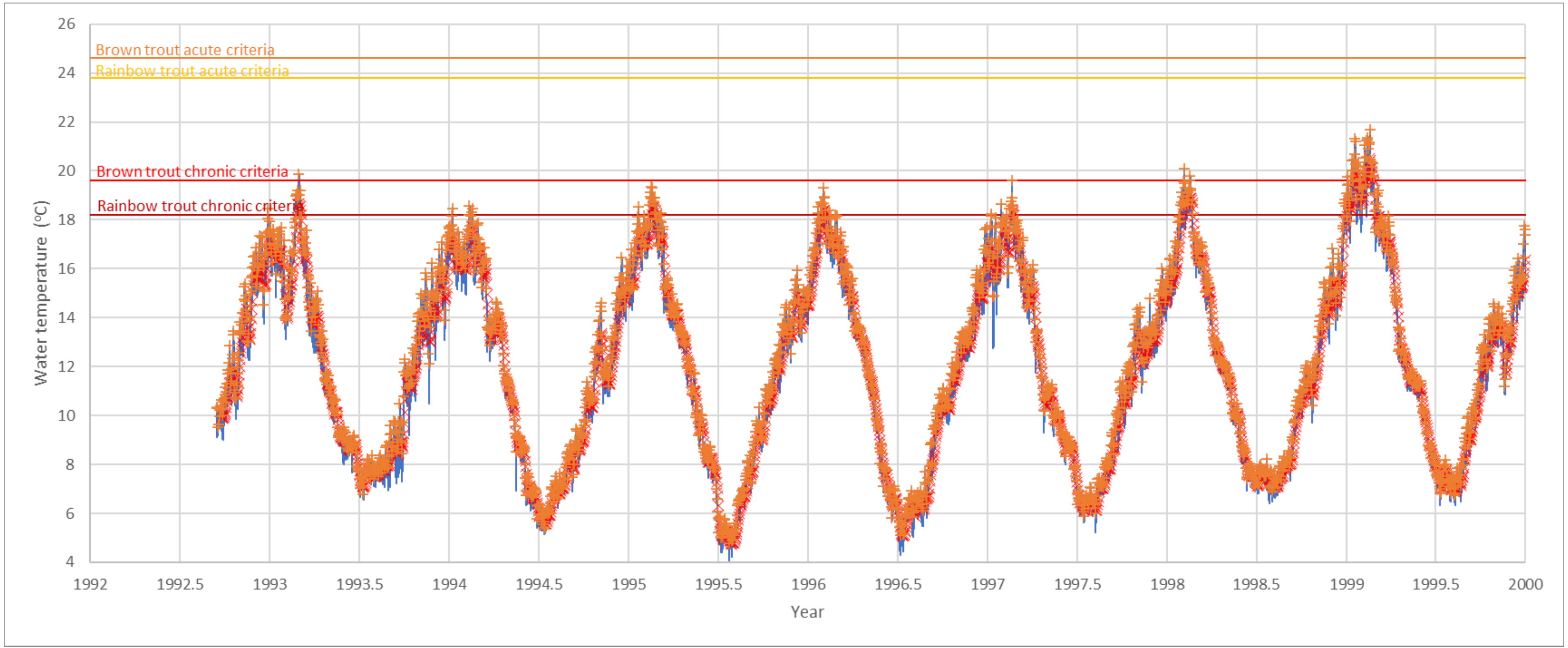

Figure 8 **Water temperature in the Clutha at Balclutha between September 1992 and December 1999. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red circles are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.**

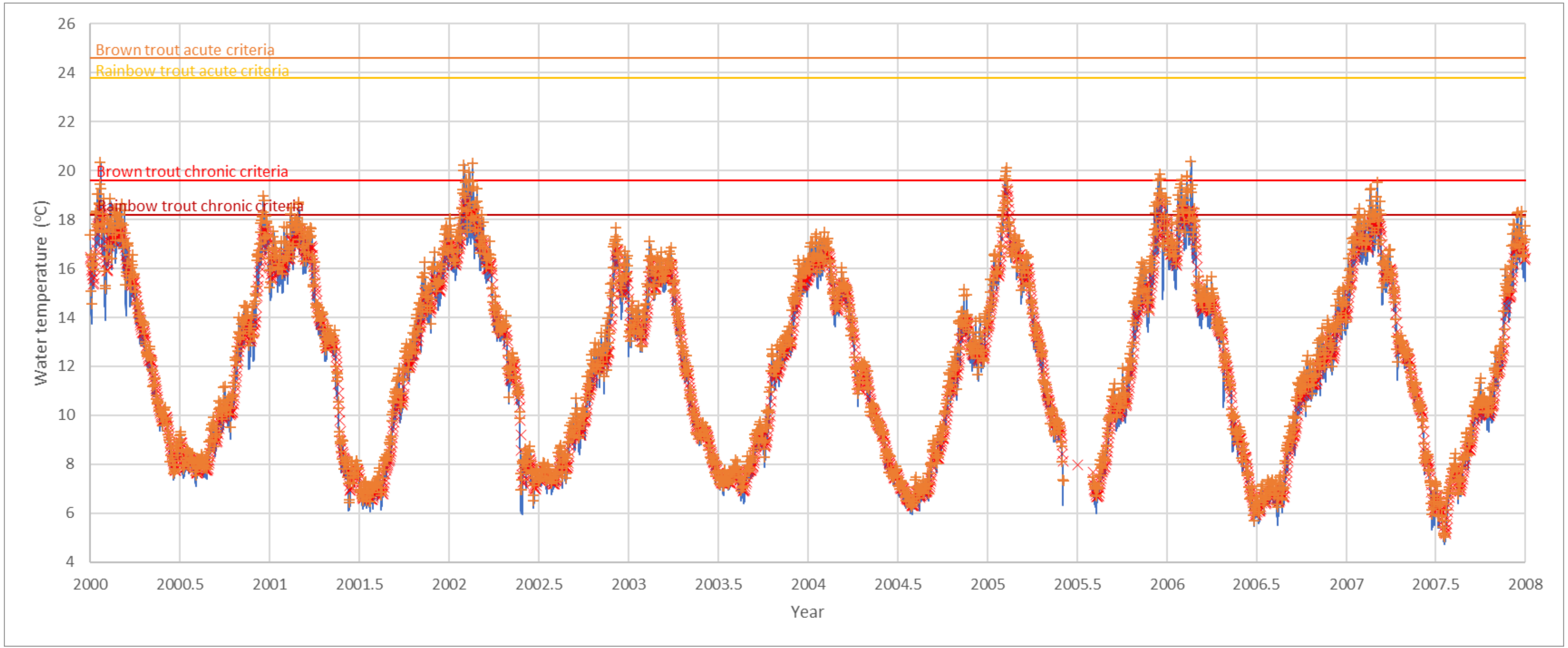

Figure 9 **Water temperature in the Clutha at Balclutha between January 2000 and December 2007. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red circles are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.**

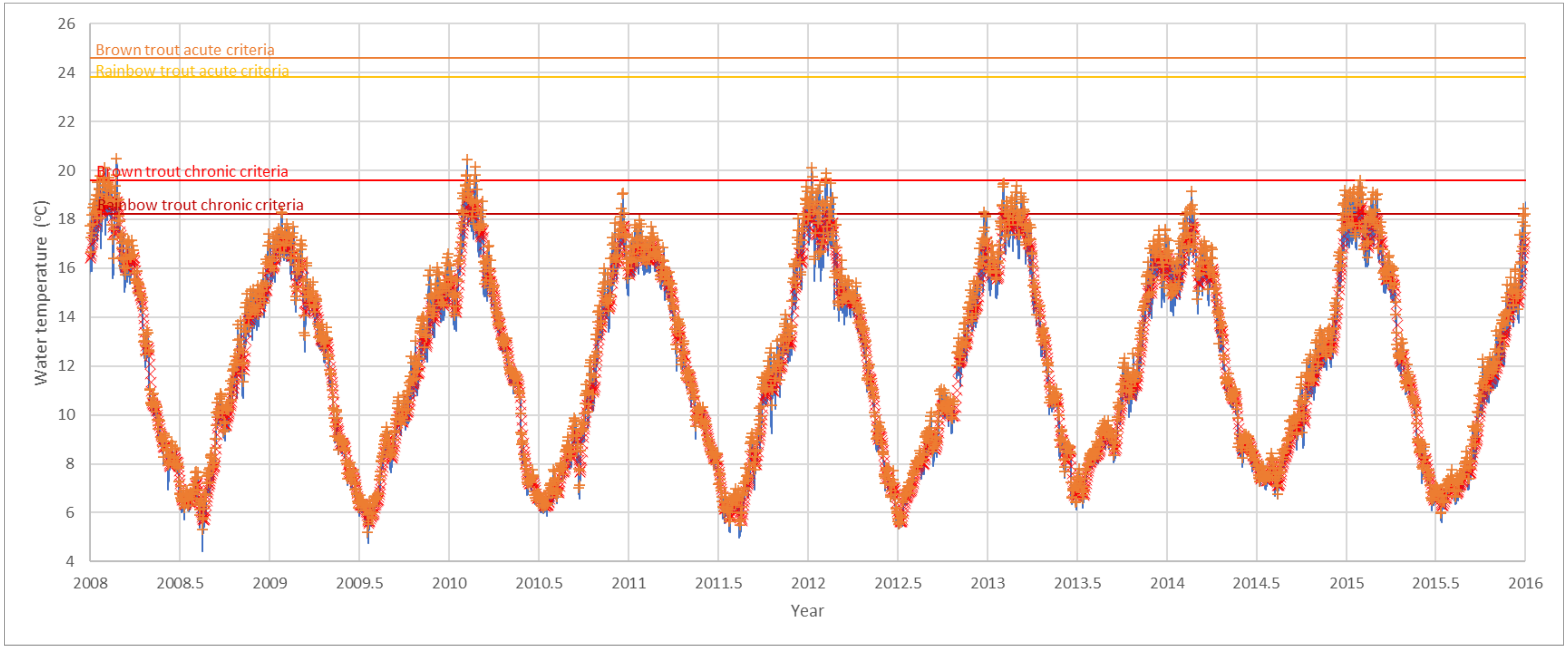

Figure 10 **Water temperature in the Clutha at Balclutha between January 2008 and December 2016. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red circles are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.**

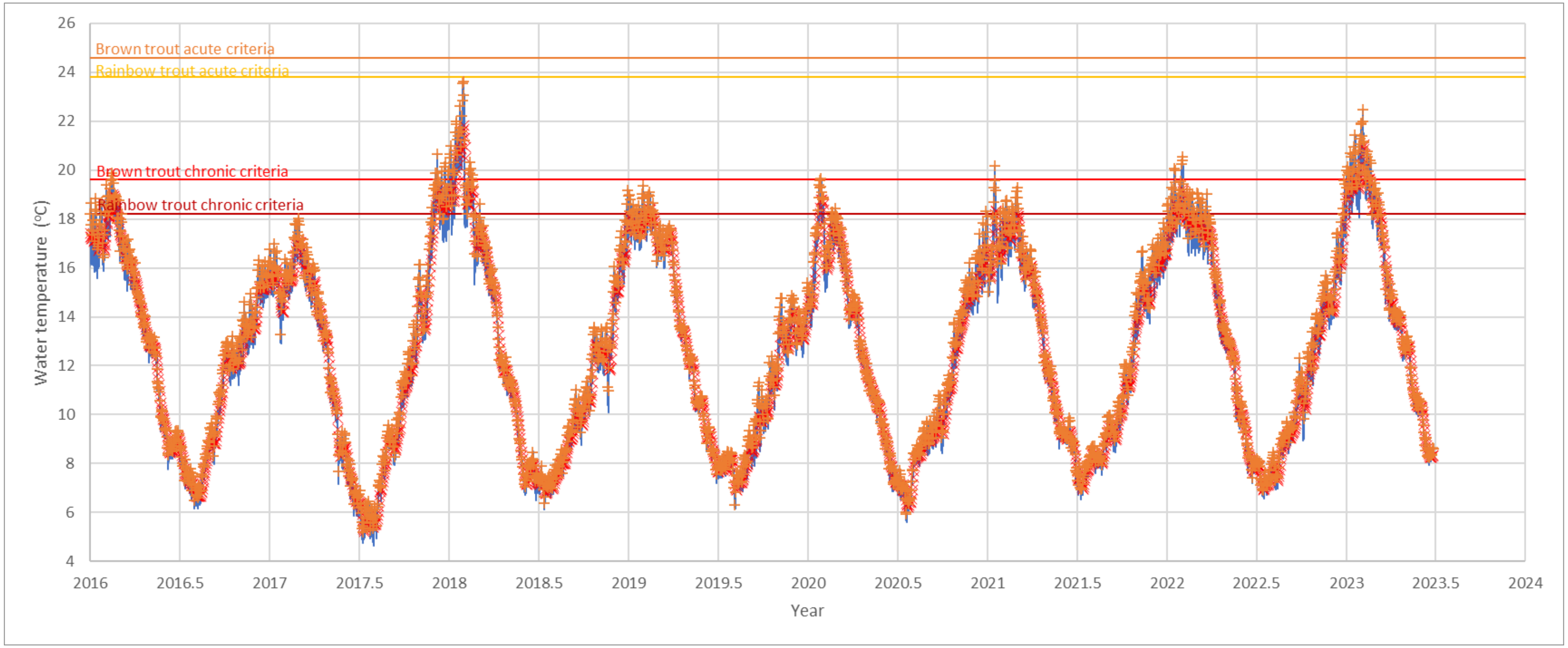

Figure 11 **Water temperature in the Clutha at Balclutha between January 2016 and June 2023. Orange crosses are the maximum 2-h average water temperature for comparison with acute thermal criteria. Red circles are the seven-day average of mean daily temperatures for comparison with chronic thermal criteria.**

7. Values of the Clutha/Mata-Au & Kawarau Rivers

7.1. Schedule 1A of the RPW

Schedule 1A of the RPW identifies some of the natural and human use values of Otago's lakes and rivers. Table 7 presents the values identified for the Clutha/Mata-Au and Kawarau Rivers. The outstanding natural features identified for the Kawarau River in Table 7 are those identified in the Water Conservation (Kawarau) Order.

