Update of scientific information for the

Arrow catchment: 2012-2017

Dec 2017

Otago Regional Council

Update of scientific information for the Arrow catchment: 2012-2017

July 2017

Otago Regional Council

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

ISBN [get from Comms Team]

Report writer: Dean Olsen, Manager, Resource Scientist
Xiaofeng Lu, Resource Scientist, Hydrology
Pete Ravenscroft, Environmental Resource Scientist, Freshwater

Reviewed by: Maurice Duncan, NIWA Scientist Applied Hydrology

Published [Dec 2017]

Technical summary

The Arrow River (catchment area: 236 km^2) is located in Central Otago. Its headwaters are in the Harris Mountains, and in the lower reaches it is bordered by the Crown Range; it flows in a south-east direction, joining the Kawarau River near the township of Arrowtown. The climate is typical of Central Otago being characterised by cold winters and warm, dry summers.

There are 22 existing surface water takes in the Arrow River catchment, with a total allocation of 2.03m^3/s, although the measured usage does not exceed 1 m3/s and the average take is approximately 0.55 m^3/s.

The objective of this report is to present the findings of further investigations into the hydrology, ecology, and irrigation practices of the Arrow catchment since the last published report on this topic in 2012 (*Management flows for aquatic ecosystems in the Arrow River* (2012).

This report summarises the results of the work undertaken since 2012 and discusses the implications for the minimum flow process in the Arrow River catchment.

This information includes the following:

- Hydrology and existing water allocation in Arrow River,
- The aquatic values of the Arrow River,
- Presentation, analysis and interpretation of the results of instream habitat modelling flows to maintain aquatic ecological values in the Arrow River.

Naturalised low-flow statistics were estimated by adding water take data upstream of the Cornwall Street recorder to flows recorded at this same site. There are three operational water takes above the flow recorder; with water take data being recorded for at least the past four years. This meant that three years of flow data recorded at Cornwall Street were unable to be used in this analysis. The results of this analysis is summarised in the following table:

Location	Flow data type	7-d MALF[1] (m^3/s)
Arrow at Cornwall Street	Measured flows	1.03
Arrow at Cornwall Street	Naturalised	1.43 ~ 1.44

Instream habitat modelling was conducted to determine how changes in flow affect habitat for fish, macroinvertebrates and algae in two reaches in the Arrow catchment.

Appropriate objectives for the management of the aquatic ecosystems of the Arrow River include maintaining the locally-significant trout fishery and to protect its life-supporting capacity including macroinvertebrate populations and limiting the risk of periphyton

[1] 7-d MALF = the seven-day mean annual low flow, the average of the lowest arithmetic mean of seven consecutive daily values of flows.

proliferation. The flow requirements for key values of the lower Arrow River are presented in the following table:

Instream value	Season	Fishery or conservation value	Recomm. % habitat retention	Flow to maintain suggested habitat retention (l/s)	Flow below which habitat rapidly declines (l/s)	Optimum flow (l/s)
Adult trout	All year	Locally significant†	70%	553	-	1,600
Juvenile trout	All year	Locally significant†	70%	198	500	900
Brown trout - spawning (May-August)	Winter	Locally significant†	70%	44	400	600
Rainbow trout - spawning (May-August)	All year	Locally significant†	70%	127	400	600
Food producing	All year	Life supporting capacity	70%	392	600	900
Long filamentous algae	Summer	Nuisance	<150%	>755	800	-

† Based on the assessment in Otago Fish & Game Council (2015).

Contents

List of figures

List of tables

1. Introduction

The Otago Regional Council (ORC) has continued to measure flows in the Arrow River since the publication of the report *Management flows for aquatic ecosystems in the Arrow River* (Kitto, 2012). This 2017 report presents an updated hydrological analysis for the Arrow River using data collected from the Cornwall Street flow site, including analyses to estimate naturalised flows for several seasons and an updated instream habitat analysis.

The Arrow River (catchment area: 236 km^2) is located in Central Otago. Its headwaters are in the Harris Mountains, and in the lower reaches it is bordered by the Crown Range; it flows in a south-east direction, joining the Kawarau River near the township of Arrowtown. The climate is typical of Central Otago being characterised by cold winters and warm, dry summers.

The upper reaches of the Arrow catchment are relatively unmodified with predominately steep tussock-covered mountain slopes. The catchment descends abruptly with dramatic landforms and ice-carved landscapes. In the mid to lower reaches there is a contrast of rocky bluffs and tussock; the vegetation changes from tall tussock to short tussock, exotic grasses, sweet briar and grey shrub-lands as you move down the catchment.

The Arrow River forms an integral part of the picturesque setting of today's Arrowtown. There are numerous bike and walking trails that follow the river margins and there are several recreational parks where local people and a large number of tourists sit and paddle in the waters of the Arrow River. The clean and clear nature of the river bed and inanga/pale green coloured pools add as much to the tranquillity of Arrowtown as do the autumn tones of the deciduous trees that frame the township.

The river formed part of the 1860 Central Otago gold rush and provided a rich vein of gold for the many European and Chinese that settled in the area. At the peak of this period, 1,500 miners occupied the banks of the river[2] and gold is still found in the river today. Many of the historic dwellings that were established during the early history form part of Arrowtown's charm.

Māori referred to the Arrow River as Haihainui (meaning big scratches), a name which possibly reflected the local plant community, which was dominated by the prickly Matagouri, *Dracophyllum and Aciphylla* species. Summer seasonal hunts were undertaken collecting native birds such as weka. Māori also gathered pounamu (greenstone) in the Wakatipu area; although it's unclear whether any pounamu was found within the Arrow River catchment.

There are 22 existing surface water takes in the Arrow River catchment, with a total allocation of 2.25 m^3/s, although the measured usage does not exceed 1 m^3/s and the average take is about 0.55 m^3/s.

[2] http://www.arrowtown.com/our-town/then-now/

2. Report Objective

The objective of this report is to present the findings of further investigations into the hydrology, ecology, and irrigation practices of the Arrow catchment since the last published report on this topic in 2012 (*Management flows for aquatic ecosystems in the Arrow River* (2012)).

This report summarises the results of the work undertaken since 2012 and discusses the implications for the minimum flow process in the Arrow River catchment.

This information includes the following:

- Hydrology and existing water allocation in Arrow River,
- The aquatic values of the Arrow River,
- Presentation, analysis and interpretation of the results of instream habitat modelling flows to maintain aquatic ecological values in the Arrow River.

3. Rainfall patterns and naturalised flows in the Arrow catchment

3.1. Rainfall statistics

The climate of the Arrow catchment is consistent with other parts of Central Otago, with cold winters and hot and dry summers. The catchment is affected by westerly weather systems that spill over the Southern Alps.

There are three rainfall stations located in the immediate vicinity of the Arrow catchment (Figure 3.1). The gauges are located at Queenstown Aero Automatic Weather Station (AWS) (34 years record to 2017), the Shotover at Peat's Hut (20 years to 2017), and Matukituki at West Wanaka (19 years to 2017).

Rainfall at Queenstown Aero AWS does not have a strong seasonal distribution (refer Figure 3.2). The rain gauges at Peat's Hut shows higher rainfall compared with Queenstown Aero AWS, likely due to the Peat's Hut site being more affected by westerly air flows bringing heavy spill-over rain over the Southern Alps. Matukituki at West Wanaka also generally has higher monthly rainfall totals than those recorded at the Queenstown Aero AWS. February, March, and April appear to be the months where all sites consistently receive the lowest monthly rainfalls.

Annual rainfall statistics for Queenstown Aero AWS, Shotover at Peat's Hut, and Matukituki at West Wanaka are summarised in Table 3.1 . The Shotover at Peat's Hut (923 mm) has the highest mean rainfall, while Queenstown Aero AWS has the lowest recorded rainfall of all the sites (569 mm recorded in 2005). Matukituki at West Wanaka had the highest maximum annual rainfall of all three sites, with 1199 mm recorded in 2004.

The rainfall distribution map (Figure 3.3) shows that the highest annual rainfall totals occur in the headwaters of the catchment where there is spill-over rain from westerly storms. Rainfall decreases from north to south, where the annual rainfalls are in the range of 700 – 750 mm. The mean annual rainfalls are: Queenstown, 733 mm; the Shotover at Peat's Hut, 939 mm; and for the Matukituki at West Wanaka, 918 mm. The long-term mean annual rainfall for the Arrow River catchment (Figure 3.3) is calculated as 701 mm.

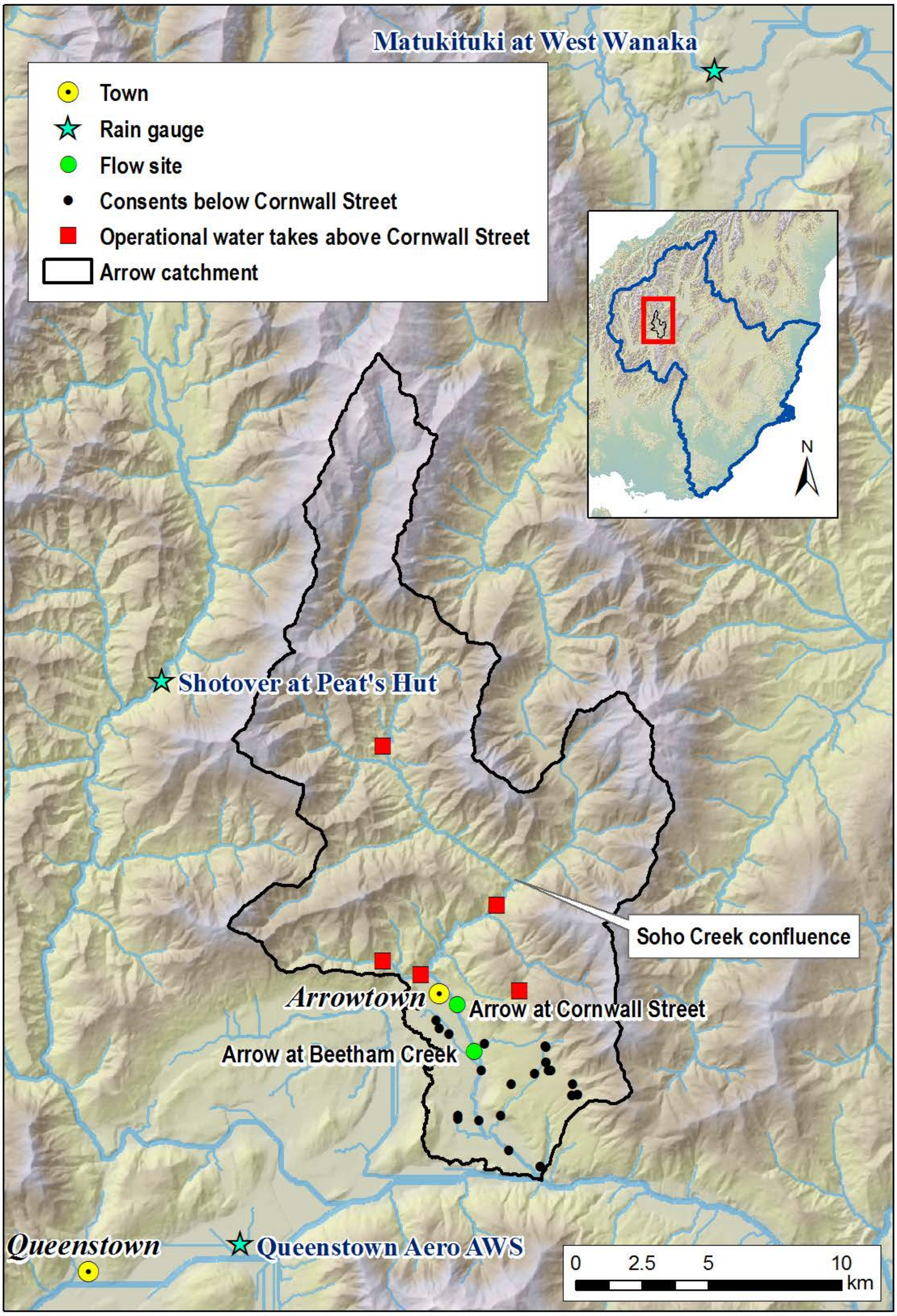

Figure 3.1 **The flow recorders, water takes in the Arrow catchment, and the nearby rain gauges (Source: Otago Regional Council)**