Table 7 **Natural values identified for the mainstem of the Clutha River/Mata-Au and Kawarau River in Schedule 1A of the Regional Plan: Water.**

Water body	Ecosystem Values	Outstanding natural feature or landscape	Significant indigenous vegetation and significant habitat of indigenous fauna
Clutha River/Mata-Au between Alexandra and Lake Wānaka	Large river size, bed composed of bedrock, gravel, spawning habitat (trout & salmon), riparian vegetation, habitat for juvenile trout & salmon, significant presence of trout, eel and salmon, presence of indigenous fish species threatened with extinction, significant diversity of indigenous waterfowl.		*Significant habitat* for flathead galaxiid (tributaries).
Clutha River/Mata-Au between Alexandra and Island Block	Large river size, bed composed of bedrock, gravel and sand, riparian vegetation, significant presence of trout, eel and salmon, significant diversity of indigenous waterfowl, spawning habitat (salmon) below Roxburgh dam, significant vegetation below Roxburgh dam.		*Significant habitat* for lamprey (uncommon in Otago).
Clutha River/Mata-Au between Island Block and Balclutha	Large river size, unimpeded passage to the sea, bed composed of gravel and sand, spawning habitat (trout & salmon), habitat for juvenile fish, significant presence of trout, eel and salmon, significant vegetation, significant diversity of indigenous waterfowl, presence of indigenous fish species threatened with extinction, indigenous fish diversity, regionally significant presence of gamebirds between Balclutha and Tuapeka River mouth.	Beaumont and Rongahere Gorge	*Significant habitat:* Remnant indigenous ecosystem at Birch Island. *Significant vegetation:* Rare association of aquatic plants above confluence with Tuapeka
Clutha River/Mata-Au between Balclutha and the sea	Large river size, unimpeded passage to the sea, bed composed of gravel and sand, spawning habitat (salmon), habitat for juvenile trout & salmon, significant presence of trout, eel and salmon, indigenous fish diversity, presence of indigenous fish species threatened with extinction, regionally significant presence of gamebirds.		

Table 7 **Natural values identified for the mainstem of the Clutha River/Mata-Au and Kawarau River in Schedule 1A of the Regional Plan: Water.**

Water body	Ecosystem Values	Outstanding natural feature or landscape	Significant indigenous vegetation and significant habitat of indigenous fauna
Kawarau River between Lake Dunstan and Lake Whakatipu	Large river size, bed composed of gravel and bedrock, significant presence of trout, eel and salmon, presence of indigenous fish species threatened with extinction, absence of aquatic pest plants upstream of Lake Dunstan.	Outstanding: (a) for its wild, scenic characteristics; (b) natural characteristics, in particular the return flow in the upper section when the Shotover River is in flood; (c) for scientific values, in particular the return flow in the upper section when the Shotover is in flood; (d) for recreational purposes, in particular rafting, jet boating and kayaking. Spectacular and rugged river gorge, schistose landscape, fast flowing white water and rapids, old gold sluicing landscape, from confluence with Arrow River to Lake Dunstan.	*Significant habitat* for kōaro including many tributaries.

7.2. Water Conservation (Kawarau) Order

The provisions of the Water Conservation (Kawarau) Order relevant to this report are outlined in Section 4.3.2. The Water Conservation (Kawarau) Order recognises a number of outstanding values for the mainstem of the Kawarau River. These values include: wild and scenic characteristics, natural characteristics, scientific values (in particular the return flow in the upper section when the Shotover River is in high flood) and recreational values, in particular rafting, jetboating, and kayaking.

7.3. Indigenous fish

Twenty-four indigenous fish species have been recorded from the Clutha catchment (Table 8). Indigenous fish species include giant kōkopu, kōaro, banded kōkopu, four bully species (upland, common, giant and redfin bully), longfin and shortfin eels, common smelt, inanga, torrentfish, and black flounder.

Of the indigenous fish species found in the Clutha/Mata-Au catchment, eleven species are classified as "threatened": two are classified as nationally critical (Clutha flathead galaxias, Teviot galaxias), four are classified as nationally endangered (alpine galaxias "Manuherekia", dusky galaxias, Nevis galaxias, and Central Otago roundhead galaxias) and five are classified as nationally vulnerable (alpine galaxias "Southland", Gollum galaxias, Pomahaka galaxias, Southern flathead galaxias, and kanakana/lamprey) (Dunn et al. 2018; Table 8). In addition, five species recorded from the Clutha/Mata-Au catchment are classified as "at risk, declining": longfin eel, torrentfish, giant kokopu, inanga and kōaro (Dunn et al. 2018; Table 8). Shortfin eel, common bully, upland bully, redfin bully, banded kōkopu, yelloweye mullet, common smelt, and black flounder are not considered to be threatened, while giant bully are classified as "at risk, naturally uncommon" (Dunn et al. 2018; Table 8).

Shortfin and longfin eels, torrentfish, common bully, giant bully, redfin bully, banded kōkopu, giant kōkopu, inanga, kōaro, lamprey, black flounder and common smelt are all migratory species which require access to the sea in order to complete their life cycle (although common bully and kōaro can form land-locked populations). The current distributions of these species are altered by the presence of hydroelectric dams at Roxburgh, Clyde, and Hāwea. These barriers prevent migration to and from the headwater lakes without human intervention. Eels represent a specific concern, particularly for iwi. Eels return to the ocean to spawn once at the end of their life. Because of their particularly long lifespans in southern New Zealand (>80 years), there are remaining populations of adults in upstream areas whose final seaward migrations are impeded by downstream hydroelectric dams. As a result, eel populations in the upper Clutha are likely to be declining. Yelloweye mullet are a marine fish that are commonly found in freshwaters close to the coast.

Kōaro are present in the lower Clutha in low numbers but commonly form landlocked populations in tributaries upstream of lakes or reservoirs such as Wānaka, Whakatipu and Hāwea. These landlocked populations of kōaro are often of high density and form inland whitebait runs on the Matukituki, Makarora, Reese and Dart rivers. However, whitebaiting on these rivers is currently not permitted. Establishment of kōaro in manmade reservoirs (such as Lake Dunstan) represents a potential threat to non-migratory galaxiids as kōaro occupy a similar environmental role and may out compete non-migratory species when in close proximity to a lake.

The wider Clutha catchment contains ten non-migratory galaxiids which are restricted to tributaries. These galaxiids all have highly significant conservation and scientific values due to their conservation status and unique evolutionary histories (Table 8). While distributed throughout the Clutha catchment, these species are generally restricted to tributaries where trout are absent. Clutha flathead galaxias and lower Clutha galaxias are distributed in pockets throughout the Clutha basin suggesting at least some non-migratory species were likely distributed throughout the main stem of the Clutha River before the introduction of trout.

Whilst neither are fish, the New Zealand Freshwater Fish Database contains records of koura (freshwater crayfish; *Paranephrops zealandicus*) and kākahi (freshwater mussels; *Echyridella menziesii*) in the catchment. Both have a threat classification of "at risk, declining" (Granger et al., 2018). Freshwater shrimp (*Paratya curvirostris*) are present in the lower Clutha/Mata-Au and have a threat classification of "not threatened" (Granger et al., 2018).

7.4. Sports fish

Five sport fish species have been recorded within the Clutha catchment: brown and rainbow trout, Chinook salmon, brook char and perch. Lakes Wānaka, Whakatipu, Hāwea, Dunstan, and Roxburgh provide angling opportunities for landlocked Chinook salmon as well as brown and rainbow trout. Tributaries of the headwater lakes (Wānaka, Whakatipu, Hāwea) such as the Greenstone, Lochy, Hunter and others form some of New Zealand's world renowned and premier backcountry fisheries (Otago Fish & Game Council, 2015). These lakes and tributaries also support many commercial guiding services contributing to the local tourism economy.

The lower reaches of the Clutha River/Mata-Au provide angling opportunities for rainbow trout as well as sea-run populations of both salmon and brown trout. Brook char tend to form self-sustaining populations of small, stunted fish high in the headwater streams of the Nevis, Manuherekia and tributaries draining the Pisa Range. Perch are present in Lake Hayes/ Waiwhakaata, Lake Dunstan, the mainstem of the Clutha/Mata-Au below the Clyde Dam, and in the Manuherekia catchment (Otago Fish & Game Council, 2015).

The Upper Clutha River is a nationally significant salmon and trout (rainbow and brown) fishery while the Lower Clutha River is considered to be a regionally significant salmon and brown trout fishery (Otago Fish & Game Council, 2015). Table 7.3 presents angler effort on the Clutha River, recorded during National Angler Surveys conducted in 1994/95, 2001/2002, 2007/08 and 2014/15. Angler use appears to be variable with a general increase from the 2001/02 to the 2007/08 survey followed by a decline in the 2014/15 survey (Unwin, 2016). Angler hours tend to be concentrated on the large lakes which comprise up to 50% of Otago's angler use hours making the Clutha catchment a particularly important fishery in both Otago and New Zealand (Otago Fish & Game Council, 2015).

Table 8 **Fish species of the Clutha/Mata-Au and Kawarau catchments, conservation threat classification, and distribution. Threat classification based on Dunn *et al.* (2018).**

Common name	Taxonomic name	Threat classification	Upper Clutha	Kawarau	Lake Dunstan-Roxburgh Dam	Lower Clutha
Shortfin eel	*Anguilla australis*	Not threatened				X
Longfin eel	*Anguilla dieffenbachii*	Declining	X	X	X	X
Torrentfish	*Cheimarrichthys fosteri*	Declining				X
Upland bully	*Gobiomorphus breviceps*	Not threatened	X	X	X	X
Common bully	*Gobiomorphus cotidianus*	Not threatened	X	X	X	X
Giant bully	*Gobiomorphus gobioides*	Naturally uncommon				X
Redfin bully	*Gobiomorphus huttoni*	Not threatened				X
Alpine galaxias "Manuherekia"	*Galaxias aff. paucispondylus* "Manuherikia"	Nationally Endangered			X	
Alpine galaxias "Southland"	*Galaxias aff. paucispondylus* "Southland"	Nationally vulnerable		X		
Banded kokopu	*Galaxias fasciatus*	Not threatened				
Clutha flathead galaxias	*Galaxias sp. D*	Nationally Critical	X		X	X
Dusky galaxias	*Galaxias pullus*	Nationally Endangered				X
Giant kokopu	*Galaxias argenteus*	Declining				X
Gollum galaxias	*Galaxias gollumoides*	Nationally Vulnerable				X
Inanga	*Galaxias maculatus*	Declining				X
Kōaro	*Galaxias brevipinnis*	Declining	X	X	X	X
Nevis galaxias	*Galaxias* "Nevis"	Nationally Endangered		X		
Pomahaka galaxias	*Galaxias "Pomahaka"*	Nationally Vulnerable				X
Central Otago roundhead galaxias	*Galaxias anomolus*	Nationally Endangered			X	
Southern flathead galaxias	*Galaxias "Southern"*	Nationally Vulnerable		X		
Teviot flathead galaxias	*Galaxias "Teviot"*	Nationally Critical				X
Lamprey	*Geotria australis*	Nationally Vulnerable			X	X
Yelloweye mullet	*Aldrichetta forsteri*	Not threatened				X
Black flounder	*Rhombosolea retiaria*	Not threatened				X
Common smelt	*Retropinna retropinna*	Not threatened				X
Goldfish	*Carassius auratus*	Introduced and naturalised	X	X		
Perch	*Perca fluviatilis*	Introduced and naturalised		X	X	X
Brook char	*Salvelinus fontinalis*	Introduced and naturalised	X	X	X	X
Brown trout	*Salmo trutta*	Introduced and naturalised	X	X	X	X
Chinook salmon	*Oncorhynchus tshawytscha*	Introduced and naturalised	X	X	X	X
Rainbow trout	*Oncorhynchus mykiss*	Introduced and naturalised	X	X	X	X