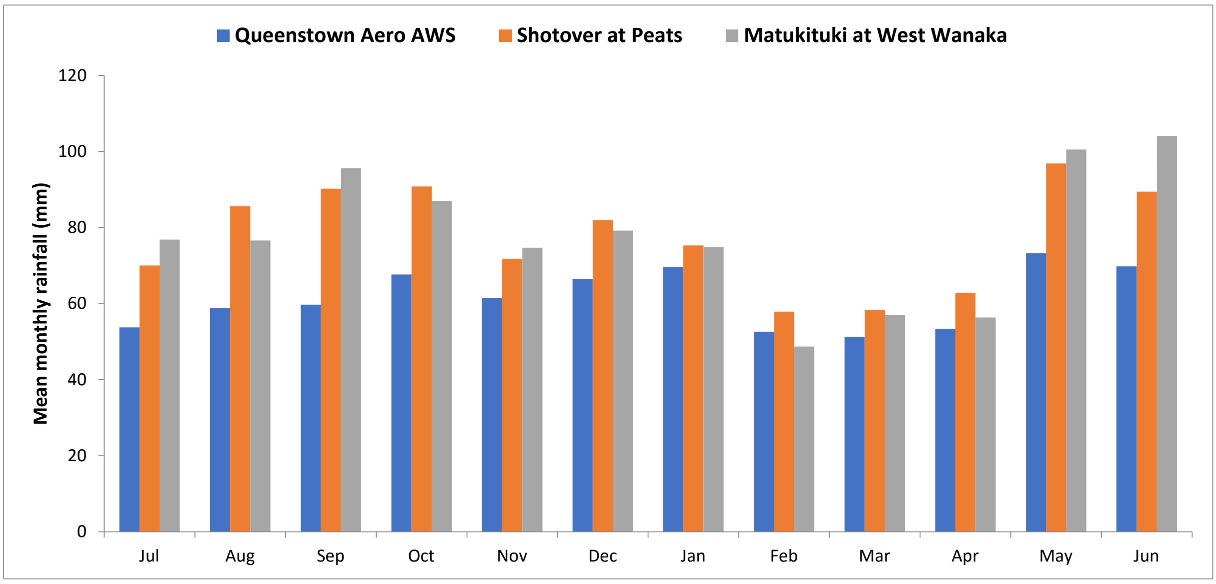

Figure 3.2 **Average monthly rainfall totals for the rainfall sites at Queenstown Aero AWS (NIWA), Shotover at Peat's Hut (ORC), and Matukituki at West Wanaka (ORC)**

Table 3.1 **Summary of annual rainfall statistics for Queenstown Aero AWS, the Shotover at Peat's Hut, and Matukituki at West Wanaka**

	Queenstown Aero AWS (Nov 1982-May 2017)	Shotover at Peat's Hut (Jan 1997-Apr 2010)	Matukituki at West Wanaka (Feb 1998-Apr 2017)
Min (mm)	569	691	682
Mean (mm)	733	939	918
Max (mm)	1077	1130	1199
Years of record	34	20	19

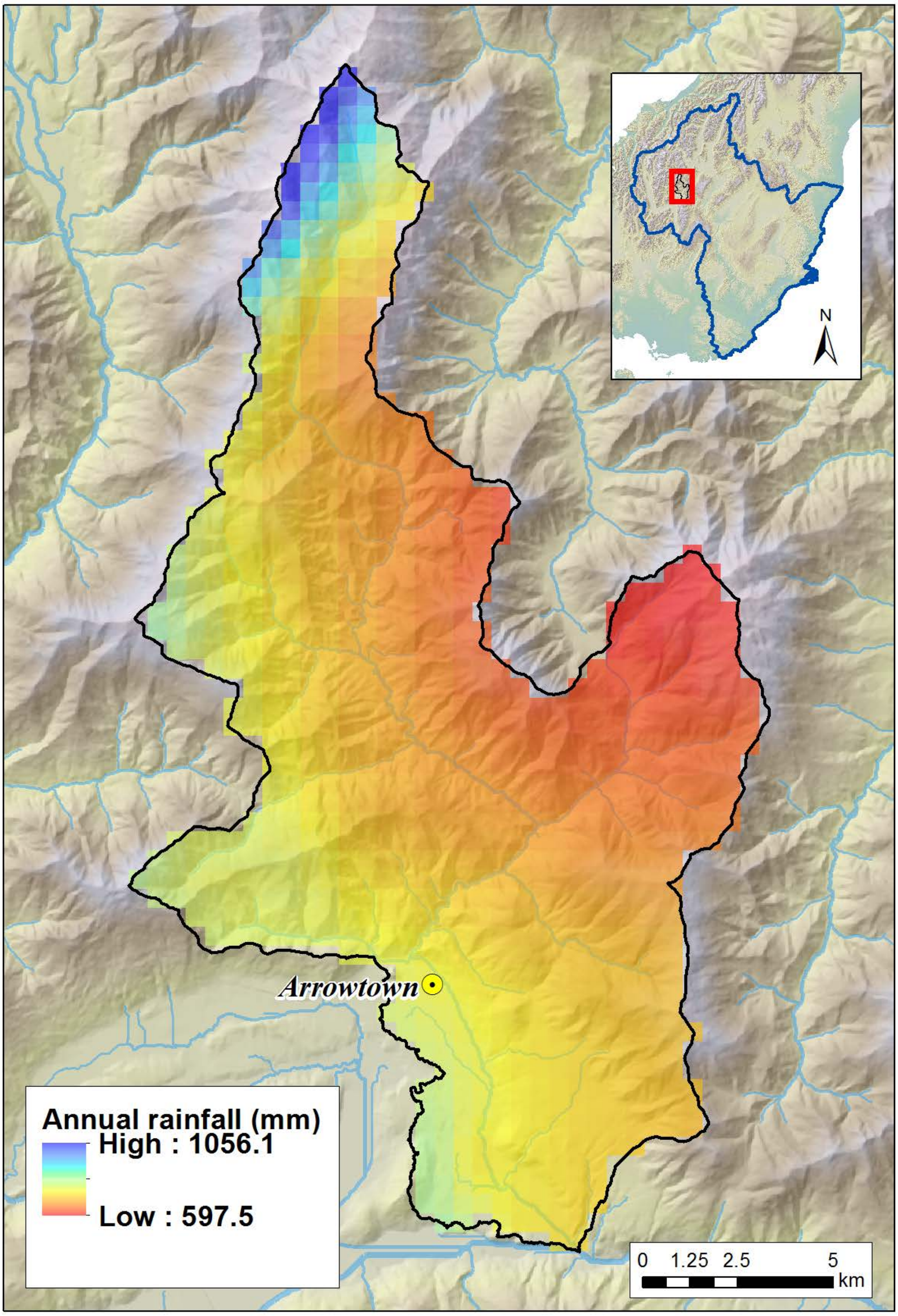

Figure 3.3 **Long-term rainfall distribution for the Arrow River catchment (Tait et al. 2006)**

3.2. Naturalised flows in the Arrow River at Cornwall Street

This section details the methods applied to derive the naturalised flows for the Arrow River at the Cornwall Street flow site. Flow descriptions include comparisons of flow statistics summarised from the measured and estimated naturalised flows at Cornwall Street, including the estimated naturalised 7-day mean annual? low flow (7dMALF).

3.2.1. Methods

The Ministry of Works established a flow site on the Arrow River upstream of Beetham Creek in April 1981 and removed the site in January 1994. The site is 2 km downstream from the ORC's Arrow at Cornwall Street stage recorder and has a catchment area that is 7.5% larger, yet the measured 7dMALF is 0.88 m^3/s from the 12-year record (16/4/1981 – 23/1/1994) compared to the measured 7dMALF at Cornwall Street from a 7-year record (30/12/2010 – 9/10/2017) of 1.026 m^3/s. Table 3.2 sets out a comparison of the basic flow statistics from the two sites.

Table 3.2 **The flow statistics for all the available measured flow sites within the Arrow River catchment**

Flow site	Availability (daily time series)	7dMALF (m^3/s), Jul - Jun	7dMALF (m^3/s), Oct - Apr	Minimum (m^3/s)	Median (m^3/s)	Mean (m^3/s)	Maximum (m^3/s)
Arrow at Beetham Creek	16/4/1980 - 23/1/1994	0.88	0.88	0.136	2.72	3.44	46.11
Arrow at Cornwall street d/s	30/12/2010 – 9/10/2017	1.03	1.03	0.631	2.80	3.49	63.09

The differences between the flow statistics for these two sites could be explained by:

a) Differences in the water takes from the river (which are unknown for all but the last four years of the Cornwall Street record). The Beetham Street site is downstream of the Arrow Irrigation Company off-take, or

b) They could be explained by different weather conditions during the two periods of record.

A flow recorder was established in the Arrow River at Cornwall Street in December 2010. Since the water take time-series data is available for takes above the Cornwall Street site, the flow at this site can be naturalised by totalling the measured flows and all consumptive water takes upstream. In other words, the naturalised flows for the Arrow at Cornwall Street = the measured flows at Arrow at Cornwall Street + all upstream water takes.

There is insufficient flow and water take data for the reach of the Arrow River from Cornwall Street flow recorder downstream to the confluence with the Kawarau River. Due to this flow statistics were not calculated for this reach of the river.

Similarly, water use data records were not available for the Beetham Creek flow site (Apr 1981 – Jan 1994), making it impossible to use any flow information from Beetham Creek to estimate naturalised flows. As a consequence, we have chosen to develop naturalised time-series for this study based on data from the Cornwall Street site, as we have concurrent water use data for much of the record period.

3.2.2. Data

Table 3.3 lists the time series data used for deriving the naturalised flows for the Arrow River at Cornwall Street.

Table 3.4 lists the seven-day low flow (7dLF) for each irrigation season (Oct - Apr) for all the available flow records for the Arrow at Cornwall Street.