Table 9 **Angler effort in the Clutha/Mata-Au and Kawarau Rivers and associated lakes (angler days ± standard error) based on the National Angler Survey (Unwin 2016).**

Angling water	Angler usage (angler days ± SE)			
	2014/15	2007/08	2001/02	1994/95
Clutha River/Mata-Au (Wānaka to Lake Dunstan)	6,670 ± 1,330	20,900 ± 3,220	20,160 ± 2,760	11,440 ± 2130
Clutha River/Mata-Au (Clyde to Alexandra)	1,280 ± 770			
Clutha River/Mata-Au (below Roxburgh), salmon	6,760 ± 2,700			
Clutha River/Mata-Au (below Roxburgh), trout	16,660 ± 2,770			
Clutha River/Mata-Au (below Roxburgh)		12,550 ± 1,940	14,450 ± 2,950	14,890 ± 2390
Clutha River/Mata-Au (undefined)		4,640 ± 1,140	2,710 ± 980	
Clutha River/Mata-Au(total)	**31370 ± 4160**	**38090 ± 3930**	**37320 ± 4160**	**26340 ± 3210**
Lake Roxburgh	1,420 ± 580	3,080 ± 1,150	210 ± 90	50 ± 40
Kawarau River	1,630 ± 600	1,930 ± 750	1,700 ± 770	3,500 ± 1,000
Lake Whakatipu	21,860 ± 3,170	20,970 ± 2,230	17,720 ± 1,910	2,1410 ± 2,180
Lake Dunstan	17,080 ± 2,120	26,030 ± 2,800	19,480 ± 2,910	22,250 ± 1,750
Hāwea River	480 ± 170	710 ± 310	4,970 ± 1,310	1,920 ± 470
Lake Hāwea	13,640 ± 2,490	21,920 ± 2,750	28,160 ± 3,670	18,820 ± 2,260
Lake Wānaka	22,410 ± 3,180	39,070 ± 5,710	25,270 ± 2,310	25,530 ± 2,370
Total, Clutha/Mata-Au catchment	**136,420 ± 7,420**	**182,830 ± 8,670**	**173,150 ± 7,800**	**149,100 ± 5,840**

7.5. Riverine birds

Thirty-four species of riverine birds have been recorded from the Clutha/Kawarau catchment of which thirty-two are native (Forest & Bird, 2016). The Clutha/Mata-Au catchment provides a wide variety of habitats for riverine birds. The Hunter, Makarora and Matukituki rivers are braided with extensive gravel beds as well as permanent inland deltas and tussock river flats. These catchments differ from other areas of the Clutha by residing in national parks and having extensive native beech (*Fuscospora*[16] and *Lophozonia*[17]) forest in riparian areas (Forest & Bird 2016). As a result, these catchments may have predator control programs providing habitat and predator densities which favour survival of vulnerable species such as whio/blue duck. Riparian areas of these tributaries also provide habitat for species such as fantail, tomtit and other native songbirds.

The upper Clutha/Mata-Au catchment (Wānaka outflow to Roxburgh dam) provides extensive gravel beds, swamps, permanent inland deltas, riparian willow, riparian pasture and two large freshwater

[16] Formerly *Nothofagus*, *Fuscospora* includes red beech (*F. fusca*), hard beech (*F. truncata*), mountain beech (*F. cliffortioides*) and black beech (*F. solandri*)
[17] Silver beech (*Liophozonia menziesii*), formerly *Nothofagus menziesii*.

lakes (Dunstan and Roxburgh) (Forest & Bird, 2016). These areas generally lack the native beech forest and predator control programs undertaken in the large tributaries to the headwater lakes.

The lower Clutha River (Matau and Koau Branches) provides coastal shoreline, estuarine, brackish lagoon, gravel beds, swamps, as well as riparian willow and pasture habitats. As a result, the lower Clutha supports many marine gull species as well as wading and some inland species (Forest & Bird 2016).

Of particular note on the Clutha River/Mata-Au are populations of the nationally endangered black-fronted tern, nationally vulnerable grey duck (though most grey duck are likely to have interbred with mallard), Caspian tern, southern white-fronted tern, kāmana/Australasian crested grebe, and whio/blue duck (Robertson et al. 2021). The nationally critical kakī/black stilt have been sighted in the upper Clutha catchment (near Makarore/Makarora). Other species found in the catchment including banded dotterel, black-billed gull, red-billed gull, eastern bar-tailed godwit, New Zealand pipit, South Island pied oystercatcher and marsh crake are considered to be at risk, declining (Robertson et al. 2021).

Royal spoonbill and Australian coot are considered to be naturally uncommon, while black shag and little shag are considered to be relict[18] taxa. Buff weka are also classified as relict and have been reintroduced onto islands on Lakes Wānaka and Whakatipu Waimaori. Southern black-backed gull, black swan, mallard, white-faced heron, pūtangitangi/paradise shelduck, spur-winged plover, poaka/pied stilt, kotare/New Zealand kingfisher, Australasian shoveler, grey teal, pūkeko, and pāpango/New Zealand scaup are also known to occur and are not threatened (Roberstson et al. 2021). Wrybill are classified as nationally increasing (Roberstson et al. 2021).

7.6. Game birds

The upper and lower reaches of the Clutha River provide habitat and hunting opportunity for six game birds including mallard, black swan, paradise shelduck, Australasian shoveler, and grey duck. Pukeko, Canada goose and grey teal are also present in the Clutha catchment. Hunting often occurs in wetlands, swamps, deltas and small lagoons of the Clutha and its tributaries (Otago Fish & Game Council, 2015).

[18] Taxa that have undergone a documented decline within the last 1000 years, now occupy < 10% of their former range and meet one of the following criteria: A) 5000–20 000 mature individuals; population stable (± 10%), B) >20 000 mature individuals; population stable (± 10%) or increasing at > 10%

7.7. Summary of instream values

The waterways in the Clutha and Kawarau catchments provide habitat for fish, birds, and plants, many of which are threatened, rare or declining native species. Twenty-four species of indigenous fish are present in the Clutha catchment. This includes two species which are listed as “nationally critical”, five species listed as “nationally endangered”, two species listed as “nationally vulnerable”, and eight species listed as “at risk declining”. (Dunn et al. 2018). In addition, koura (freshwater crayfish; *Paranephrops zealandicus*) and kākahi (freshwater mussels; *Echyridella menziesii*) are also present in the catchment. Both have a threat classification of “at risk, declining” (Granger et al., 2018). Freshwater shrimp (*Paratya curvirostris*) are present in the lower Clutha/Mata-Au and have a threat classification of “not threatened” (Granger et al., 2018).

The upper Clutha River is a nationally significant trout and salmon fishery, and the lower Clutha is a regionally significant trout and salmon fishery. When combined with lakes inside the catchment, the Clutha may comprise over 50% of Otago’s angling effort. Along with fish, the Clutha also provides habitat for thirty-four species of bird of which three are critically endangered, one is endangered, five are declining, six are vulnerable, four are naturally uncommon and six are game species. The Clutha catchment also contains sixty-six regionally significant wetlands.

The highest in-stream conservation values present within the Clutha/Mata-Au catchment, such as Clutha flathead galaxias, Teviot galaxias and other non-migratory galaxiids, are not found within the main stem of the Clutha River affected by flow alteration and are not considered as part of this instream habitat assessment.

Of the bird species recorded in the Clutha/Mata-Au, black-fronted terns are likely to be the most flow-dependant species because they feed on adult aquatic invertebrates (especially mayflies). However, given the very large size of the upper Clutha and their preference for braided habitats, it is expected that the primary potential effects of minimum flow/ allocation on black-fronted terns is the effect on habitat for their macroinvertebrate prey.

8. Flow setting for the Upper Clutha/Mata-Au

A two-dimensional hydraulic model was produced for a single reach of the Clutha River/Mata-Au by NIWA in 2016 (Figure 12) and formed the basis for instream habitat modelling and the trout bioenergetics model produced by Cawthron in 2017 (Hayes et al. 2018). The study reach covered a 0.9 km reach near Queensberry. This reach was chosen as representative of much of the upper Clutha River/Mata-Au between the confluences of Clutha/Mata-Au with the Hāwea (upstream) and Lindis (downstream) Rivers. The full assessment is presented in Hayes et al. (2018) and what follows is a summary of the key aspects of those analyses that are relevant to flow setting in the upper Clutha/Mata-Au.

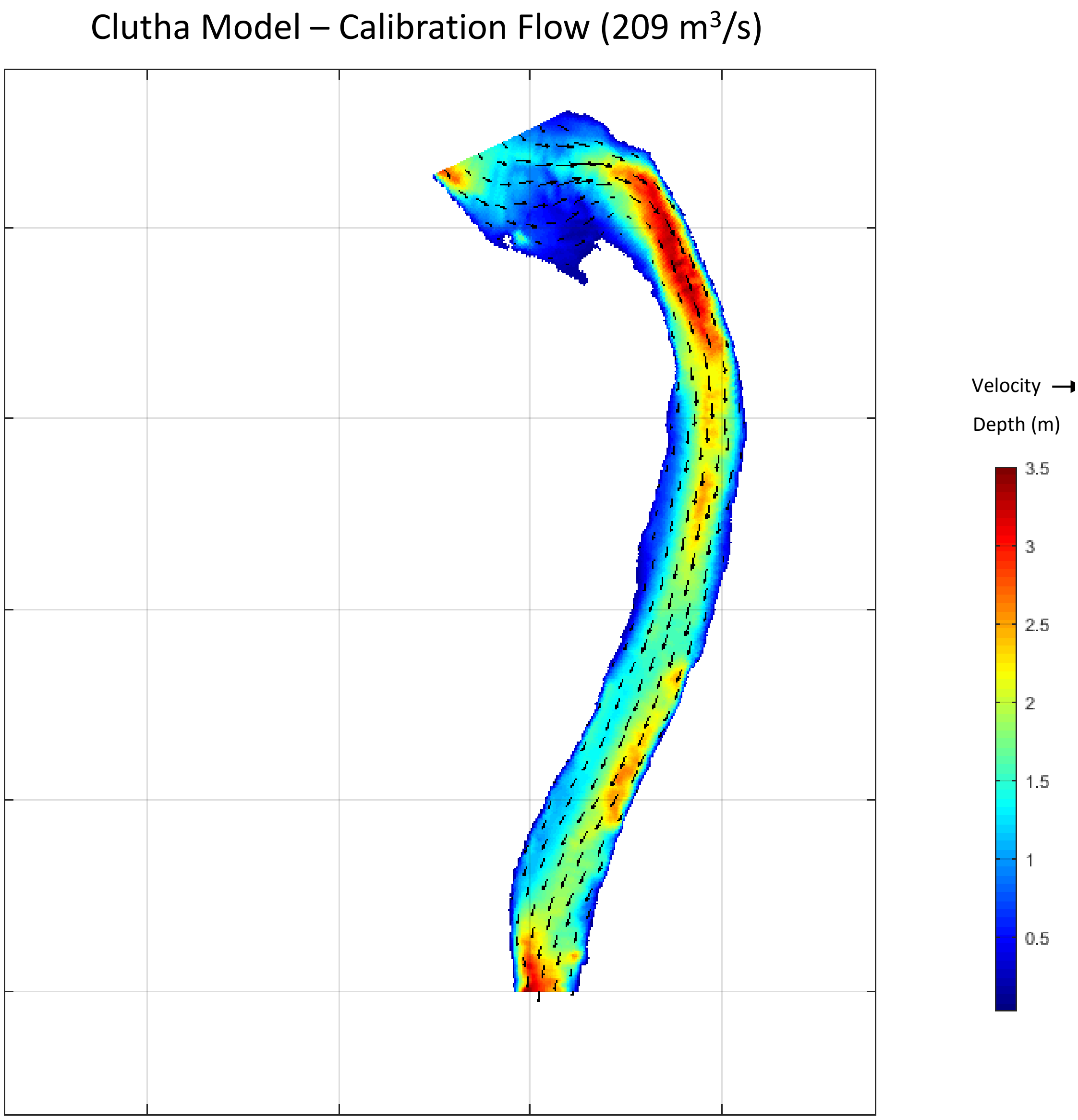

Figure 12 **Hydraulic model of the 900 metre study reach in the upper Clutha River/Mata-Au near Queensberry at a flow of 209 m^3/s showing water depth (colour scale) and water velocity vectors (the length of the arrow indicates the velocity of the water). From Hayes et al. (2018).**

8.1. Habitat suitability curves

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

Table 10 **Habitat suitability curves used in instream habitat modelling in the upper Clutha River/Mata-Au.**

Group	HSC name	HSC source
Periphyton	Cyanobacteria	Ex Heath *et al.* (2013)
	Diatoms	Unpublished NIWA data
	Didymo (Waitaki)	Jowett
	Long filamentous	Unpublished NIWA data
	Short filamentous	Unpublished NIWA data
Macro-invertebrates	Food producing	Waters (1976)
	Mayfly nymphs *(Deleatidium)*	Jowett *et al*. (1991)
	Mayfly nymphs *(Coloburiscus)*	Jowett *et al*. (1991)
	Net-spinning caddis fly (*Aoteapsyche*)	Jowett *et al.* (1991)
Fish	Brown trout adult	Hayes & Jowett (1994)
	Brown trout adult - South Platte (depth modified)	Bovee (1993)
	Brown trout adult – Clutha (depth modified)	Jowett & Davey (2007)
	Adult trout T2	Wilding *et al.* (2014)
	Juvenile trout (T1)	Wilding *et al.* (2014)
	Brown trout (< 100 mm) (depth modified)	Jowett & Richardson (2008)
	Rainbow trout > 40 cm (Clutha) (depth modified)	
	Rainbow trout adult (depth modified)	Thomas & Bovee (1993)
	Rainbow trout juvenile	Thomas & Bovee (1993)
	Brown trout spawning	Shirvell & Dungey (1983)

8.2. Periphyton

Periphyton is a term referring to the community that 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 many stream food webs; 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 may detrimentally affect instream values, such as aesthetics, biodiversity, recreation (swimming and angling), water takes (irrigation, stock/drinking water and industrial) and water quality. Thus, instream habitat modelling is usually used to consider the risk of the development of nuisance growths of periphyton.

The analyses undertaken by NIWA and presented in Hayes et al. (2018) consider HSC for five classes of periphyton: cyanobacteria (specifically the benthic cyanobacterium previously known as *Phormidium*, now known as *Microcoleus autumnalis*), diatoms (thin to medium growths of native diatom species), didymo (*Didymosphenia geminata*, an invasive non-native diatom), short filamentous algae and long filamentous algae (Figure 13). These periphyton classes were included in these analyses to consider how changes in flow may affect periphyton cover and composition, and the potential impacts on other instream values.

Cyanobacteria were included because some types may produce toxins that pose a health risk to humans and animals. These include toxins that affect the nervous system (neurotoxins) and liver (hepatotoxins), and dermatotoxins that can cause severe irritation of the skin. The presence of potentially toxic cyanobacteria is undesirable as it can affect the suitability of a waterway for drinking, recreation (swimming), dogs, stock drinking water and food-gathering (by affecting palatability or through accumulation of toxins in organs such as the liver). Cyanobacteria-produced neurotoxins have been implicated in the deaths of numerous dogs in New Zealand (Hamill, 2001; Wood et al., 2007). Instream habitat modelling for the Clutha/Mata-Au suggests that habitat quality for *Phormidium* increases with decreasing flow across the modelled flow range (Hayes et al. 2018).

Native diatoms are generally considered a desirable component of the periphyton community, while didymo is an invasive, non-native diatom that can form dense, extensive mats (Figure 13c) that can affect recreational and ecosystem values, as well as water use (ORC, 2007; Larned *et al*., 2007). Habitat for diatoms and Didymo are predicted to increase with decreasing flows across the modelled flow range (Hayes et al. 2018).

Filamentous algae, and in particular long filamentous algae, can form nuisance blooms during periods of stable flows and high nutrient conditions. Such blooms can affect a range of instream values, including aesthetics, biodiversity, recreation (swimming and angling), water takes (irrigation, stock/drinking water and industrial) and water quality. Habitat for short filamentous algae are predicted to increase with decreasing flows across the modelled flow range (80-370 m^3/s; Hayes et al. 2018). While habitat for long filamentous algae is predicted to gradually increase with decreasing flows across the modelled flow range, the predicted increase in habitat suitability is smaller than for other species considered (Hayes et al. 2018).

Periphyton cover in the upper Clutha/Mata-Au is currently dominated by Didymo. The results of instream habitat modelling suggest that in the absence of substantial changes in water quality, the periphyton in the upper Clutha/Mata-Au is unlikely to change appreciably. However, there is a chance that reduced flows may create more favourable conditions for Didymo, which may increase the extent and thickness of Didymo cover. There is also more risk of an increase in cover by benthic cyanobacteria.

Figure 13 **Periphyton types a) benthic cyanobacteria (*Phormidium*), b) native diatoms, c) underwater photograph showing an extensive growth of didymo in the Hāwea River and d) long and short filamentous algae (and cyanobacteria).**

8.3. 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), and were included in these analyses to consider how changes in flow in the modelled reaches may affect food availability for fish and birds. HSC for "food producing habitat" (conditions representative of the most productive habitats in rivers) and three taxa that are likely to be common in the Clutha River/Mata-Au: the common mayfly *Deleatidium*, the net-spinning caddis fly *Hydropsyche*[19] and the filter-feeding mayfly *Coloburiscus* (Figure 14). *Deleatidium* is arguably the most widespread and common freshwater invertebrate in New Zealand. Both *Hydropsyche* and *Coloburiscus* are also widespread and common in New Zealand rivers, but particularly common in lake-fed rivers. Hayes et al. (2018) found that *Deleatidium* (18%) and *Hydropsyche* (17%) were the two most abundant macroinvertebrate taxa in their survey reach.

[19] This taxon was formerly in the genus *Aoteapsyche*, however taxonomic revision shifted *Aoteapsyche* to a sub-genus within the *Hydropsyche* genus (Geraci et al. 2010)

Both *Hydropsyche* and *Coloburiscus* are filter-feeders; *Hydropsyche* constructs a silk net that catches food as it is washed downstream in the current (Figure 15), while *Coloburiscus* uses long hairs on its legs to trap food from the current. Because these species feed on suspended organic matter, they not rely on the growth of periphyton on rock surfaces for food, but rather on suspended, drifting food particles. This means that they are not restricted to shallower areas where periphyton can grow (especially where periphyton receives enough light for photosynthesis) and prefer areas with swift flow (as this delivers more food to them).

The large size of both *Hydropsyche* and *Coloburiscus* makes them more visible to drift-feeding trout and they provide a greater amount (dry mass) of food per prey item caught (i.e., more energy per prey caught). Trout feeding on smaller prey must catch more prey for the same energy intake, which means that they will expend a greater amount of energy on foraging than if they were able to consume fewer, large prey items. The result may be that they will have less energy for growth and reproduction, which translates to smaller fish and reduced population productivity.

The quality and extent of habitat for all macroinvertebrate species was predicted to increase with decreasing flows (Hayes et al. 2018).

Figure 14 **Macroinvertebrate taxa considered in these analyses: a) a nymph of the common mayfly (*Deleatidium*), b) a larva of the net-spinning caddis fly (*Hydropsyche*) and c) nymph of the filter-feeding mayfly (*Coloburiscus*).**

Figure 15 **A larva of the net-spinning caddis fly *Hydropsyche* showing the rough retreat it makes attached to a rock (in this case, made of pieces of wood) and the silk net it uses to capture food.**

8.4. Native fish

Habitat for all species of indigenous fish present in the upper Clutha/Mata-Au was predicted to increase with decreasing flows (Hayes et al. 2018).

Recruitment of longfin eels to the upper Clutha and Kawarau catchments is prevented by the presence of Roxburgh and Clyde Dams, therefore habitat is not currently the main factor affecting the distribution and abundance of longfin eels in the Clutha catchment. Contact Energy operates a trap and transfer programme at Roxburgh Dam as a consent condition. Trapped elvers are released at multiple locations in the Clutha/Mata_Au catchment upstream of Roxburgh Dam. It is unlikely that the longfin eels are habitat-limited in the upper Clutha/Mata-Au and Kawarau catchments. However, instream habitat model predicts that the abundance of longfin eels should increase as flows decrease.

The habitat suitability curves available for kōaro (Richardson & Jowett, 1995) were included in these analyses, but they were based on data from steep cascade habitat in the Onekaka River (a small steep river in Golden Bay) and their applicability to the type of habitat present in the Clutha River is doubtful. The predictions for kōaro in the upper Clutha/Mata-Au should, therefore, be interpreted with caution. It is likely that the distribution of kōaro in the upper Clutha/Mata-Au was affected by the creation of Lake Dunstan, which provides additional larval rearing habitat to the natural lakes in the upper Clutha Mata-Au and may have increased the number and range of kōaro resident in the upper Clutha/Mata-Au since the late 1990's.

8.5. Sports fish

8.5.1. Instream habitat modelling

Both brown and rainbow trout are found in the Clutha River/Mata-Au. Several HSC for different life stages of brown trout and for adult rainbow trout were included in these analyses to consider how changes in flow in the modelled reach will affect habitat availability for sports fish. The choice of HSC can have consequences for the outcome of instream habitat modelling, so for transparency, a number of different HSC were run for each life-stage (Table 10). Two of the HSC run for adult trout were developed in the upper Clutha River, while HSC for brown trout spawning (Shirvell & Dungey 1983), brown trout juveniles (Jowett & Richardson 2008) and brown trout adult (Hayes & Jowett 1994) were developed in smaller New Zealand rivers and other adult trout HSC used in this analysis were developed in North America.

Habitat for all species and life-stages of sports fish was predicted to increase with decreasing flows (Hayes et al. 2018). The exception to this was habitat for adult rainbow trout developed for the Clutha/Mata-Au (referred to as Rainbow, >400 mm (Clutha depth modified) in Hayes et al. 2018), which is predicted to decline with decreasing flows below the 7-d MALF, although this decline is predicted to be very gradual, with 100% habitat retention at 100 m^3/s, 98% at 89 m^3/s and 96% at 78 m^3/s (Table 12 of Hayes et al. 2018).

8.5.2. NREI modelling

In addition to the traditional approach of instream habitat modelling, Hayes et al. (2018) used coupled drift-dispersion/Net-Rate of Energy Intake (NREI) modelling to consider the potential effects of flow on adult brown trout in the upper Clutha/Mata-Au. This modelling considers the effect of flow on the entry and transport of drifting macroinvertebrates and the effect of this on drift-feeding by brown trout (whilst considering the metabolic costs of feeding based on water velocities and water temperature).

The results of drift-NREI modelling indicates that reducing flows to 78 m^3/s (~70% of the naturalised MALF) could increase the potential instantaneous carrying capacity for adult (52 cm) drift-feeding trout by 21–32%, depending on relative drift concentrations (Table 21 of Hayes et al. 2018).

8.6. Ecological consequences of flow fluctuations

In large rivers, high water velocities and depths can limit the habitat value of large portions of the middle part of the river channel, with the most productive portion of the channels along the margins of the channel (Figure 16a). High water velocities can move smaller substrates, even at low flows. Thus, an increase in flow may result in little change in habitat suitability, or even a reduction in habitat suitability – as is evident in the outputs of instream habitat modelling for the upper Clutha/ Mata-Au (Hayes et al. 2018; Figure 16b vs. Figure 16a).

Flow fluctuations over short periods of time can occur due to the operation of hydro-electric power schemes. In the Clutha/Mata-Au, Lake Hāwea is the primary water storage for the hydro-electric dams at Clyde and Roxburgh, which can result in fluctuating flows in the upper Clutha/Mata-Au downstream of the confluence of the Hāwea River (Figure 17a) as well as in the Clutha/Mata-Au downstream of Clyde Dam (Figure 17b) and downstream of Roxburgh Dam (Figure 17c). Fluctuating flows can affect the suitability of habitat for aquatic organisms and create a "varial zone", the area on the channel margins that are periodically wetted and dried (as reviewed in Section 9.3.1 of Hayes et al. 2018). Drying of the varial zone during the low part of the fluctuating flow cycle combined with excessive water velocities in the mid-channel during high flows can further reduce the diversity, density and productivity of macroinvertebrate communities (Figure 16c) with flow-on effects to higher trophic levels.