Table 3.3 The available flow data and water metering time series used to derive naturalised flows for the Arrow River at Cornwall Street in this study

Consent No. and flow site	Water meter number	Data type	Data availability	Max rate of take (l/s)
WR1440AR	WM0667	Consumptive primary water take	9/10/2013 – 20/10/2017	1389
95696	WM0733	Consumptive primary water take	4/6/2015 – 20/10/2017	83.33
2007.049	WM0458 and WM0459	Consumptive primary water take	13/6/2010 – 20/10/2017	108
Arrow River at Cornwall Street		Measured flow	30/12/2010 – 9/10/2017	

Notes:

- Consent number 2003.670 is non-consumptive.
- Consent number 2007.410 is not used. The Queenstown Lake District Council (QLDC) advised the ORC in 2016: “There has never been a draw of water from Bush Creek under this 2007.410 consent, however QLDC retains this one in case of an emergency.”

Table 3.4 The 7dLF's for each irrigation season for the entire flow record for the Arrow at Cornwall Street

Season start	Season end	7dLF	Gap (day)	Minimum (m^3/s)	Median (m^3/s)	Average (m^3/s)	Maximum (m^3/s)
30/12/2010	30/04/2011	1.65	1	1.47	2.14	2.50	12.87
1/10/2011	30/04/2012	0.86	NA	0.83	2.18	3.25	22.13
1/10/2012	30/04/2013	1.07	NA	1.05	2.57	3.42	13.17
1/10/2013	30/04/2014	1.09	NA	1.06	2.39	3.20	16.52
1/10/2014	30/04/2015	1.06	NA	1.01	1.92	2.75	18.8
1/10/2015	30/04/2016	0.702	NA	0.631	1.29	1.99	6.62
1/10/2016	30/04/2017	1.37	15	1.33	3.28	3.84	12.9
1/10/2017	9/10/2017	4.03	NA	3.81	4.17	4.14	4.64

Figure 3.4 illustrates the entire measured water take and flow time-series for the Arrow at Cornwall Street mentioned in Table 3.3.

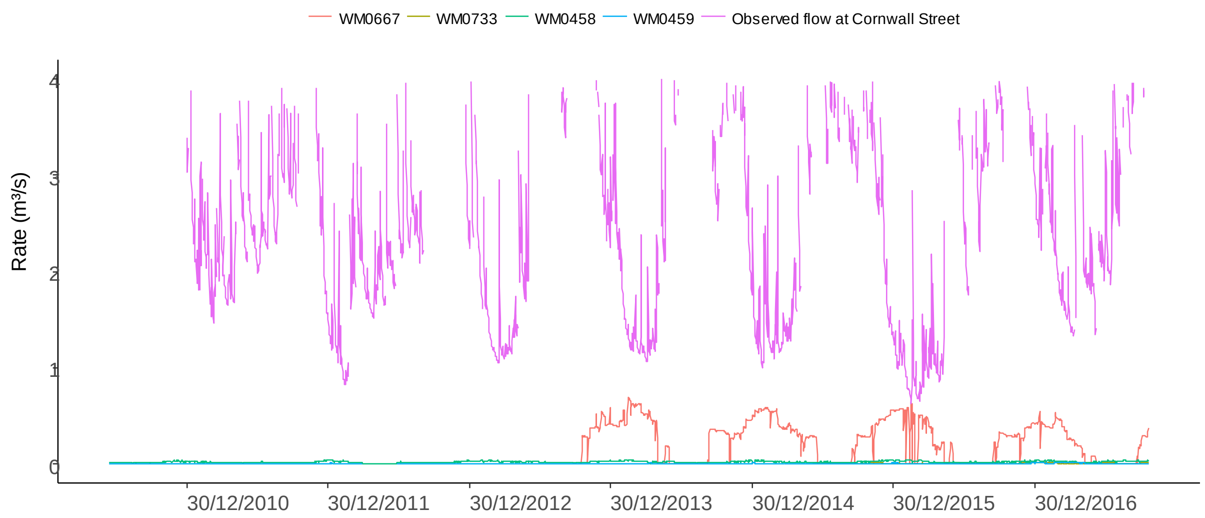

Figure 3.4 The overplot of all the measured water take time-series and the flow time-series at Cornwall Street mentioned in Table 3.3

3.2.3. Total water take above the Arrow at Cornwall Street

Based on the water metering data listed in Table 3.3, the total water take above Cornwall Street can be derived. Figure 3.5 shows the monthly average percentages of consented water takes for Consent No's 2007.049, 95696, and WR1440AR across the water metering period. Figure 3.6 illustrates the monthly average rate of total take and the average ratio of the measured total take to the total consented take above the Arrow at Cornwall Street site.

Figure 3.5 and Figure 3.6 confirm that the quantity of the water taken for the three consents is well below their respective consented maximum rates of take. Consent No. 95696 has a very short period of water metering data in comparison to the remaining two water takes (Table 3.3), with only two years of water take data available. Using only two years of data would severely limit the usable flow data recorded at Cornwall Street.

By examining the available water take metering data for Consent No. 95696, the maximum daily rate of take for this consent is 23.8 l/s, which is well below its consented allocation limit (83.33 l/s). To expand the length of the estimated naturalised flow time series by the proposed method described above (Section 3.2.1), the daily average rate of take for Consent No. 95696 between 9/10/2013 and 3/6/2015 can be assumed to be from zero (lower level) to 20 l/s (upper level). Using this assumed range (i.e. 0-20 l/s) allows an additional two years of flow data at Cornwall Street to be utilised, giving a total of four years (from 9/10/2013 to 20/10/2017) used in the analysis of naturalising flows in the Arrow River.

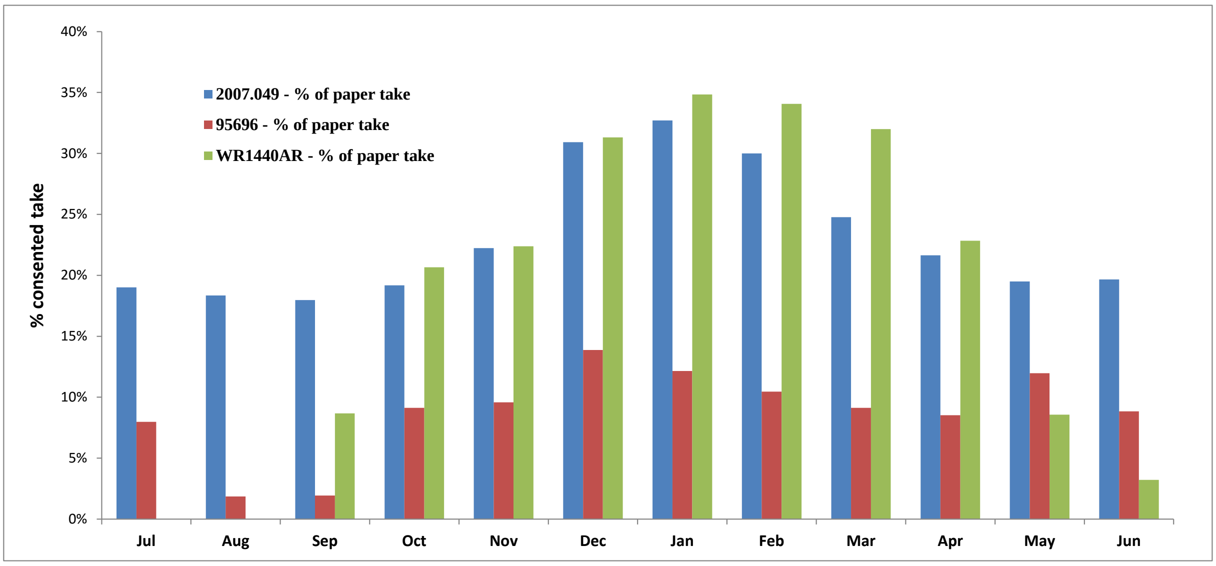

Figure 3.5 **The percentages of water takes for consents 2007.049, 95696, and WR1440AR across the available actual water take data**

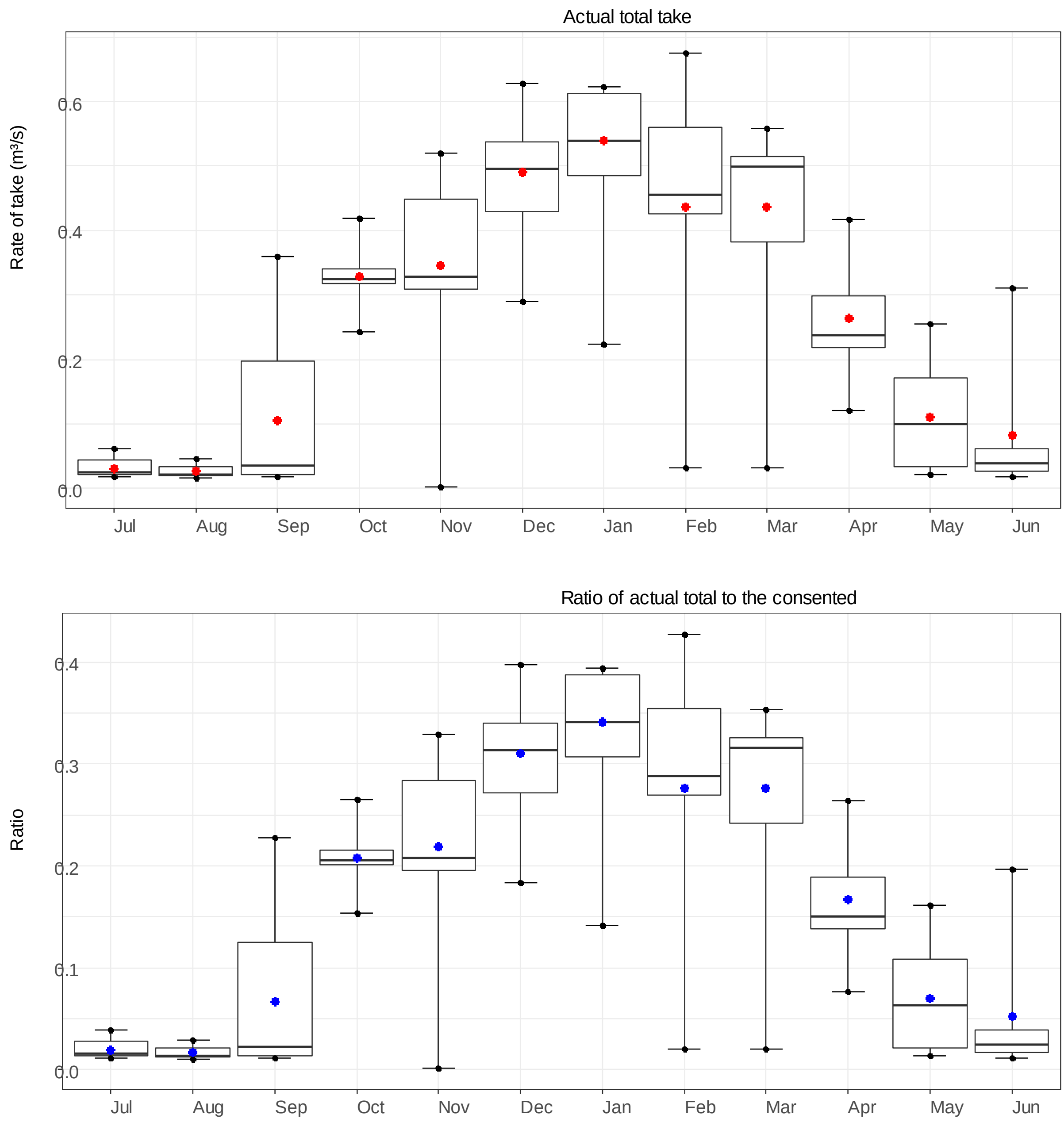

Figure 3.6 **The monthly average rate of measured take and ratio of the measured-to-the-total-consented take above the Arrow at Cornwall Street between 9/10/2013 and 20/10/2017**

3.2.4. Naturalised low-flow statistics of the Arrow River

A major objective of this study is to provide an understanding of the flows required to maintain the instream values and natural character of the Arrow River. Understanding the low flow hydrology of the Arrow River is an essential step in achieving this objective.

As mentioned in Section 3.2.1, naturalised flows for the Arrow at Cornwall Street can be calculated by adding the upstream total water take to its measured flows. Flow naturalisation at the Arrow River at Cornwall Street is a reasonably straightforward task in comparison to many other waterways within Otago. The limiting factor in undertaking the analysis to naturalise the surface flows in the Arrow catchment is that the data set is restricted to a four-year period. This is because there is only four years of water take data available (including the two-year extended water take data for Consent 95696, details in Section 3.2.3), so that only four of the seven years of hydrological information collected at Cornwall Street can be utilised.

Table 3.5 compares the low-flow statistics between the measured and derived naturalised flows for the Arrow at Cornwall Street. The analysis indicates that the estimated average naturalised 7-day mean low flow (7dMLF) between 2013 and 2017 was in the range of 1.43 to 1.44 m³/s. This range is due to the assumptions regarding water use for Consent No. 95696.

Table 3.6 lists the flow statistics during winter months (May-September) for both measured and estimated naturalised flow records for the flow site at Cornwall Street.

Table 3.5 The comparisons of 7dLFs between the measured and naturalised flows for each irrigation season for the Arrow River flow site at Cornwall Street

Low-flow season	Measured flow at Cornwall Street		Naturalised flow at Cornwall Street	
	7dLF (m³/s)	Mean daily (m³/s)	7dLF (m³/s)	Mean daily (m³/s)
Oct 2010 – Apr 2011	1.65	2.50	Not available	Not available
Oct 2011 – Apr 2012	0.87	3.25	Not available	Not available
Oct 2012 – Apr 2013	1.07	3.42	Not available	Not available
Oct 2013 – Apr 2014	1.09	3.20	1.64 ~ 1.66	3.58 ~ 3.60
Oct 2014 – Apr 2015	1.06	2.75	1.60 ~ 1.62	3.19 ~ 3.21
Oct 2015 – Apr 2016	0.70	1.99	0.83	2.42
Oct 2016 – Apr 2017	1.37	3.84	1.65	4.23
7dMALF (Oct – Apr)	**1.12**		**1.43 ~ 1.44**	

The low-flow statistics for October 2015 through to April 2016 are much lower in comparison to other low-flow seasons. This is due to the dry weather conditions that occurred from October 2015 through to April 2016.

Table 3.7 lists the rainfall totals during these low-flow seasons for the nearby rain gauges (with respective rainfall totals shown during an average irrigation season), and the possible weather conditions categorised by the Standardised Precipitation Index (SPI).

Table 3.6 The comparisons of 7dLFs between the measured and derived naturalised flows for each winter season (May - September) for the Arrow River flow site at Cornwall Street

Winter months	Measured flow at Cornwall Street		Naturalised flow at Cornwall Street	
	7dLF (m^3/s)	Mean daily (m^3/s)	7dLF (m^3/s)	Mean daily (m^3/s)
May 2011 – Sep 2011	2.04	2.66	Not available	Not available
May 2012 – Sep 2012	1.69	2.43	Not available	Not available
May 2013 – Sep 2013	1.83	4.36	Not available	Not available
May 2014 – Sep 2014	2.27	4.01	2.33 ~ 2.35	4.98 ~ 5.00
May 2015 – Sep 2015	3.03	4.16	3.31 ~ 3.33	4.82 ~ 4.82
May 2016 – Sep 2016	1.02	3.37	1.24	3.56
May 2016 – Sep 2017	1.61	2.73	1.72	3.53
7dMALF (May – Sep)	**1.87**		**2.13 ~ 2.16**	

Note: The 7dLF for season May 2014 – September 2014 is not involved in calculating the 7dMALF (May – Sep), as it has a 72-day data gap.

Table 3.6 shows, the 7dMALF for the measured flows at Cornwall Street during the winter months (May - Sep) is 1.87 m^3/s, compared to the 7dMALF for the derived naturalised flows of 2.13 to 2.161 m^3/s. The lowest flows recorded for the winter months occurred during the early May 2016.

Table 3.7 **The rainfall totals during the low-flow seasons (between 2010 and 2017) for the nearby rain gauges at: the Shotover at Peat's Hut, Queenstown Aero AWS, and Matukituki at West Wanaka, with the weather conditions categorised by the Standardised Precipitation Index (SPI)**

Low-flow season	Shotover at Peat's Hut, with an average rainfall of 499 mm (Oct-Apr)		Queenstown Aero AWS, with an average rainfall of 422 mm (Oct-Apr)		Matukituki at West Wanaka, with an average rainfall of 478 mm (Oct-Apr)	
	Rain (mm)	SPI category	Rain (mm)	SPI category	Rain (mm)	SPI category
Oct 2010 – Apr 2011	519	Normal	452	Normal	533	Normal
Oct 2011 – Apr 2012	526	Normal	388	Normal	444	Normal
Oct 2012 – Apr 2013	584	Moderately wet	390	Normal	492	Normal
Oct 2013 – Apr 2014	501	Normal	383	Normal	438	Normal
Oct 2014 – Apr 2015	503	Normal	467	Normal	432	Normal
Oct 2015 – Apr 2016	392	Severely dry	299	Severely dry	280	Extremely dry
Oct 2016 – Apr 2017	575	Moderately wet	448	Normal	503	Normal

Table 3.7 shows that there was much less rainfall received during the October 2015 to April 2016 period (compared to the respective average rainfall total during a normal low-flow season), which is consistent with the very low flows observed at Cornwall Street over this same period. Based on the calculated SPI values for these three gauges (SPI values of -1.829 at Shotover at Peat's, -1.664 at Queenstown Aero AWS, and -2.740 at Matukituki at West Wanaka), the rainfall total (during the 2015/16 low-flow season) is a 1 in 20 to 30-year event (World Meteorological Organization, 2012)).

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 Arrow catchment, brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) are likely to be the most sensitive to high water temperatures. Their thermal requirements are relatively well understood, and Todd et al. (2008) calculated acute and chronic thermal criteria for both 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 defined 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). Most native fish species with available thermal tolerance data are more tolerant of high temperatures than trout (Olsen et al. 2012).

Limited water temperature data were available for the Arrow River – with just over 3 months recorded from 30 December 2010 to 4 April 2011 (Figure 3.7). Water temperatures over this period were well within the thermal tolerances of brown and rainbow trout, with peak temperatures well within acute criteria for both brown and rainbow trout (Figure 3.7).

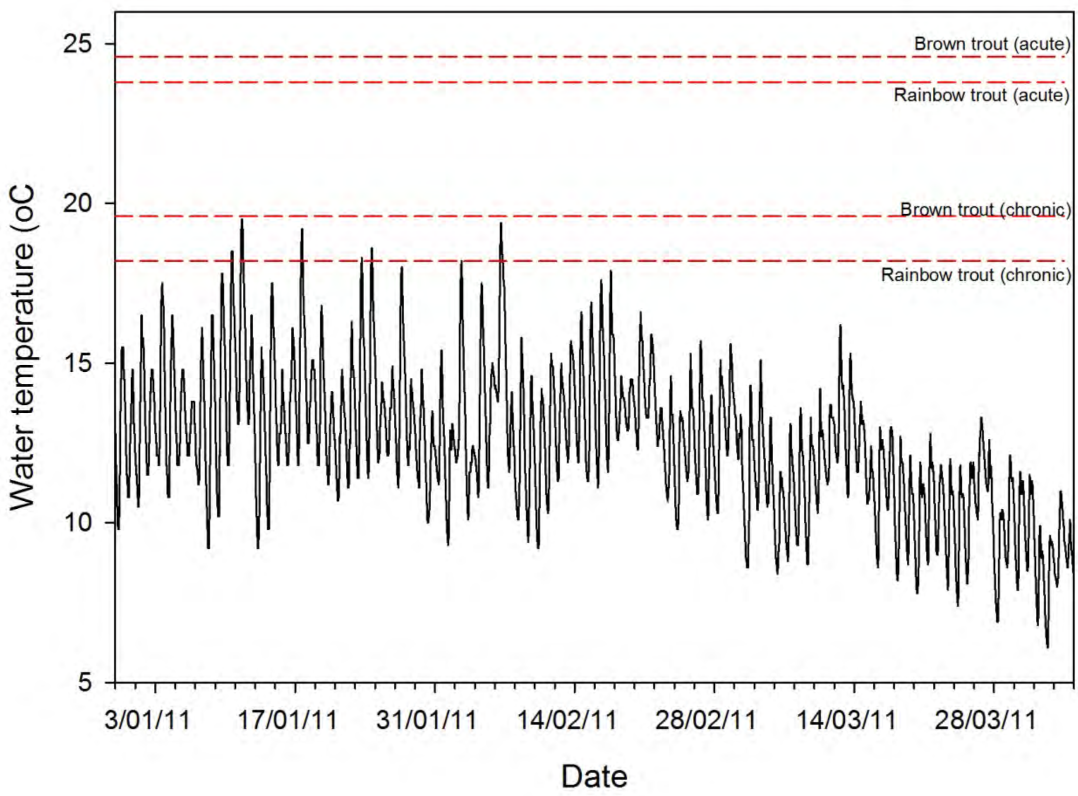

Figure 3.7 **Water temperature variations for the Arrow River at the Cornwall Street flow site.**

4. Aquatic ecosystem values of the Arrow River

Schedule 1A of the Regional Plan: Water for Otago (RPW) outlines the natural and human use values of Otago's surface water bodies. The Arrow River is identified as having the following values:

- Gravel and sand bed composition of importance to resident biota,
- Access within the main-stem of a catchment through to the sea or a lake unimpeded by artificial means, such as weirs, and culverts,
- Presence of significant areas for fish spawning and development of juvenile fish,
- Absence of aquatic pest plants identified in the Pest Plant Management Strategy for the Otago region,
- Significant presence of trout,
- A high degree of naturalness above 900 m above sea level.

The Soho Creek catchment, which is a sub-catchment of the Arrow catchment is also identified in Schedule 1A of the RPW with the following values:

- Weed free,
- Presence of a rare macro-invertebrate.

4.1. Native fish

There is a single record documenting the presence of an indigenous fish species within the Arrow catchment (Figure 4.1). The fish, commonly known as koaro (*Galaxias brevipinnis*), was found near the confluence of the main-stem of the Arrow River and Soho Creek, five kilometres upstream of Arrowtown. Whether this species occupies other parts of the catchment is unknown, however if it does, then it appears that koaro abundance is potentially very low. Koaro is listed as "At Risk, Declining" in the most recent threat classification (Goodman et al*.* 2014).