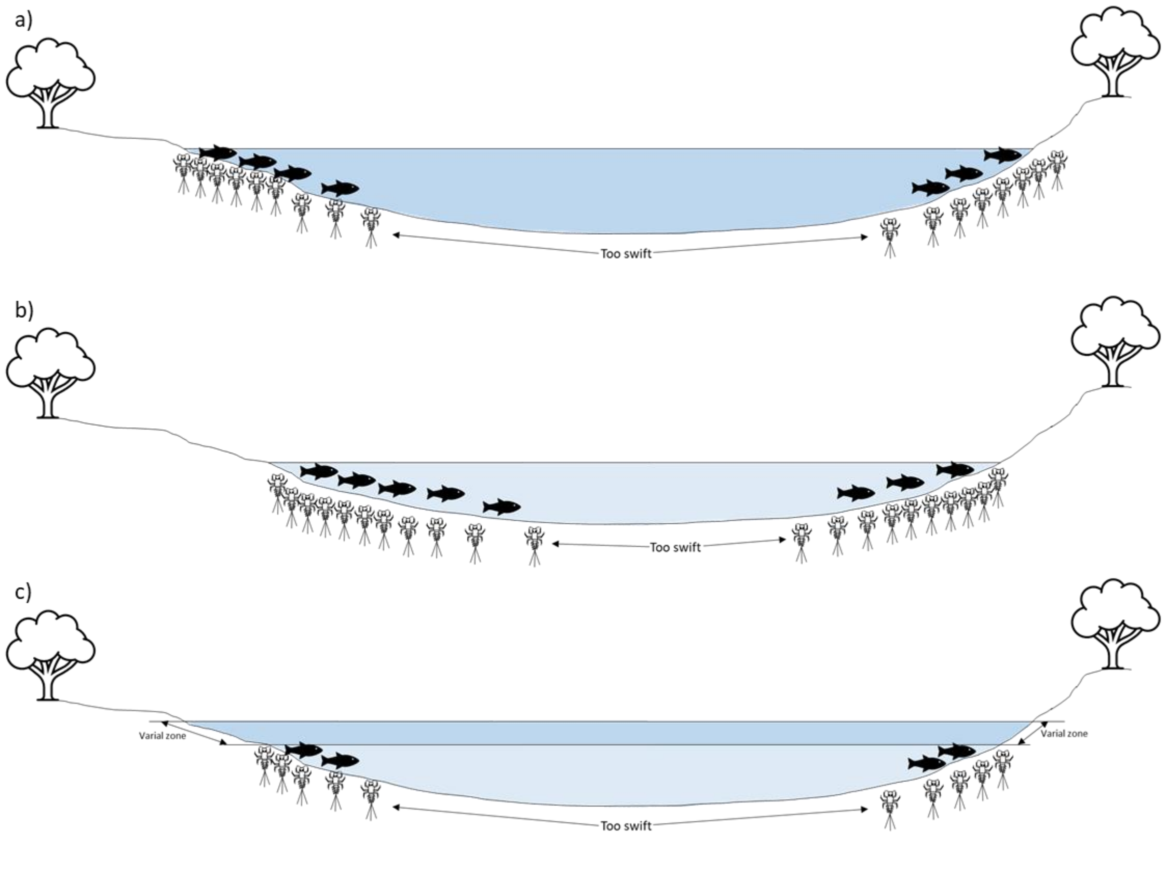

Figure 16 **Conceptual diagram of the effect of flow on habitat for fish and macroinvertebrates in large rivers. a) low flows, b) high flows, c) variable flows.**

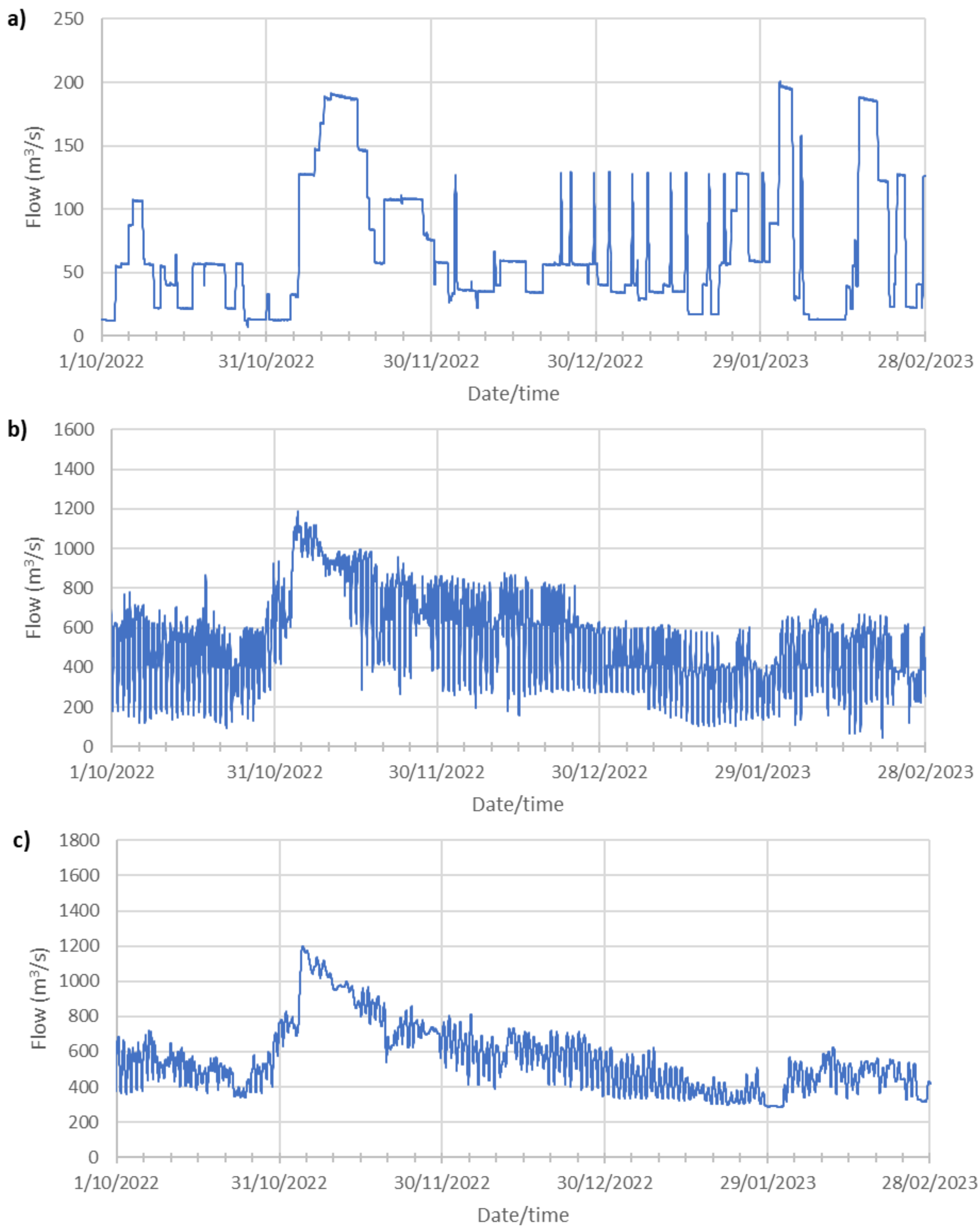

Figure 17 **Hydrographs showing the effects of hydro-electric power generation on a) Hāwea River at Camphill Bridge, b) Clutha at Clyde, and c) Clutha at Balclutha. Data courtesy of NIWA and data for the Hāwea and Clutha at Clyde courtesy of Contact Energy.**

8.7. Summary of instream habitat assessments

Instream habitat modelling undertaken in the upper Clutha/Mata-Au by Cawthron and NIWA predicts that habitat for most species declines with increasing flows between 80 m^3/s and 370 m^3/s (Hayes et al. 2018). This was confirmed by bioenergetics (NREI) modelling. This result is typical for very large river systems, with high water velocities in the central portion of the channel limiting the habitat value of much of this part of the river channel and resulting in the most productive portion of the channel being along the channel margins.

Table 11 presents an assessment of habitat retention in the upper Clutha/Mata-Au. Instream habitat modelling suggests that there is an enhanced risk of nuisance periphyton growth at flows of less than 95 m^3/s (long filamentous algae). Habitat for macroinvertebrates, indigenous fish and trout are all predicted to increase with decreasing flows, with optimum flows predicted to be below 80 m^3/s. The exception to this was habitat for adult rainbow trout (as modelled by the Clutha adult (> 400 mm) rainbow trout HSC), which predicted optimum habitat for rainbow trout at flows of 120-160 m^3/s. However, this prediction was not supported by the bioenergetics modelling, which predicted that the observed drift concentrations were insufficient to sustain trout within the study reach, but that at higher drift concentrations (scaled up by between 8- and 100-fold), the number of trout predicted to occur within the study reach increased with decreasing flows (Hayes et al. 2018).

Table 11 **Assessment of instream habitat values at sites in the Upper Clutha/Mata-Au with recommended levels of habitat retention (based on the approach of Jowett & Hayes, 2004).**

Instream value	Fishery or conservation value	Level of habitat retention	Flow to maintain suggested level of habitat retention
Cyanobacteria	Nuisance, potentially toxic	<120%	<80 m^3/s
Diatoms	Indigenous biodiversity	>80%	<80 m^3/s
Didymo	Nuisance, aesthetics, effects on other taxa	<120%	>91 m^3/s
Short filamentous	Nuisance, aesthetics	<120%	>93 m^3/s
Long filamentous	Nuisance, aesthetics	<120%	>95 m^3/s
Food producing (Waters)	Life-supporting capacity	Optimum	<80 m^3/s
Aoteapsyche	Life-supporting capacity	Optimum	<80 m^3/s
Deleatidium	Life-supporting capacity	Optimum	<80 m^3/s
Longfin eel	Declining	Optimum	<80 m^3/s
Brown trout - adult	Nationally significant	Optimum	<80 m^3/s
Brown trout – juvenile rearing	Nationally significant	Optimum	<80 m^3/s
Brown trout – spawning (May-August)	Nationally significant	Optimum	<80 m^3/s
Rainbow trout - adult	Nationally significant	Optimum	120-160 m^3/s
		90%	<80 m^3/s
Rainbow trout – juvenile rearing	Nationally significant	Optimum	<80 m^3/s
Rainbow trout – spawning (September-November)	Nationally significant	Optimum	<80 m^3/s

8.7.1. Applicability to the Kawarau and lower Clutha/Mata-Au

The instream habitat modelling in the upper Clutha/Mata-Au and the concept that the value of mid-channel habitat is limited by high water velocities indicate that the most productive portion of the channel is along the channel margins. These results can be applied to both the Kawarau and lower Clutha/Mata-Au. Both arguably represent harsher environments for most aquatic life due to the steepness and very high sediment supply (from the Shotover catchment) in the Kawarau and the lower water clarity and much larger size of the lower Clutha/Mata-Au compared with the upper river.

9. Minimum flows and allocation limit options

9.1. Upper Clutha River/Mata-Au

Table 11 presents several minimum flow/allocation options that would provide for aquatic values in the upper Clutha/Mata-Au. Instream habitat modelling and bioenergetics modelling suggest that reducing flows down to 80 m^3/s is expected to provide enhanced habitat relative to the natural 7-d MALF (see Section 8). These options cover a range of minimum flows, from an option that will result in low flows that are relatively unimpacted by run-of-river takes (minimum flow of 100% of the 7-d MALF, current allocation) to options that provide increased allocation potential within the theoretical flow standard suggested by Hayes et al. (2023) (80%of the 7-d MALF; Table 11). These options also include a range of allocation options ranging from current allocation (13% of the 7-d MALF) to options with 4 m^3/s (17% of the 7-d MALF) and 8 m^3/s of additional allocation (20% of the 7-d MALF; a 54% increase in allocation; Table 11).

Given the large size of the upper Clutha/Mata-Au and the increase in habitat with reduced flows predicted by instream habitat and bioenergetics modelling, an argument could be made against the need for a minimum flow in the upper Clutha/Mata-Au. Acceptable environmental outcomes could be achieved by an appropriate allocation limit alone for the mainstem of the Clutha/Mata-Au. Such an approach has been applied in Water Conservation Orders for the Buller/Kawatiri, Mataura and Motueka Rivers, where a proportion (between 5 and 10%) of the flow present is allocated to out-of-stream users. The upper Clutha/Mata-Au is much bigger than the Buller (7-d MALF = 22 m^3/s), Mataura (22 m^3/s) or Motueka (9.4 m^3/s) and given the predictions of habitat modelling that the optimal flow for most values is predicted to occur at flows of less than 70% of the natural 7-d MALF (80 m^3/s), such an approach would provide for aquatic values in the upper Clutha/Mata-Au and is consistent with the high values present in this river.

The Lake Wānaka Preservation Act (1973) requires preservation of the natural rate of flow in the Clutha/Mata-Au upstream of the Cardrona confluence, which is the source of most of the flow in the upper Clutha/Mata-Au (72% at the naturalised 7-d MALF – Table 4), meaning that the majority of the allocation pressure in the upper Clutha/Mata-Au will come in the 48 km section of river between the Cardrona confluence and Lake Dunstan and from the tributaries of this upper section of the Clutha Mata-Au. In addition, flows in the upper Clutha/Mata-Au are affected by the highly modified flows in the Hāwea River resulting from the management of storage within Lake Hāwea for hydro-electric power generation (see Figure 17a), and such modifications are likely to overshadow those resulting from run-of-the-river allocation.