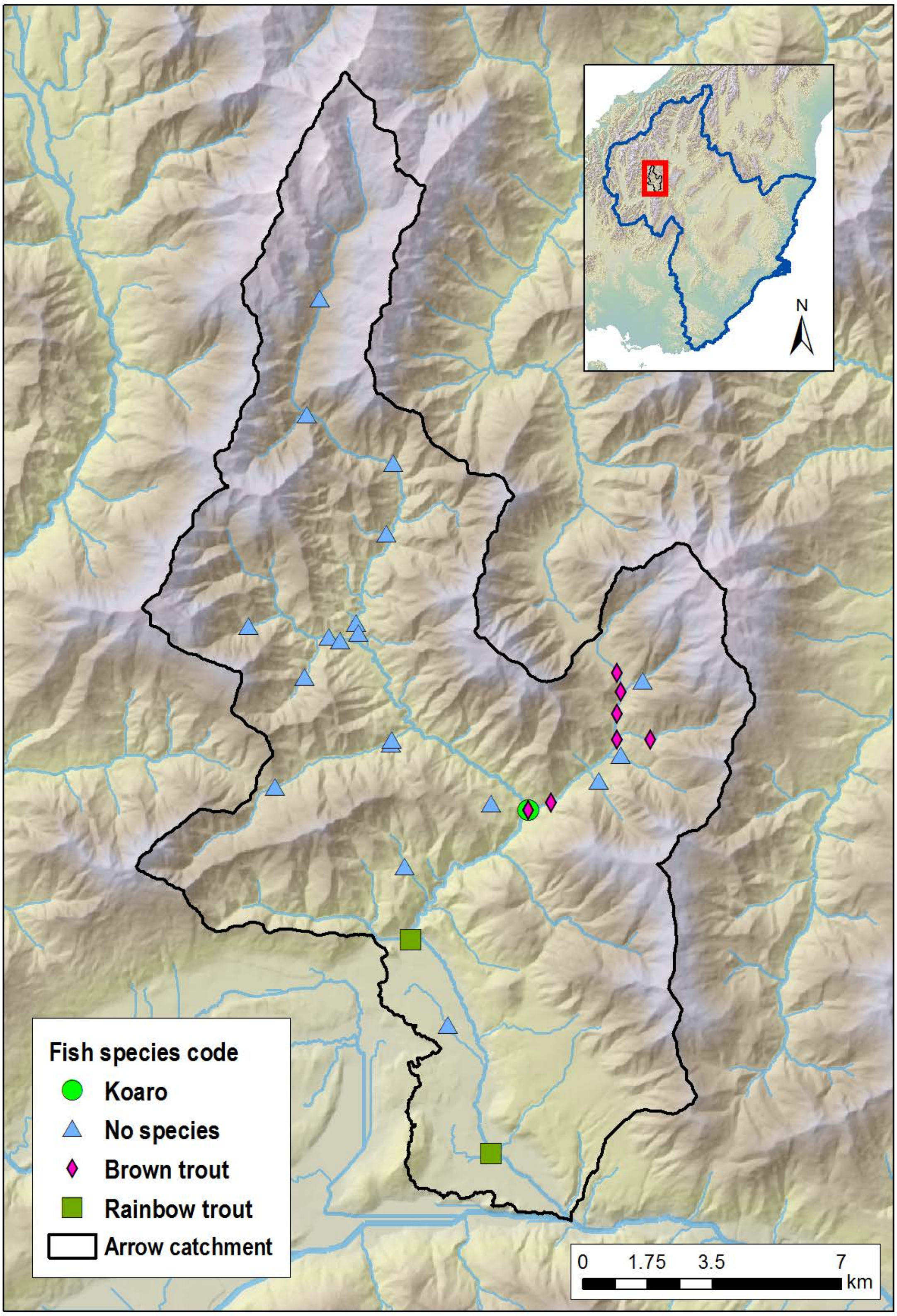

Figure 4.1 Location of fish records in the Arrow River (New Zealand Freshwater Fish Database)

Although not recorded in the Arrow River, it is probable that longfin eels were once present. The construction of Roxburgh and Clyde Dams has blocked both up and downstream passage to and from the sea and sea migration for eels is an obligatory part of their lifecycle. Although there are trap and transfer programmes being operated at Roxburgh Dam, eel numbers in the Upper Clutha catchment (above Roxburgh Dam) have declined markedly over time. Commercial eel fishing may also have contributed to the decline, however construction of the Roxburgh and Clyde Dams has accelerated the loss by preventing recruitment of young eels.

Roxburgh Dam was constructed in 1956 and the construction of the Clyde Dam was started in 1982 and finally filled in 1993. Eel passage to and from the Central Otago Lakes has been impeded for the past 61 years.

4.2. Sports fish

The Arrow River supports a locally significant sports-fish fishery (Otago Fish & Game Council, 2015). Although local angler use has declined over time; usage by overseas anglers has only been considered in the most recent national angler survey (Unwin, 2016). Table 4.1 presents 'angler effort' on the Arrow River, recorded during National Angler Surveys conducted in 1994/95, 2001/02, 2007/08 and 2014/15. Overall angler usage is relatively low, with those anglers who target the early part of the fishing season taking advantage of the occasional trophy sized trout. It's probable that these fish have remained in the river after spawning and will, over time, move out of the catchment. There is still however a small resident population of both brown and rainbow trout that remain within the catchment. These trout do grow to a 'catchable length' and consequently do provide some angling value.

Fish survey records retrieved from the New Zealand Freshwater Fish Database (NZFFD) indicate that no fish species have been recorded in the Arrow River above its confluence with Soho Creek (Figure 4.1). Below the confluence, brown trout are scattered throughout the lower catchment and there is a healthy resident population of brown trout located within Soho Creek. Rainbow trout appear to have a restricted distribution within the catchment, being more confined to the lower reaches of the Arrow River, downstream of the gorge.

Table 4.1 **Angler effort on the Arrow River based on the National Angler Survey (Unwin, 2016).**

Source	Angler usage (angler days ± SE)			
	1994/95	**2001/02**	**2007/08**	**2014/15**
NZ resident	210 ± 120		350 ± 160	160 ± 100
Overseas				250 ± 240
Total	210 ± 120		350 ± 160	**410 ± 260**

4.3. Summary of aquatic ecosystem values

There is limited diversity of fish species in the Arrow catchment, with three fish species being recorded. Two sports-fish, both the rainbow and brown trout, and the native fish koaro have been recorded. Such low fish diversity could be a combination of several factors including: detrimental impacts of historic mining practices, combined with the difficulty of recruitment from outside the catchment (due to the boisterous nature of the flows of the Kawarau River and the presence of dams on the Clutha River).

Angler surveys indicate that angler use for the Arrow catchment is relatively low and there has been a decline in local use of the river (Table 4.2).

Table 4.2 Assessment of instream habitat values in the Arrow River, with recommended levels of habitat retention (based on the approach of Jowett & Hayes, 2004).

Instream value	Fishery or conservation value	Recommended % habitat retention
Brown trout - adult	Locally significant†	70
Brown trout - juvenile	Locally significant†	70
Brown trout - spawning (May-August)	Locally significant†	70
Longfin eel	Declining‡	80
Koaro	Declining‡	80

† Based on the assessment in Otago Fish & Game Council (2015).

‡ Based on Goodman et al. (2014).

5. Instream habitat modelling

Instream habitat assessments were conducted for two reaches of the Arrow River by Jowett and Hayes (2004). They surveyed an upper reach near Eight Mile Hut, just downstream of Macetown, and a lower reach between the SH6 Bridge and the confluence with the Kawarau River. The instream habitat modelling presented in this report is based on the lower survey reach.

5.1. Instream habitat modelling

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

Instream habitat modelling requires detailed hydraulic data, as well as knowledge of the ecosystem and the physical requirements of stream biota. The basic premise of habitat methods is that a given species cannot exist without a suitable physical habitat (Jowett & 2004. However, if there is physical habitat available for that species, it may or may not be present in a survey reach, depending on other factors not directly related to flow or to flow-related factors that have operated in the past (e.g. floods). In other words, habitat methods can be used to set the outer envelope of suitable living conditions for the target biota (Jowett, 2005).

Instream habitat is expressed as Reach Area Weighted Suitability (RAWS), a measure of the total area of suitable habitat per metre of stream length. It is expressed in square metres per metre (m^2/m). The reach-averaged Combined Suitability Index (CSI) is another metric used and is a measure of the average habitat quality provided at a particular flow. CSI is useful when considering the effects of changes in flow regime on periphyton, where it is the percentage cover across the riverbed that is of interest, rather than the overall population response (such as for fish).

5.2. Habitat suitability curves

Habitat suitability curves (HSC) for a range of organisms present in the Arrow catchment were modelled (Table 5.1). This was required to understand the full range of potential effects of flow regime changes in the Arrow catchment – from changes in the cover and type of periphyton, to changes in the availability of macroinvertebrate prey, to changes in the habitat. It should be noted that the HSC used in these analyses may differ from those presented in the original report, as the analyses were re-run using the most up to date habitat modelling curves.

Table 5.1 Habitat suitability curves used in instream habitat modelling for the Arrow catchment.

Group	HSC name	HSC source
Periphyton	Cyanobacteria	Ex Heath et al (2013)
	Diatoms	Unpublished NIWA data
	Didymo (Waitaki)	Unpublished NIWA data
	Long filamentous	Unpublished NIWA data
	Short filamentous	Unpublished NIWA data
Macro-invertebrates	Food producing	Waters (1976)
	Cased caddis fly (*Pycnocentrodes*)	Jowett *et al.* (1991)
	Mayfly nymphs (*Deleatidium*)	Jowett *et al.* (1991)
	Net-spinning caddis fly (*Aoteapsyche*)	Jowett *et al.* (1991)
Fish	Brown trout - adult	Hayes & Jowett (1994)
	Brown trout - spawning	Shirvell & Dungey (1983)
	Brown trout - juvenile	Jowett & Richardson (2008)
	Juvenile trout	Wilding *et al.* (2014)
	Adult trout	Wilding *et al.* (2014)
	Rainbow trout - spawning	Jowett *et al.* (1996)

5.2.1. Periphyton

The periphyton community forms the slimy coating on the surface of stones and other substrates in freshwaters and can include a range of different types and forms. Periphyton is an integral part of 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 can detrimentally affect other instream values, such as aesthetics, biodiversity, recreation (swimming and angling), water takes (irrigation, stock/drinking water and industrial) and water quality.

The analyses presented in this report consider HSC for five classes of periphyton: cyanobacteria, diatoms, didymo (*Didymosphenia geminata*, an invasive non-native diatom), short filamentous algae and long filamentous algae (Figure 5.1). 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), 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).

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 5.1c). Didymo can affect recreational and ecosystem values, as well as water use (ORC, 2007; Larned et al. 2007).

Filamentous algae, particularly long filamentous algae, can form nuisance blooms under nutrient-rich conditions during periods of stable flow. 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.

Figure 5.1 **Periphyton types considered in these analyses: a) benthic cyanobacteria (*Phormidium*), b) native diatoms, c) underwater photograph showing an extensive growth of didymo in the Hawea River and d) long and short filamentous algae (and cyanobacteria).**

5.2.2. Macroinvertebrates

Macroinvertebrates are an important part of stream food webs, linking primary producers (periphyton and terrestrial leaf litter) to higher trophic levels (fish and birds). They were included in these analyses to consider how changes in flow in the modelled reaches may affect food availability for fish and bird life. HSC for "food producing habitat" (conditions representative of the most productive habitats in rivers) and four widespread and common macroinvertebrate taxa were included in this analysis.

Figure 5.2 **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) larvae of the sandy-cased caddis fly (*Pycnocentrodes*).**

5.2.3. Native fish

HSC are available for koaro and longfin eels. However, the habitat suitability curves available for koaro (Richardson & Jowett, 1995) were not included in these analyses, as they were based on data from a steep cascade habitat in the Onekaka River (Golden Bay) and their applicability to the type of habitat present in the Arrow River is uncertain.

Habitat is not currently the main factor affecting the distribution and abundance of longfin eels in the Arrow catchment. Recruitment of longfin eels to the upper Clutha and Kawarau catchments is low due to the physical barrier presented by the Roxburgh and Clyde Dams.

5.2.4. Sports fish

Both brown and rainbow trout are found in the Arrow catchment. Several HSC for different life stages of brown trout and for adult rainbow trout were included in these analyses, allowing consideration of how changes in flow in the modelled reaches will affect habitat availability for sports fish.

5.3. Approaches to flow setting

There are a number of approaches to determining the appropriate flows needed to achieve management objectives. A simple approach is to identify the flow that provides the maximum (or optimum) habitat for a particular species. However, providing such flows is often unrealistic for flow-demanding species, as optimum habitat may occur at a flow well in excess of those commonly experienced. As a result, this approach is usually only applied when optimum habitat occurs at flows below the 7dMALF.

Another common approach is to identify the “tipping point” - the flow below which the rate of habitat decline accelerates as flows reduce, often incorrectly referred to as the inflection point. A disadvantage of this approach is that it can be difficult to identify the exact point at which this occurs, and assessments can differ between practitioners.

Probably the most common, transparent and defensible method is to calculate the amount of habitat retained relative to some baseline flow. For fish species, this baseline flow is usually the naturalised 7dMALF.

5.4. Physical characteristics

The hydraulic component of this study’s instream habitat modelling made predictions about how water depth, channel width and water velocity will change with changes in flow (Figure 5.3). The most notable pattern is that there is a gradual decline in channel width and depth with declining flows down to 100 l/s, below which width and depth drop rapidly. Water velocity is predicted to reduce rapidly with declining flows.

5.5. Periphyton

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

Flow was predicted to have little effect on habitat quality for cyanobacteria (*Phormidium*) with a decline in habitat quality for both species predicted below 0.5 m^3/s (Figure 5.4). Habitat quality for didymo was predicted to increase with flow up to 900 l/s before declining gradually with flow above 1200 l/s. Habitat quality for native diatoms was predicted to increase with flow up to 1500 l/s, before declining at higher flows. Habitat quality for short filamentous algae was predicted to increase with increasing flows to 600 l/s before declining at higher flows, while habitat quality for long filamentous algae was predicted to be highest in the absence of flow and then to decline across the modelled flow range.

This analysis suggests that when flows are less than 755 l/s in the lower Arrow there is a significantly higher risk of proliferation of long filamentous algae, compared with naturalised flows. This risk is predicted to rise further as flows drop below this value, with habitat quality for long filamentous algae at 600 l/s predicted to be approximately twice that at the naturalised MALF (Table 5.2).

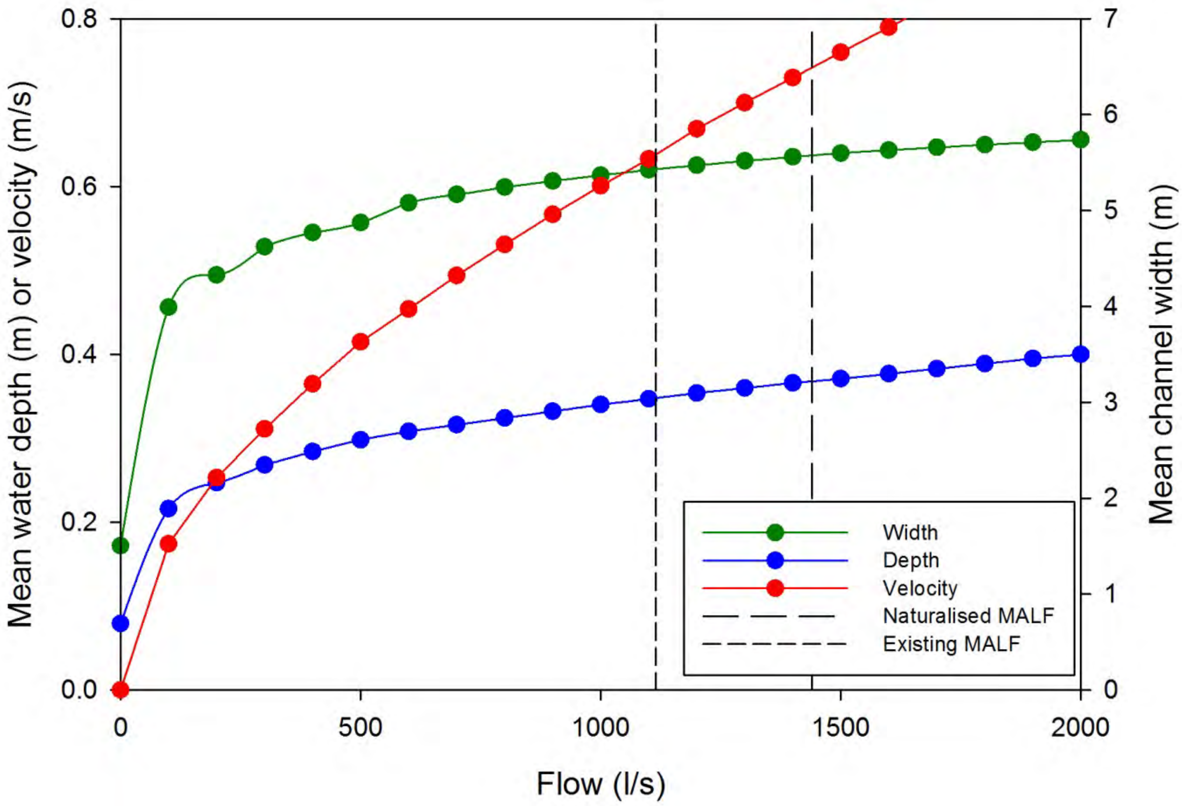

Figure 5.3 **Changes in mean channel width, mean water depth and mean water velocity with changes in flow in the lower Arrow River.**

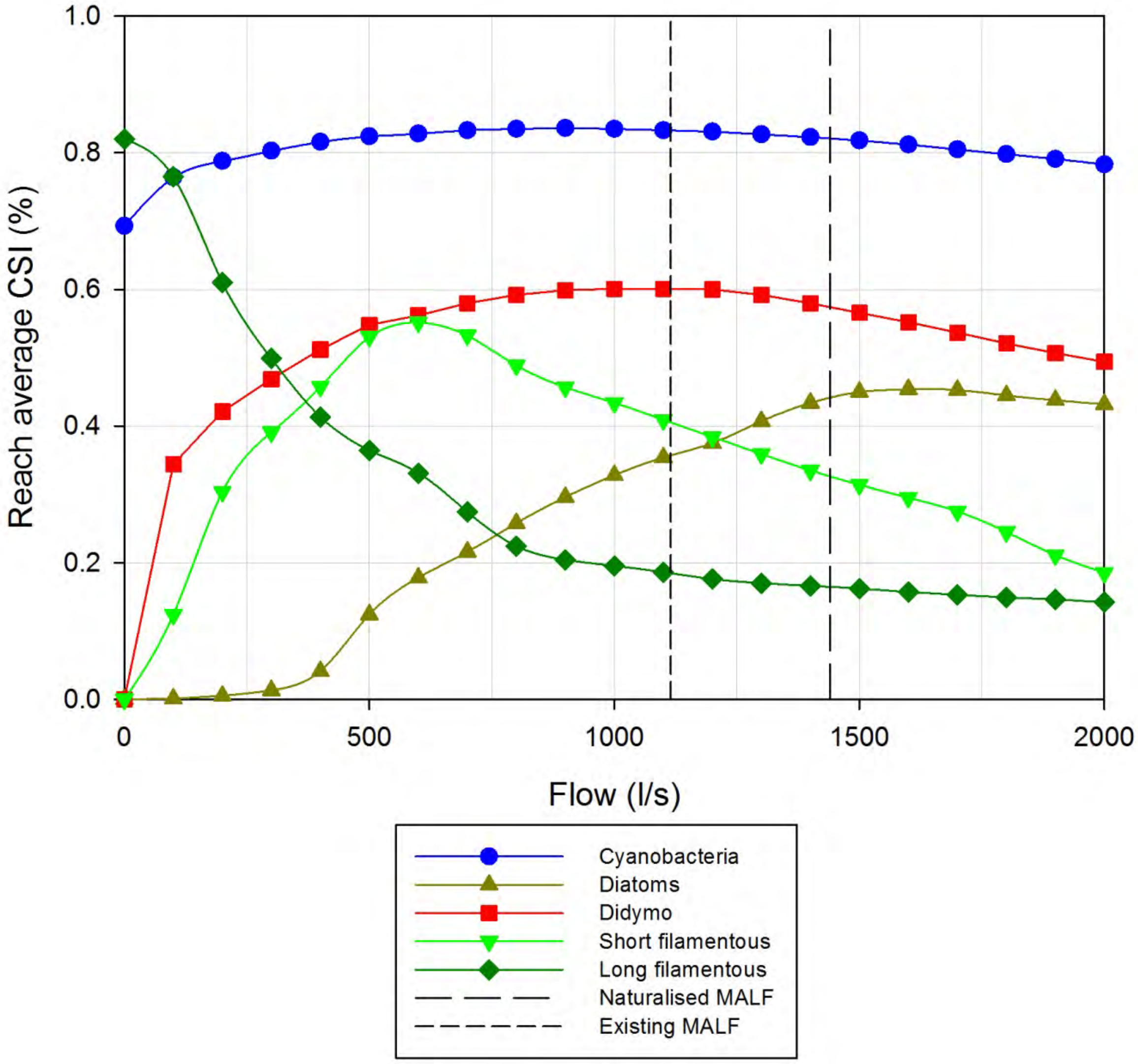

Figure 5.4 **Variation in instream habitat quality (reach-averaged CSI) for periphyton classes relative to flow in the lower Arrow River.**

Table 5.2 **Flow requirements for periphyton habitat in the lower Arrow River. Flows required for the various habitat retention values are given relative to naturalised flows (i.e. flows predicted in the absence of any abstraction)**

Species	Optimum flow (l/s)	Flow below which habitat rapidly increases (l/s)	Flow at which % habitat retention occurs (l/s)		
			150%	200%	300%
Cyanobacteria	900	-	-	-	-
Diatoms	1,600	-	-	-	-
Didymo	1,000	-	-	-	-
Short filamentous	600	-	798	-	-
Long filamentous	0	800	755	604	404

5.6. Macroinvertebrates

Food producing habitat is predicted to increase with increasing flow to 900 l/s, above which habitat is predicted to decline (Figure 5.5). Habitat for net-spinning caddis fly larvae was predicted to increase with increasing flow across the modelled flow range. Habitat for the common mayfly *Deleatidium* is predicted to increase with increasing flow up to 1300 l/s, above which habitat is predicted to decline. Habitat for the cased caddis *Pycnocentrodes* was predicted to rise with increasing flows, reaching a peak at 700 l/s, above which habitat was predicted to gradually decline. For most of the macroinvertebrate species modelled, habitat was predicted to decline rapidly as flows dropped below 500 l/s.