Collectively, the current allocation in the upper Clutha/Mata-Au is approximately 14.7 m^3/s (13% of the 7-d MALF), with approximately 4 m^3/s of consented take from the upper Clutha/Mata-Au itself. However, the current permitted activity rule allows for takes of up to 100 l/s[20], which means that there could be water take from the upper Clutha that is currently unaccounted for.

It should be kept in mind that these allocation values represent the paper allocation rather than actual use, and that actual use in tributaries will likely be constrained by catchment minimum flows and/or

[20] Rule 12.1.2.2 of the RPW - subject to a daily volume limit of 1,000,000 m^3, no more than one such take occurs per landholding, no backflow of contaminated water and fish are prevented from entering the intake structure.

residual flows when flows in the upper Clutha/Mata-Au are low. An allocation of up to 10% of the flow in the upper Clutha/Mata-Au (across the entire flow range) would provide for aquatic values as well as maintaining flow variability in the upper Clutha/Mata-Au.

Considerations other than the aquatic ecosystem will contribute to the development of flow management in the upper Clutha/Mata-Au, including (but not limited to) aesthetics and flows for recreation activities (including jetboating, rafting, and kayaking). Water quality outcomes can be affected by irrigation development and may constrain water use in areas such as the upper Clutha/Mata-Au.

Table 12 **Minimum flow and mainstem allocation limit options for the upper Clutha/Mata-Au.**

Minimum flow		Allocation limit			
Option	% 7-d MALF	Mainstem allocation	Total allocation	Total allocation % 7-d MALF	Description
Upper Clutha					
None	-	4 m^3/s	14.7 m^3/s	13%	No minimum flow, current mainstem allocation (total allocation 13% of MALF).
110 m^3/s	100%	4 m^3/s	14.7 m^3/s	13%	Minimum flow 100% of the naturalised 7-d MALF and current mainstem allocation (total allocation 13% of MALF).
		8 m^3/s	18.7 m^3/s	17%	Minimum flow 100% of the naturalised 7-d MALF and 4 m^3/s additional mainstem allocation (total allocation 13% of MALF).
		12 m^3/s	22.7 m^3/s	20%	Minimum flow 100% of the naturalised 7-d MALF and 8 m^3/s additional mainstem allocation (total allocation 13% of MALF).
100 m^3/s	90%	4 m^3/s	14.7 m^3/s	13%	Minimum flow 90% of the naturalised 7-d MALF and current mainstem allocation (total allocation 13% of MALF).
		8 m^3/s	18.7 m^3/s	17%	Minimum flow 90% of the naturalised 7-d MALF and 4 m^3/s additional mainstem allocation (total allocation 13% of MALF).
		12 m^3/s	22.7 m^3/s	20%	Minimum flow 90% of the naturalised 7-d MALF and 8 m^3/s additional mainstem allocation (total allocation 13% of MALF).
90 m^3/s	80%	4 m^3/s	14.7 m^3/s	13%	Minimum flow 80% of the naturalised 7-d MALF and current mainstem allocation (total allocation 13% of MALF).
		8 m^3/s	18.7 m^3/s	17%	Minimum flow 80% of the naturalised 7-d MALF and 4 m^3/s additional mainstem allocation (total allocation 13% of MALF).
		12 m^3/s	22.7 m^3/s	20%	Minimum flow 80% of the naturalised 7-d MALF and 8 m^3/s additional mainstem allocation (total allocation 13% of MALF).

9.1.1. Potential effects of climate change in the Upper Clutha/Mata-Au

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

The projected effects of climate change (from Macara et al. 2019) are not expected to significantly increase the probability, magnitude and duration of low flow events in the upper Clutha/Mata-Au (Table 13).

The NREI model predicted that adult trout abundance would decrease steadily with increasing water temperature (assuming constant drift concentrations), due to higher metabolic costs resulting from warmer water (Hayes et al. 2018). The predicted increase in mean temperature in the upper Clutha/Mata-Au, may translate to a reduction of approximately 1 trout within the NREI model reach (based on Figure 43 of Hayes et al. 2018).

Table 13 Potential effects of climate change on the upper Cluhta/Mata-Au 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 the upper Clutha/Mata-Au	Potential ecological consequences
Temperature	• Increased mean temperatures (~ +1°C) • Increased annual mean maximum temperature (1.1-1.3°C) • Increase in number of hot days (>30°C) (increase of ~6 days per annum) • Reduced frost days (11-12 fewer frost days per annum)	• Increased evapotranspiration • Faster flow recession • Slightly increased irrigation demand	• Higher water temperatures, reduced suitability for sensitive species • Faster accrual of periphyton biomass
Rainfall	• Small increase in annual mean rainfall (~4%) • Increased summer mean rainfall (+7-8%) • Little change in risk of low rainfall events • Little change in heavy rain days	• Little change in likelihood and/or magnitude of low flow events • Little change in likelihood of high rainfall events	
Snow	• No change in snow days		
Hydrology	• No change to slight increase in Q95 flow (-5 - +10%) • Little change in reliability for irrigators	• Little change in low flows	• Little change in habitat availability

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9.2. Kawarau River

Table 14 presents minimum flow/allocation options that would provide for aquatic values in the Kawarau River. These options cover a range of minimum flow/allocations, from an option that provides for existing use, which will result in low flows that are relatively unimpacted by run-of-river takes (minimum flow of 100% of the 7-d MALF, current allocation) to options that provide for increased allocation potential but with a conservative allocation limit of 10% for the whole of the Kawarau catchment.

Given the large size of the Kawarau River and the harsh environment it provides for aquatic life (see Section 8.7.1), an argument could be made against the need for a minimum flow. Acceptable environmental outcomes could be achieved by an appropriately conservative allocation limit for the mainstem of the Kawarau and as discussed above (Section 9.1), this approach is consistent with that in other Water Conservation Orders. Given the current very low take from the Kawarau River itself, such a management approach would maintain the outstanding characteristics recognised in the Water Conservation (Kawarau) Order, which include wild and scenic characteristics and recreation (particularly rafting, jetboating and kayaking) as well as the aquatic systems of the Kawarau.

Table 14 Minimum flow and mainstem allocation limit options for the Kawarau River.

Minimum flow		Allocation limit			
Option	% 7-d MALF	Mainstem allocation	Total allocation	Total allocation % 7-d MALF	Description
Kawarau River					
None	-	0.1 m^3/s	3.5 m^3/s	4%	Current environment. No minimum flow and current mainstem allocation (total allocation 4% of MALF).
88.5 m^3/s	100%	0.1 m^3/s	3.5 m^3/s	4%	Minimum flow 100% of the naturalised 7-d MALF and current mainstem allocation (total allocation 4% of MALF).
		1.5 m^3/s	6 m^3/s	7%	Minimum flow 100% of the naturalised 7-d MALF and 2.5 m^3/s additional mainstem allocation (total allocation 7% of MALF).
		5.5 m^3/s	9 m^3/s	10%	Minimum flow 100% of the naturalised 7-d MALF and 9 m^3/s additional mainstem allocation (total allocation 10% of MALF).
80 m^3/s	90%	0.1 m^3/s	3.5 m^3/s	4%	Minimum flow 90% of the naturalised 7-d MALF and current mainstem allocation (total allocation 4% of MALF).
		1.5 m^3/s	6 m^3/s	7%	Minimum flow 90% of the naturalised 7-d MALF and 2.5 m^3/s additional mainstem allocation (total allocation 7% of MALF).
		5.5 m^3/s	9 m^3/s	10%	Minimum flow 90% of the naturalised 7-d MALF and 9 m^3/s additional mainstem allocation (total allocation 10% of MALF).
70 m^3/s	79%	0.1 m^3/s	3.5 m^3/s	4%	Minimum flow 80% of the naturalised 7-d MALF and current mainstem allocation (total allocation 4% of MALF).
		1.5 m^3/s	6 m^3/s	7%	Minimum flow 80% of the naturalised 7-d MALF and 2.5 m^3/s additional mainstem allocation (total allocation 7% of MALF).
		5.5 m^3/s	9 m^3/s	10%	Minimum flow 80% of the naturalised 7-d MALF and 9 m^3/s additional mainstem allocation (total allocation 10% of MALF).

9.2.1. Potential effects of climate change in the Kawarau catchment

The projected effects of climate change (from Macara et al. 2019) are not expected to significantly increase the probability, magnitude and duration of low flow events in the Kawarau River and may result in higher flows in the Kawarau River (Table 15).

Table 15 Potential effects of climate change on the Kawarau River 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 the Kawarau River	Potential ecological consequences
Temperature	• Increased mean temperatures (~+1°C) • Increased annual mean maximum temperature (1-1.5°C) • No increase in number of hot days (>30°C) (increase of <2 days per annum) • Reduced frost days (10-12 fewer frost days per annum)	• Increased evapotranspiration • Faster flow recession • Slightly increased irrigation demand	• Higher water temperatures, reduced suitability for sensitive species • Faster accrual of periphyton biomass
Rainfall	• Slight increase in annual mean rainfall (4-6%) • No change to slight increase in summer mean rainfall (-2% - +4%) • No change to slight increase in risk of low rainfall events • Small increase in heavy rain days	• Little change in likelihood and/or magnitude of low flow events • Little change in likelihood of high rainfall events	
Snow	• No change in snow days		
Hydrology	• Increase in Q95 flow (+5 - +20%) • Little change in reliability for irrigators	• Increase in magnitude of low flows	• Little change in habitat availability

10. Lower Clutha/Mata-Au

Flows in the lower Clutha/Mata-Au are affected by the operation of the hydro-electric power schemes at Hāwea, Clyde and Roxburgh (see Figure 17b & Figure 17c). The resource consents held by Contact Energy (expiring in 2042) require that a flow of 250 m^3/s is maintained downstream of Roxburgh Dam at all times, unless the combined inflows to the Clutha/Mata-Au system are below 250 m^3/s, in which case the minimum discharge below Roxburgh Dam shall not be less than that combined daily mean inflow. This permit (2001.394.V1) also requires maintenance of a stable minimum flow of 300-400 m^3/s between September-mid October.

Table 16 presents minimum flow/allocation options that would provide for aquatic values in the lower Clutha River/Mata-Au. These options cover a range of minimum flows, from an option that would restrict water users when flows are at or below Contact Energy's minimum flow to an option that would allow water allocation to be fully exercised down to flows equivalent to Contact Energy's minimum flow. Allocation options presented range from one that provides for existing use to options that would provide for increased allocation potential but with an allocation limit of 30% for the whole of the Clutha/Mata-Au catchment.

Given the very large size of the Clutha River/Mata-Au and the findings of habitat and bioenergetics modelling in the upper Clutha/Mata-Au, an argument could be made against the need for a minimum flow. Acceptable environmental outcomes could be achieved by an appropriately conservative allocation limit for the Clutha/Mata-Au as discussed above (Section 9.1).

Considerations other than the aquatic ecosystem will contribute to the development of flow management in the lower Clutha/Mata-Au, including (but not limited to) aesthetics and flows for recreation activities (e.g. jetboating). Water quality at most monitoring sites in the lower Clutha Rohe is generally poor, although in recent years there are indications of improving trends (Ozanne et al. 2023). Water quality outcomes can be affected by irrigation development and may constrain water use in areas such as the lower Clutha/Mata-Au.

Table 16 Minimum flow and mainstem allocation limit options for the lower Clutha River/Mata-Au.

Minimum flow		Allocation limit			
Option	**% 7-d MALF**	**Mainstem allocation[21]**	**Total allocation**	**Total allocation % 7-d MALF**	**Description**
Lower Clutha					
None	-	6.75 m^3/s	63 m^3/s	21%	Minimum flow 100% of the naturalised 7-d MALF and current mainstem allocation (4% of MALF).
250 m^3/s	84%	6.75 m^3/s	63 m^3/s	21%	Current Contact Energy minimum flow and current mainstem allocation, current total allocation (21% of MALF).
		10 m^3/s	66.25	25%	Current Contact Energy minimum flow and provision for 3.25 m^3/s additional allocation (25% of MALF).
		20 m^3/s	76.25	30%	Current Contact Energy minimum flow and provision for 13.25 m^3/s additional allocation (30% of MALF).
240 m^3/s	80%	6.75 m^3/s	63 m^3/s	21%	Minimum flow at 80% MALF and current mainstem allocation (4% of MALF).
		10 m^3/s	66.25	25%	Minimum flow at 80% MALF and provision for 3.25 m^3/s additional allocation (25% of MALF).
		20 m^3/s	76.25	30%	Minimum flow at 80% MALF and provision for 13.25 m^3/s additional allocation (30% of MALF).