Flows of 350-400 l/s were predicted to retain 80% of the food producing (392 l/s) and *Deleatidium* (362 l/s) habitat available in the lower Arrow River relative to naturalised flows (Table 5.3). The flow requirements for 80% habitat of the other species considered varied widely, from 232 l/s for the cased caddis fly *Pycnocentrodes* and 1,030 l/s for the net-spinning caddis fly *Aoteapsyche*.

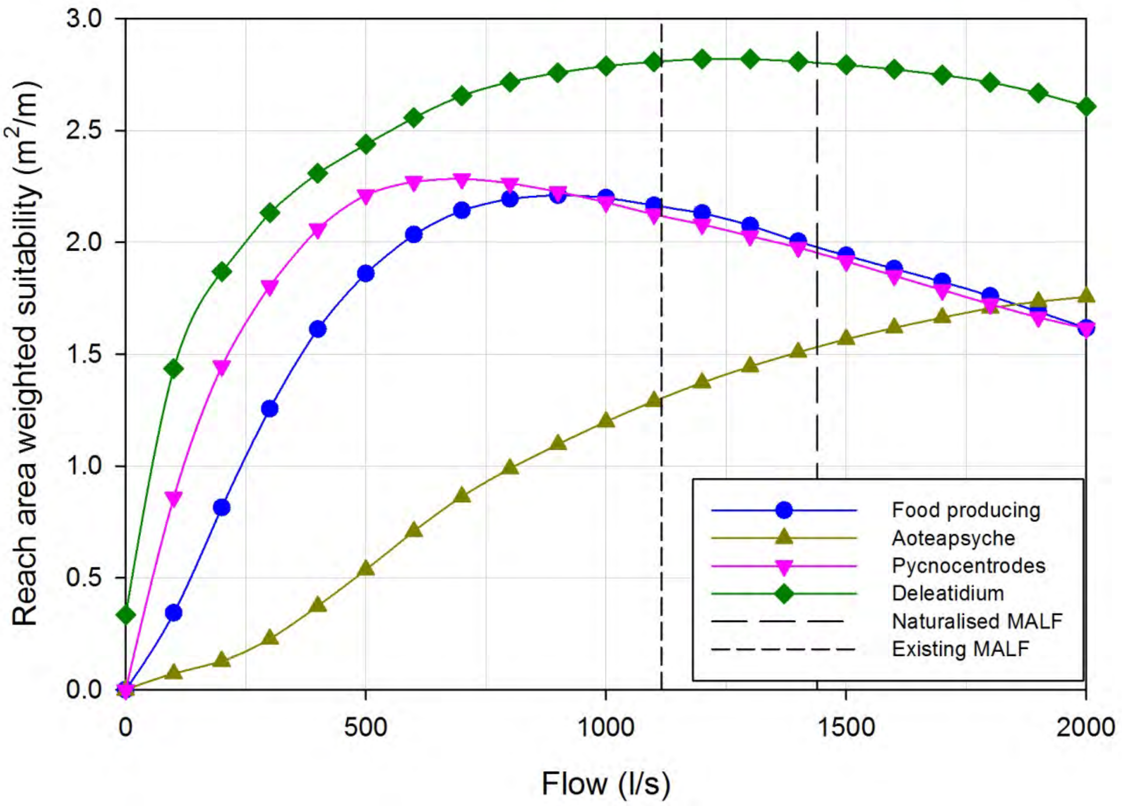

Figure 5.5 **Variation in instream habitat for common macroinvertebrates relative to flow in the survey reach of the lower Arrow River.**

Table 5.3 **Flow requirements for macroinvertebrate habitat in the lower Arrow River. Flows required for the various habitat retention values are given relative to naturalised flows (i.e. flows predicted in the absence of any abstraction)**

Species	Optimum flow (l/s)	Flow below which habitat rapidly declines (l/s)	Flow at which % habitat retention occurs (l/s)			
			60%	70%	80%	90%
Food producing	900	600	285	336	392	468
Mayfly nymphs *(Deleatidium*)	1,200	300	157	235	362	570
Net-spinning caddis fly *(Aoteapsyche)*	>2,000	-	745	878	1,030	1,208
Cased caddis fly (*Pycnocentrodes*)	700	400	153	186	232	287

5.7. Sports fish

Habitat for adult brown trout was predicted to increase with flows to 600 l/s, before declining above flows of 800 l/s, while adult trout (rainbow and brown) habitat was predicted to increase with flow to 1,600 l/s before slowly dropping with increasing flows. (Figure 5.6). Habitat for juvenile brown and rainbow trout was also predicted to increase with flows to 500 l/s before dropping gradually at flows above 900 l/s. Predicted spawning habitat increased rapidly with increasing flows to reach an optimum at 400 l/s for brown trout and 600 l/s for rainbow trout, with the amount of suitable habitat predicted to decline when flows were above the optimum for each species.

A flow of 231 l/s was predicted to retain 70% of the adult brown trout habitat compared with naturalised flows in the lower Arrow River, and flows of 198 l/s retained 70% of the juvenile trout habitat available compared with naturalised flows (Table 5.4).

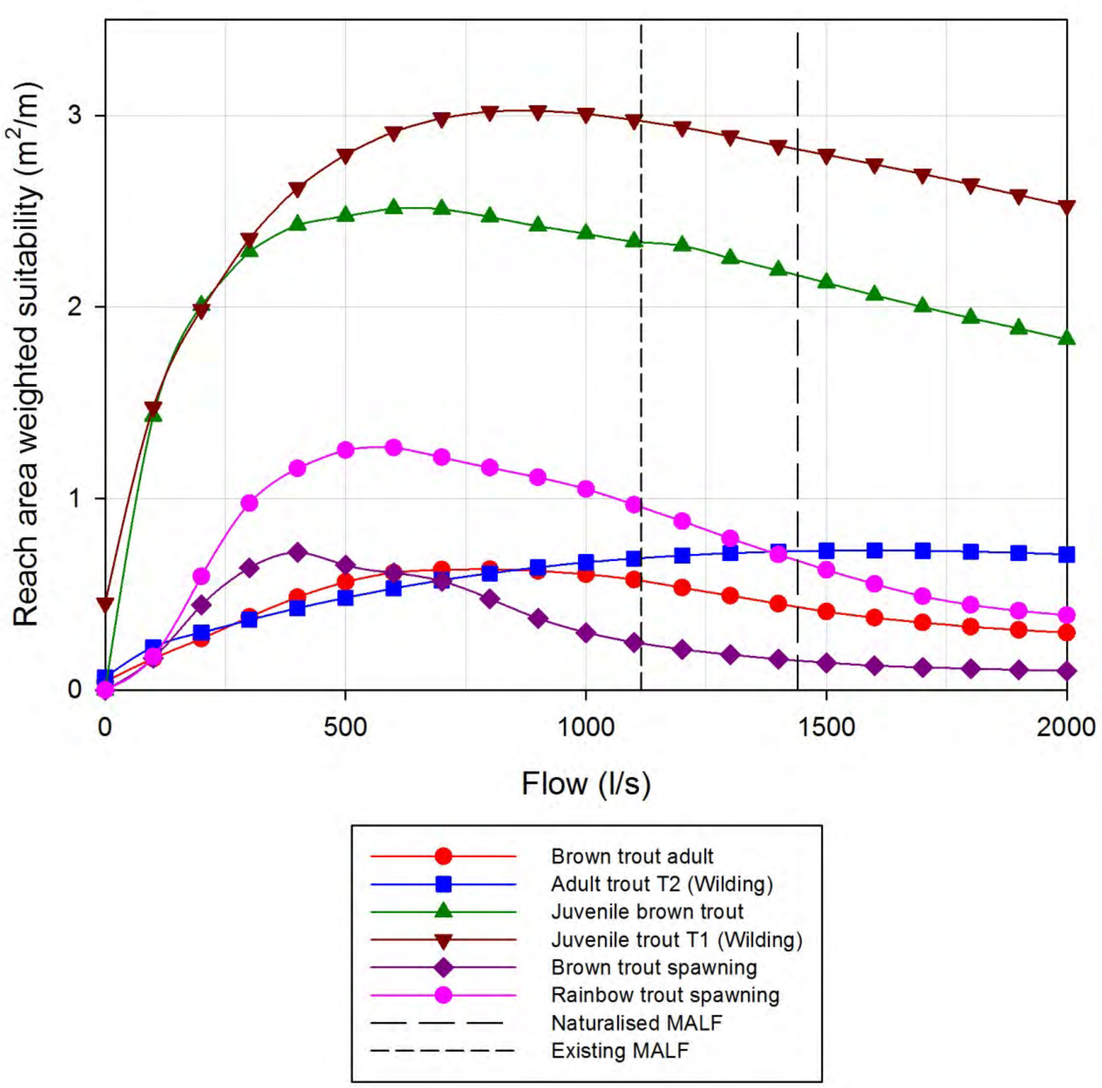

Figure 5.6 Variation in instream habitat of trout relative to flow in the lower Arrow River.

Table 5.4 **Flow requirements for trout habitat in the lower Arrow River. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e. flows predicted in the absence of all abstraction). Habitat retention levels for spawning are relative to naturalised mean annual winter (May-September) low flows.**

Species	Optimum flow (l/s)	Flow below which habitat rapidly declines (l/s)	Flow at which % habitat retention occurs (l/s)		
			70%	80%	90%
Brown trout adult	800	500	231	270	309
Adult trout (Wilding T2)	1,600	-	553	717	945
Juvenile brown trout	600	300	115	152	190
Juvenile trout (Wilding T1)	900	500	198	273	369
Brown trout spawning (May-Sep)	400	300	44	50	56
Rainbow trout spawning (Jul-Nov)	600	400	127	136	146

5.8. Effects of existing flows

Water users in the Arrow River are not currently subject to a minimum flow. The river is significantly over-allocated, at least in terms of consented maximum instantaneous rate of take, although actual use is significantly less than the consented use. The measured 7dMALF of the Arrow River retains appropriate levels of habitat (Table 5.5). However, it should be kept in mind that the measured 7dMALF represents average low flow conditions, not the low flows experienced in exceptionally dry years.

Table 5.5 Habitat retention in the lower Arrow River under the existing 7dMALF relative to the naturalised 7dMALF.