[21] Below Roxburgh Dam

10.1.1. Potential effects of climate change in the Lower Clutha/Mata-Au

The projected effects of climate change (from Macara et al. 2019) are not expected to significantly increase the probability, magnitude and duration of low flow events in the lower Clutha/Mata-Au (

Table 13).

Table 17 Potential effects of climate change on the lower Clutha/Mata-Au River 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 the lower Clutha/Mata-Au	Potential ecological consequences
Temperature	• Increased mean temperatures (0.6-0.9°C) • Increased annual mean maximum temperature (0.8-1.2°C) • No increase to increase in number of hot days (>30°C) (increase of <1-6 days per annum) • Reduced frost days (5-10 fewer frost days per annum)	• Increased evapotranspiration • Faster flow recession • Slightly increased irrigation demand	• Higher water temperatures, reduced suitability for sensitive species • Faster accrual of periphyton biomass
Rainfall	• Small increase in annual mean rainfall (3-4%) • Small increase in summer mean rainfall (0% -+5%) • Slight increase in risk of low rainfall events • Small increase in heavy rain days	• Little change in likelihood and/or magnitude of low flow events • Little change in likelihood of high rainfall events	
Snow	• No change in snow days		
Hydrology	• No change to slight increase in Q95 flow (-5 - +10%) • Little change to slight increase in reliability for irrigators	• Little change in low flows	• Little change in habitat availability

11. Conclusions: Flow requirements for aquatic ecosystems in the Clutha/Mata-Au catchment

11.1. Upper Clutha/Mata-Au

The results of instream habitat and trout bioenergetics modelling suggest that a reduction in flows is likely to result in increased habitat available for most species present, down to at least 80 m^3/s, although flows below 95 m^3/s may result in an elevated risk of periphyton proliferation.

The large flow in the upper Clutha/Mata-Au and the predicted increase in habitat with reduced flows mean that an argument could be made against the need for a minimum flow in the upper Clutha/Mata-Au. Application of a conservative allocation limit (whole-catchment allocation of ≤20% of the 7-d MALF) for the mainstem of the Clutha/Mata-Au would provide for ecological values in the upper Clutha River. Such an approach has previously been applied in Water Conservation Orders for the Buller/Kawatiri, Mataura and Motueka Rivers

Flows in the upper Clutha/Mata-Au down to the confluence of the Hāwea River are close to natural as a result of the restrictions imposed by the Lake Wānaka Preservation Act (1973). Flows in the upper Clutha/Mata-Au below the Hāwea confluence are affected by the highly modified flows in the Hāwea River. These result from the management of storage within Lake Hāwea for hydro-electric power generation in downstream power stations at Clyde and Roxburgh. The hydrological modification of flows in the upper Clutha/Mata-Au due to power generation will overshadow the current effects of run-of-the-river allocation, including the creation of a varial zone resulting from fluctuations in outflows from Lake Hāwea.

Factors other than the aquatic ecosystem will contribute to the development of flow management in the upper Clutha/Mata-Au, including (but not limited to) aesthetics and flows for recreation activities (including jetboating, rafting, and kayaking). Water allocation in areas such as the upper Clutha/Mata-Au may be constrained by the availability of suitable irrigable land or by the potential effects of irrigation development on water quality outcomes.

11.2. Kawarau River

The Water Conservation (Kawarau) Order (1997) sets out the outstanding characteristics of water bodies within the Kawarau Catchment. The mainstem of the Kawarau River from Scrubby Stream to the Lake Whakatipu control gates is listed in Schedule 2 (Waters to be protected). There is a prohibition on damming, and water quality is to be managed to Class CR standard, and the order recognises the listed outstanding characteristics, which includes wild and scenic characteristics and recreation (particularly rafting, jetboating and kayaking).

Current abstraction from the Kawarau catchment is very low, representing 4% of the 7-d MALF at the Kawarau at Chards Road flow monitoring site. Given the current low level of abstraction pressure and the outstanding characteristics of the catchment, as recognised in the WCO, there is a strong argument for conservative management of future water abstraction from the Kawarau catchment. This could be achieved by limiting water allocation to 5% or 10% of the 7-d MALF of the Kawarau River, which is in line with the provisions of other water conservation orders. With a restrictive allocation limit, there is likely to be little benefit of applying a minimum flow, but a minimum flow for mainstem takes of 100% or 90% of the 7-d MALF would be appropriate in such circumstances.

11.3. Lower Clutha/Mata-Au

Flows in the Lower Clutha/Mata-Au are currently driven by Contact Energy's consent requirements, which require maintenance of a minimum flow of 250 m^3/s at all times, unless the combined inflows to the Clutha/Mata-Au system are below 250 m^3/s, in which case the minimum discharge below Roxburgh Dam shall not be less than that combined daily mean flow. This permit (2001.394.V1) also requires maintenance of a stable minimum flow of 300-400 m^3/s between September-mid October. These consents expire on 25 May 2042.

The results of instream habitat modelling and NREI studies in the upper Clutha/Mata-Au have relevance to the lower Clutha/Mata-Au. It is likely that a reduction of flows will increase the suitability and extent of habitat for many species present, as high velocities, water depth, and sediment instability in the middle of the channel reduce the suitability for aquatic species.

The Clutha/Mata-Au is the largest river in New Zealand by flow. Given the very large size of the Clutha River/Mata-Au and the findings of habitat and bioenergetics modelling in the upper Clutha/Mata-Au, an argument could be made against the need for a minimum flow. Acceptable environmental outcomes could be achieved by an appropriate allocation limit for the lower Clutha/Mata-Au as discussed above (Section 9.1).

Considerations other than the aquatic ecosystem will contribute to the development of flow management in the lower Clutha/Mata-Au, including (but not limited to) aesthetics and flows for recreation activities (e.g. jetboating). Water quality at most monitoring sites in the lower Clutha Rohe is generally poor, although in recent years there are indications of improving trends (Ozanne et al. 2023). Water quality outcomes can be affected by irrigation development and therefore may constrain future water allocation in areas such as the lower Clutha/Mata-Au.

12. Acknowledgements

Flow data for mainstem sites on the Clutha River/Mata-Au were supplied by NIWA. Instream habitat modelling was undertaken by NIWA (under subcontract to Cawthron) and bioenergetics modelling for upper Clutha was conducted by Cawthron Institute.

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14. Appendix A

Schedule 3 of the RMA - Water quality classes

Schedule 2 of the Water Conservation (Kawarau) Order (1997) includes water quality classes for the waters to be protected. These classes are from Schedule 3 of the RMA, which is reproduced below..

Note: The standards listed for each class apply after reasonable mixing of any contaminant or water with the receiving water and disregard the effect of any natural perturbations that may affect the water body.

1 Class AE Water (being water managed for aquatic ecosystem purposes)

(1)

The natural temperature of the water shall not be changed by more than 3° Celsius.

(2)

The following shall not be allowed if they have an adverse effect on aquatic life:

(a)

any pH change:

(b)

any increase in the deposition of matter on the bed of the water body or coastal water:

(c)

any discharge of a contaminant into the water.

(3)

The concentration of dissolved oxygen shall exceed 80% of saturation concentration.

(4)

There shall be no undesirable biological growths as a result of any discharge of a contaminant into the water.

2 Class F Water (being water managed for fishery purposes)

(1)

The natural temperature of the water—

(a)

shall not be changed by more than 3° Celsius; and

(b)

shall not exceed 25° Celsius.

(2)

The concentration of dissolved oxygen shall exceed 80% of saturation concentration.

(3)

Fish shall not be rendered unsuitable for human consumption by the presence of contaminants.

3 Class FS Water (being water managed for fish spawning purposes)

(1)

The natural temperature of the water shall not be changed by more than 3° Celsius. The temperature of the water shall not adversely affect the spawning of the specified fish species during the spawning season.

(2)

The concentration of dissolved oxygen shall exceed 80% of saturation concentration.

(3)

There shall be no undesirable biological growths as a result of any discharge of a contaminant into the water.

4 Class SG Water (being water managed for the gathering or cultivating of shellfish for human consumption)

(1)

The natural temperature of the water shall not be changed by more than 3° Celsius.

(2)

The concentration of dissolved oxygen shall exceed 80% of saturation concentration.

(3)

Aquatic organisms shall not be rendered unsuitable for human consumption by the presence of contaminants.

5 Class CR Water (being water managed for contact recreation purposes)

(1)

The visual clarity of the water shall not be so low as to be unsuitable for bathing.

(2)

The water shall not be rendered unsuitable for bathing by the presence of contaminants.

(3)

There shall be no undesirable biological growths as a result of any discharge of a contaminant into the water.

6 Class WS Water (being water managed for water supply purposes)

(1)

The pH of surface waters shall be within the range 6.0–9.0 units.

(2)

The concentration of dissolved oxygen in surface waters shall exceed 5 grams per cubic metre.

(3)

The water shall not be rendered unsuitable for treatment (equivalent to coagulation, filtration, and disinfection) for human consumption by the presence of contaminants.

(4)

The water shall not be tainted or contaminated so as to make it unpalatable or unsuitable for consumption by humans after treatment (equivalent to coagulation, filtration, and disinfection), or unsuitable for irrigation.

(5)

There shall be no undesirable biological growths as a result of any discharge of a contaminant into the water.

7 Class I Water (being water managed for irrigation purposes)

(1)

The water shall not be tainted or contaminated so as to make it unsuitable for the irrigation of crops growing or likely to be grown in the area to be irrigated.

(2)

There shall be no undesirable biological growths as a result of any discharge of a contaminant into the water.

8 Class IA Water (being water managed for industrial abstraction)

(1)

The quality of the water shall not be altered in those characteristics which have a direct bearing upon its suitability for the specified industrial abstraction.

(2)

There shall be no undesirable biological growths as a result of any discharge of a contaminant into the water.

9 Class NS Water (being water managed in its natural state)

The natural quality of the water shall not be altered.

10 Class A Water (being water managed for aesthetic purposes)

The quality of the water shall not be altered in those characteristics which have a direct bearing upon the specified aesthetic values.

11 Class C Water (being water managed for cultural purposes)

The quality of the water shall not be altered in those characteristics which have a direct bearing upon the specified cultural or spiritual values.

Appendix B - Estimating naturalised low flow statistics for the Hāwea River

Available data

Outflow from Lake Wānaka – long-term flow record based on water level in Lake Wānaka (1954-2014), but the water level record for Lake Wānaka goes back to 1933.

Outflow from Lake Hāwea –flow record based on water level in Lake Hāwea (1933-1955).

Analyses

Hāwea River - Natural MALF (1933-1955)

Annual flow statistics were estimated for the Hāwea River for the period 1 January 1933 -30 June 1955. This yielded a MALF of 30.1 m^3/s for this period (23 year record).

Upper Clutha River/Matau-Au – estimating flows for the period 1933-1955

A long-term flow record is available for the upper Clutha River/Mata-Au based on water level in Lake Wānaka (1954-2014). However, the water level record for Lake Wānaka goes back to 1933. The rating for this site is very stable (Pete Stevenson, *pers. comm*). The relationship between water level and flow at this site over the period 1 January 1955-8 April 2014 is shown in Figure 0.18.

The following quadratic function was fitted to these data (R^2=0.9974):

Outflow from Lake Wānaka = 30.1996*(Lake Wānaka water level)^2 – 16580.1316*Lake Wānaka water level + 2275657.0522

This relationship was used to estimate outflows from Lake Wānaka for the period for which water level data was available prior to 1955. This assumes that the stage-flow relationship from the 1955-2014 data applied to the 1933-1955 period. Given the stability of the stage-flow relationship over a 59 year period, it is likely that this is a reasonable assumption. It should be noted that the quadratic function under-predicts flows slightly at high flows (>1200 m^3/s), but this is of little concern as this analysis is concerned with the estimation of low-flow statistics, which will not be affected.