Group	HSC name	% retention under existing 7dMALF compared with naturalised 7dMALF
Periphyton	Cyanobacteria	101%
	Diatoms	105%
	Didymo (Waitaki)	112%
	Long filamentous	124%
	Short filamentous	81%
Macro-invertebrates	Food producing	109%
	Cased caddis fly (*Pycnocentrodes*)	100%
	Mayfly nymphs *(Deleatidium)*	85%
	Net-spinning caddis fly (*Aoteapsyche*)	109%
Fish	Brown trout adult	131%
	Adult trout T2	95%
	Brown trout spawning	158%
	Brown trout Juvenile	108%
	Juvenile trout T1	105%
	Rainbow trout spawning	141%

5.9. Summary of instream habitat assessments

Appropriate objectives for the management of the aquatic ecosystems of the Arrow River include maintaining the locally-significant trout fishery and to protect its life-supporting capacity including macroinvertebrate populations and limiting the risk of periphyton proliferation. The flow requirements for key values of the lower Arrow River are presented in Table 5.6. It is likely that any minimum flow would have minimal effect on winter flows, given that demand for water is expected to be low in winter.

Table 5.6 Flow requirements to maintain the values of the Arrow River based on the instream habitat model of Jowett & Hayes (2004).

Instream value	Season	Fishery or conservation value	Recomm. % habitat retention	Flow to maintain suggested habitat retention (l/s)	Flow below which habitat rapidly declines (l/s)	Optimum flow (l/s)
Adult trout	All year	Locally significant†	70%	553	-	1,600
Juvenile trout	All year	Locally significant†	70%	198	500	900
Brown trout - spawning (May-August)	Winter	Locally significant†	70%	44	400	600
Rainbow trout - spawning (May-August)	All year	Locally significant†	70%	127	400	600
Food producing	All year	Life supporting capacity	70%	392	600	900
Long filamentous algae	Summer	Nuisance	<150%	>755	800	-

† Based on the assessment in Otago Fish & Game Council (2015).

6. Conclusions: Flow requirements for aquatic ecosystems in the Arrow catchment

The original ORC water resources report for the Arrow River (Kitto 2012) relied on flow statistics generated from comparing flows between the Cardrona River (Mount Barker) and Cornwall Street (Arrow River). There is now sufficient flow information from the Cornwall Street recorder to allow flows to be naturalised, albeit the flow records are of relatively short length.

Under the RPW, rivers will have minimum flows set to provide for the maintenance of aquatic ecosystems and natural character under low-flow conditions. Similarly, residual flows can be imposed on resource consents for water takes from tributary streams for the same reasons. The purpose of this report is to update the previous report and provide information on the Arrow catchment that assists in setting minimum flows including: the values present in the catchment, the existing use of water resources, and the flows required to maintain instream habitat (based on habitat modelling).

There are 22 existing surface water takes in the Arrow catchment, with a total allocation of 2.25 m^3/s, although the actual usage is likely to be less than half this, especially at low flows. There is a reasonably high level of water allocation, and a long history of water use and flow alteration primarily due to a single water take. The hydrology of many waterways in Otago is typically complex; but by comparison the hydrology of the Arrow catchment is reasonably straightforward.

Naturalised low-flow statistics were estimated by adding water take data upstream of the Cornwall Street recorder to flows at this same site. There are three operational water takes above the recorder (WR1440AR, 95696, and 2007.049) as shown in Figure 3.1; with water take data being recorded for at least the past four years. This meant that three years of flow data recorded at Cornwall Street were unable to be used when naturalising flows. Table 6.1 shows the comparison of the 7-day mean low flows (7dMLFs) during the low-flow seasons for Arrow at Beetham and at Cornwall Street.

Table 6.1 The comparison of the 7-day mean low flows (7dMLFs) during the irrigation seasons for Arrow at Beetham and at Cornwall Street

Site location	Data type (availability)	7dMLF (m^3/s)
Arrow at Beetham Creek	Actual (16/4/1981 – 23/1/1994)	0.88
Arrow at Cornwall Street	Actual (30/12/2010 – 9/10/2017)	1.03
Arrow at Cornwall Street	Naturalised (9/10/2013 – 9/10/2017)	1.43 ~ 1.44

The Arrow River supports a locally-important trout fishery with many overseas anglers taking advantage of early fishing season conditions. Fishing is limited to sections of the Arrow catchment downstream of the Soho Creek confluence. The catchment contains both rainbow and brown trout, with brown trout being the primary sports fish targeted by anglers.

One indigenous fish is present in the Arrow catchment, the koaro, which is a migratory galaxiid. There is a single record of this species within the catchment, which suggests that their distribution is somewhat limited. The koaro is listed as “At Risk, Declining” in the most recent threat classification (Goodman et al. 2014)

Appropriate aquatic ecosystem management objectives for the Arrow catchment are to maintain the locally important sports fishery, protect macroinvertebrate communities and maintain natural character by limiting the risk of proliferation of long filamentous algae.

The results of updated instream habitat modelling for the lower Arrow River presented in this report will be used to inform the development of future management options. The information presented here will allow the comparison of the potential effects of different options on instream values.

7. Glossary

Aquatic ecosystem

An aquatic ecosystem is an environment in a body of water, and all plants and animals live either in or on that water***.***

Catchment

The area of land drained by a river or body of water.

Combined Suitability Index (CSI)

Is a measure of the average habitat quality provided at a particular flow

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 is 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 to assist with the growing of crops and pasture.

Macroinvertebrates

Macroinvertebrates are organisms without backbones, which are visible to the eye without the aid of a microscope. Aquatic macroinvertebrates live on, under, and around rocks and sediment on the bottoms of lakes, rivers, and streams

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 flows created to simulate the natural flows of a river by removing the effect of water takes or other flow modifications.

Reach

A specific section of a stream or river.

Reach Area Weighted Suitability (RAWS)

Is a measure of the total area of suitable habitat per metre of stream length

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, farm drainage canal or canal for the supply of water for electricity power generation).

Seven-day low flow (7dLF)

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 of these averages.

Seven-day Mean Annual Low Flow (7dMALF)

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 7dMALF calculated using data from the full hydrological year or from the irrigation season should be very similar.

Taking

The process of abstracting water for any purpose and for any period of time.

Water take

A place where water is taken from a water body for the specific proposes i.e irrigation, communal water

8. References

Goodman, J. M., Dunn, N. R., Ravenscroft, P. J., Allibone, R. M., Boubee, J. A. T., David, B. O., Griffiths, M., Ling, N., Hitchmough, R. A., & Rolfe, J. R. (2014). Conservation status of New Zealand freshwater fish, 2013. *New Zealand Threat Classification Series 7*, Wellington, New Zealand: Department of Conservation. 12 p.

Hamill, K. D. (2001). Toxicity in benthic freshwater cyanobacteria (blue-green algae): first observations in New Zealand. *New Zealand Journal of Marine and Freshwater Research,* (35), pp. 1057–1059.

Hayes, J. W., & Jowett, I. G. (1994). Microhabitat models of large drift-feeding brown trout in three New Zealand rivers. *North American Journal of Fisheries Management,* (14), pp. 710–725.

Heath, M. W., Wood, S. A., Brasell, K. A., Young, R. G., & Ryan, K. G. (2013). Development of habitat suitability criteria and in-stream habitat assessment for the benthic cyanobacteria *Phormidium*. *River Research and Applications*, DOI: 10.1002/rra.2722.

Jowett, I. G., & Richardson, J. (2008). Habitat use by New Zealand fish and habitat suitability models. *NIWA Science and Technology Series*, 132 p.

Jowett, I. G., Richardson, J., Biggs, B. J. F., Hickey, C. W., & Quinn, J. M. (1991). Microhabitat preferences of benthic invertebrates and the development of generalised *Deleatidium* spp. Habitat suitability curves, applied to four New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research,* (25), pp. 187–199.

Jowett, I. G. (2004). Flow requirements for fish habitat in Luggate Creek, Arrow River, Nevis River, Stony Creek, Sutton Stream, Trotters Creek and Waiwera River. *NIWA Client Report HAM2004-081*, 58 p., plus appendices. Prepared for the Otago Regional Council

Jowett, I. G., & Hayes, J. W. (2004). Review of methods for setting water quantity conditions in the Environment Southland draft Regional Water Plan. *NIWA Client Report: HAM2004-018*.

Jowett, I. G., Rowe, D., & West, D. W. (1996). Fishery flow requirements of the Tongariro River. *NIWA Report ELE301*. Hamilton, New Zealand.

Kitto, J. (2012). Management flows for aquatic ecosystems in the Arrow River, Otago Regional Council, Dunedin, 22 p.

Larned, S., Arscott, D., Blair, N., Jarvie, B., Jellyman, D., Lister, K., Schallenberg, M., Sutherland, S., Vopel, K., & Wilcock, B. (2007). Ecological studies of *Didymosphenia geminata* in New Zealand, 2006–2007. *NIWA Client Report CHC2007-070.* Prepared for MAF Biosecurity New Zealand. 104 p. plus appendices.

Olsen, D. A., Tremblay, L., Clapcott, J., & Holmes, R. (2012). Water temperature criteria for native biota. *Auckland Council Technical Report 2012/036*, 80 p.

Otago Fish and Game Council (2015). *Sports Fish and Game Management Plan for Otago Fish and Game Region 2015–25*. Dunedin, New Zealand: Otago Fish and Game Council.

Otago Regional Council (2007). *Didymo in Otago: A Summary*, Dunedin, New Zealand: Otago Regional Council. 40 p., plus appendices.

Richardson, J., & Jowett, I. G. (1995). Minimum flow assessment for native fish in the Onekaka River, Golden Bay. *National Institute of Water and Atmospheric Research, Science and Technology Series*, (2), 13 p.

Shirvell, C. S., & Dungey, R. G. (1983). Microhabitats chosen by brown trout for feeding and spawning in rivers. *Transactions of the American Fisheries Society*, (112), pp. 355–367.

World Meteorological Organization, (2012). *Standardized Precipitation Index User Guide.* M. Svoboda, M. Hayes, and D. Wood, Eds., WMO-No. 1090, Geneva, 24 p.

Tait, A.; Henderson, R.D.; Turner, R.; Zheng, X. (2006). Spatial interpolation of daily rainfall for New Zealand. International Journal of Climatology 26(14), pp. 2097-2115.

Todd, A. S., Coleman, M. A., Konowal, A.M., May, M. K., Johnson, S., Vieira, N. K. M., & Saunders, J. F. (2008). Development of New Water Temperature Criteria to Protect Colorado's Fisheries. *Fisheries*, (33), pp. 433–443.

Unwin, M (2016). Angler usage of New Zealand lake and river fisheries: Results from the 2014/15 National Angling Survey. *NIWA Client Report 2016021CH*, Prepared for Fish & Game New Zealand. 59 p., plus appendices.

Waters, B. F. (1976). A methodology for evaluating the effects of different streamflows on salmonid habitat. In J. F. Orsborn, & C. H. Allman (Eds.), *Proceedings of the Symposium and Speciality Conference on Instream Flow Needs II*, pp. 224–234. Bethesda, MD: American Fisheries Society.

Wilding, T.K., Bledsoe, B., Poff, N.L. & Sanderson, J. (2014). Predicting habitat response to flow using generalized habitat models for trout in Rocky Mountain Streams. *River Research and Applications* **30**, pp. 805-824.

Wood, S. A., Selwood, A. I., Rueckert, A., Holland, P. T., Milne, J. R., Smith, K. F., Smits, B., Watts, L., & Cary, C. S. (2007). First report of homoanatoxin-a and associated dog neurotoxicosis in New Zealand. *Toxicon*, (50), pp. 292–301.