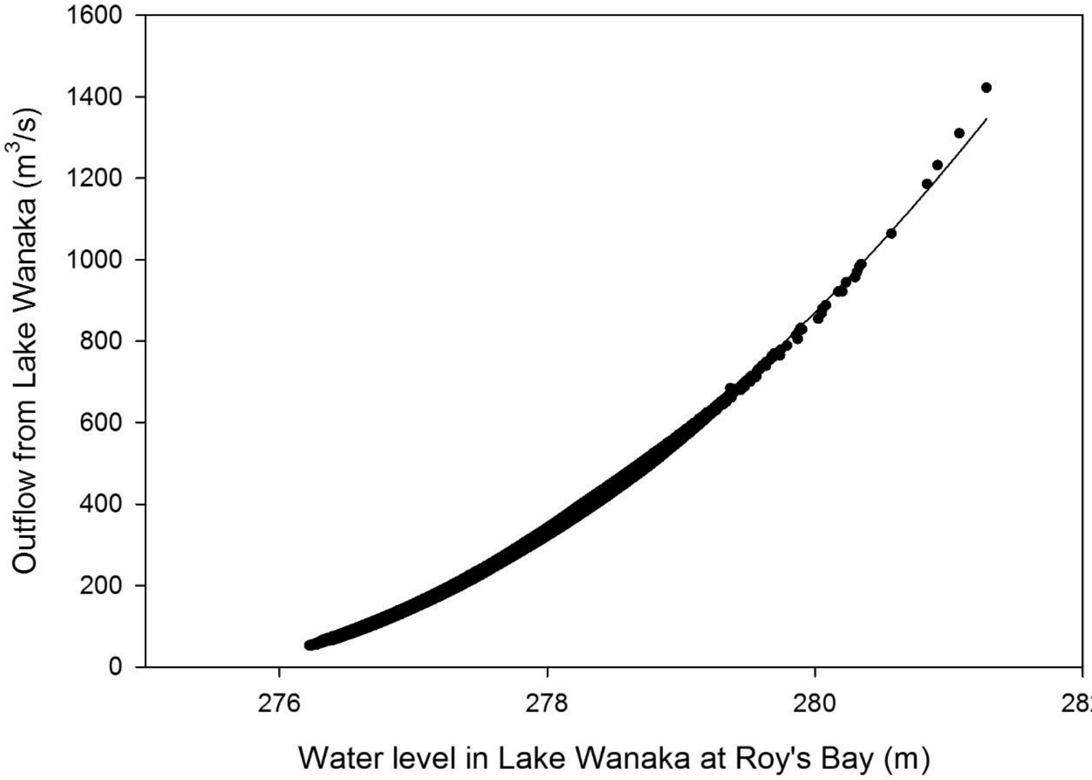

Figure 0.18 **Relationship between water level in Lake Wānaka and outflow from Lake Wānaka to the upper Clutha River/Mata-Au over the period 1 January 1955-8 April 2014. A fitted quadratic function is also shown.**

Estimating flows in the Hāwea River from Lake Wānaka outflows

The relationship between outflows from Lake Hāwea and outflows from Lake Wānaka for the period 2 February 1933 to 3 August 1955 were used to estimate naturalised low flow statistics for the Hāwea River. A linear regression between outflows from Lake Wānaka (from water levels in Lake Wānaka) with outflows from Lake Hāwea (based on water levels in Lake Hāwea prior to hydro-electric development) (Figure 19) appears to over-estimate low-flows, which means that this approach will over-estimate low flow statistics such as the 7-d MALF - as evident in Figure 20 (evidence as deviation from the 1:1 line).

To address this, a power curve was fitted to these data (Figure 21), and the resulting regression equation appears to remove the bias in estimates of the 7-d MALF for outflows from Lake Hāwea (Figure 22). Using this power regression to estimate the 7-d MALF (1933-1955) results in a value of 31 m^3/s which compares well with the estimate based on actual data of 30 m^3/s. Using actual outflows for the period 1933-1955 and using the power regression for the period 1956- 2023, the long-term 7-d MALF is estimated to be 32 m^3/s.

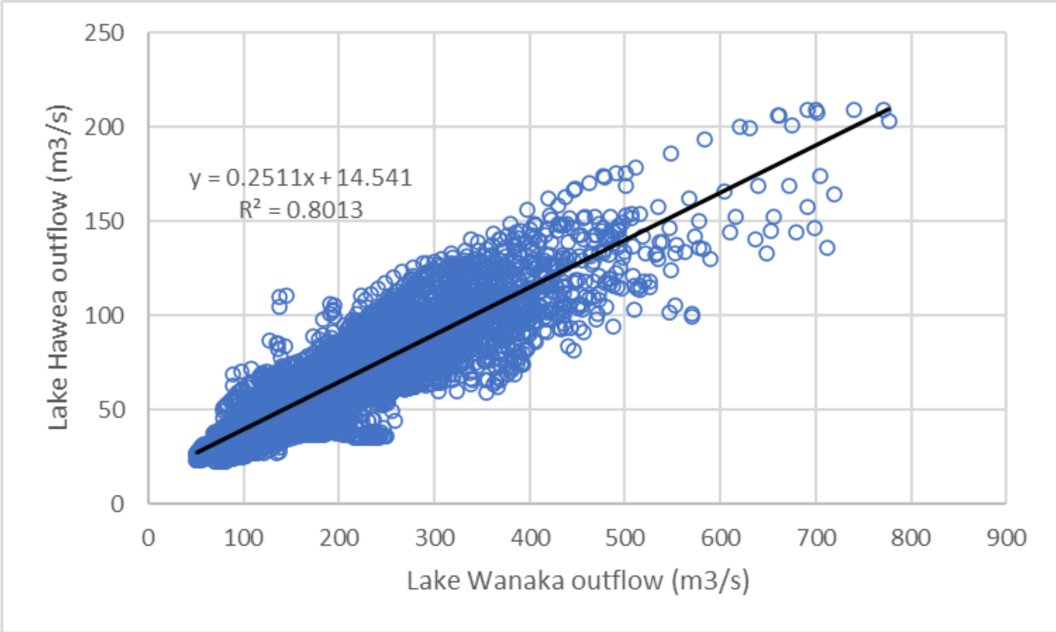

Figure 19 **Linear regression of outflows from Lake Wānaka (from water levels in Lake Wānaka) with outflows from Lake Hāwea (based on water levels in Lake Hāwea prior to hydro-electric development). Based on data from 2 February 1933 to 3 August 1955.**

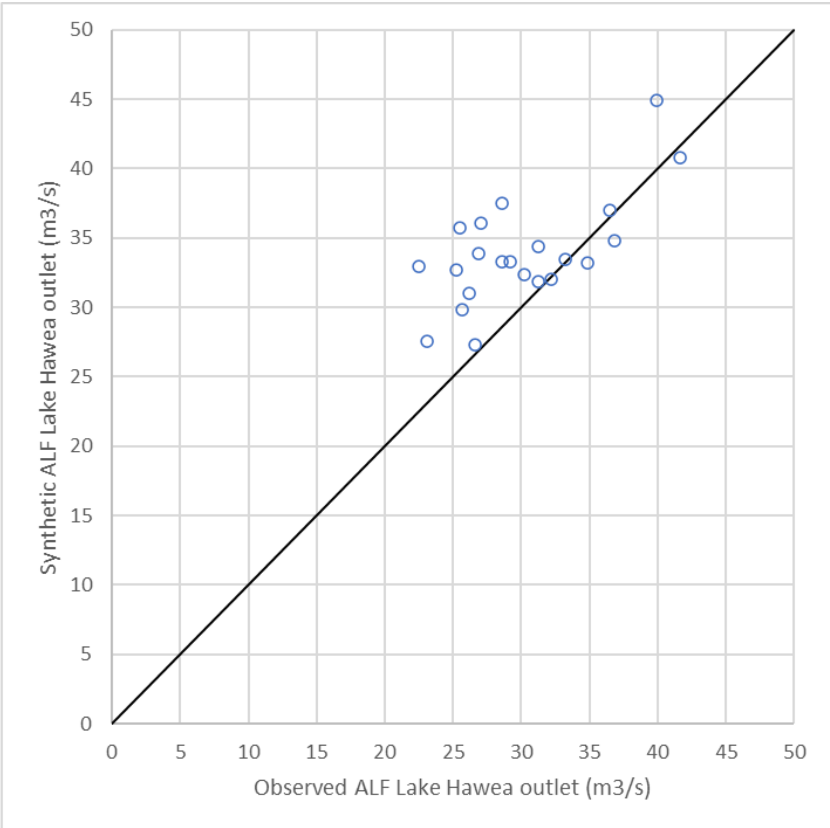

Figure 20 **Comparison of low flow statistics based on observed outflows from Lake Hāwea with synthetic low flow statistics for the Lake Hāwea outlet based on the linear regression presented in Figure 19.**

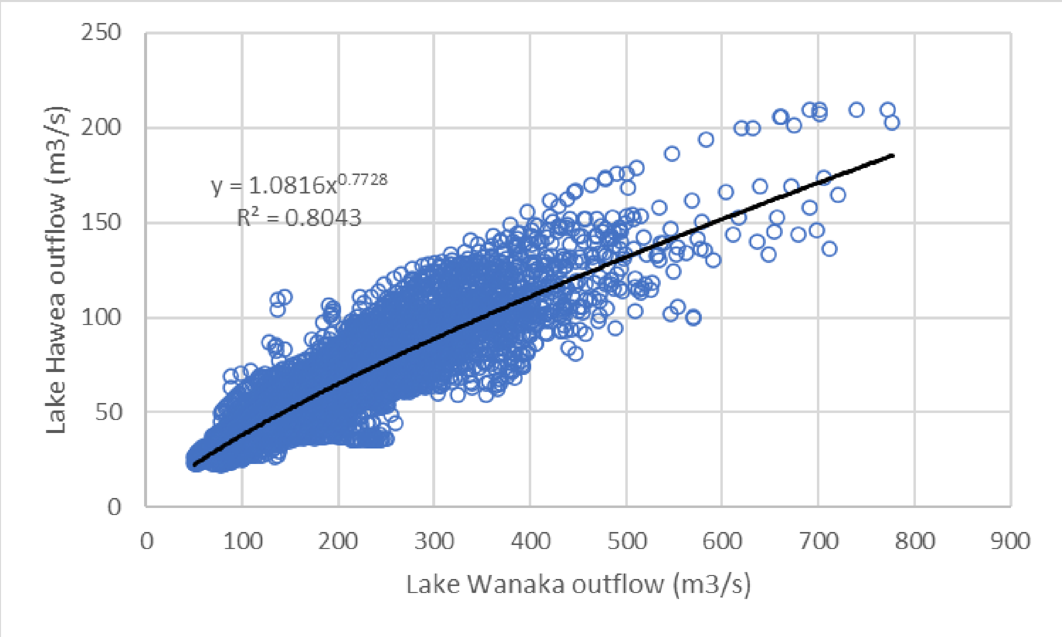

Figure 21 **Power regression of outflows from Lake Wānaka (from water levels in Lake Wānaka) with outflows from Lake Hāwea (based on water levels in Lake Hāwea prior to hydro-electric development). Based on data from 2 February 1933 to 3 August 1955.**

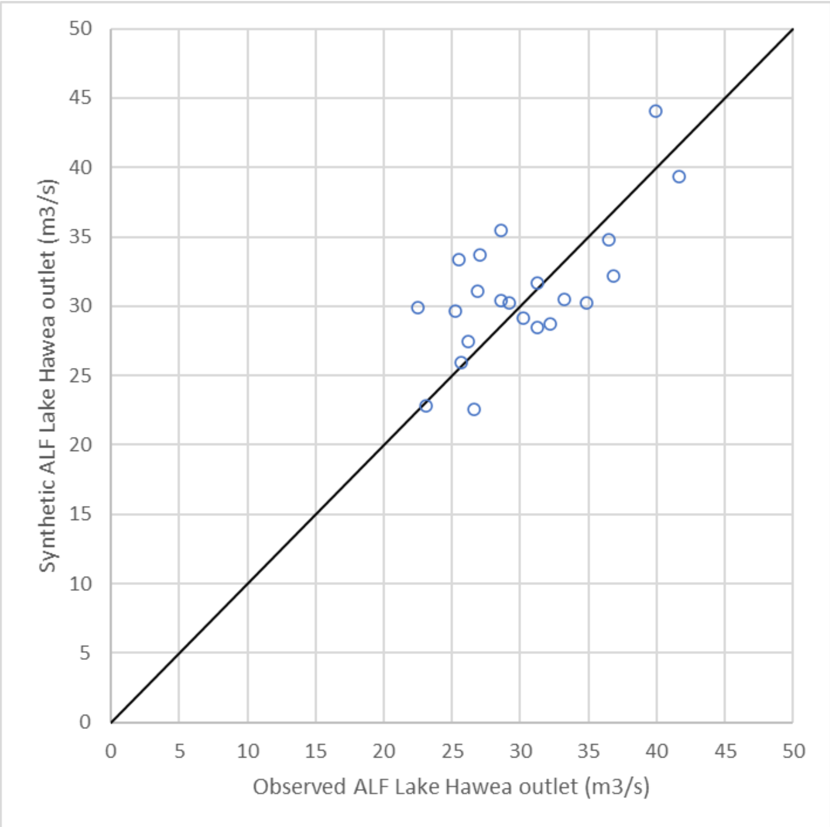

Figure 22 **Comparison of low flow statistics based on observed outflows from Lake Hāwea with synthetic low flow statistics for the Lake Hāwea outlet based on the linear regression presented in Figure 21.**