Management flows for aquatic ecosystems in the Manuherikia River and Dunstan Creek

February 2017

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ISBN 978-0-908324-39-2

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Cover photo: Manuherikia River in autumn by David Wall

Published February 2017

Technical summary

The Manuherikia River (catchment area: 3,033 km^2) is located in Central Otago. Its headwaters are in the Hawkdun and Saint Bathans Ranges and the Dunstan Mountains; it flows in a south-west direction, joining the Clutha River at the township of Alexandra. The climate of the Manuherikia catchment is considered to be the most continental in the country and is characterised by cold winters and warm dry summers.

There are 213 existing surface water takes in the Manuherikia catchment, with a total allocation of approximately 32 m^3/s, although the actual usage is considerably lower than this, especially during times of low flows. Surface water in the catchment is heavily allocated due to a combination of low rainfall and high water demand.

The objective of this report was to present relevant information on the Manuherikia catchment to inform the setting of minimum flows in the main stem of the Manuherikia River and Dunstan Creek. This information includes the following:

- hydrology and existing water allocation in Manuherikia River
- aquatic values of Manuherikia River
- presentation, analysis and interpretation of the results of instream habitat modelling undertaken for three sites (upper and lower Manuherikia River and Dunstan Creek)
- flows to maintain aquatic ecological values in Manuherikia River and Dunstan Creek.

Recorded flows in Dunstan Creek at Gorge and in the upper Manuherikia River downstream of Fork were the key reference flow sites. They were used to estimate the naturalised low-flow statistics for other locations within the upper catchment, which are summarised in the following table:

Location	Flow data type	7-d MALF[1] (m³/s)
Upper Manuherikia River downstream of Fork	Naturalised (gaps filled)	1.009
Manuherikia River at Falls Dam (downstream)	Naturalised	1.532
	Existing	1.737
Manuherikia River at Blackstone Bridge	Naturalised	1.779
	Estimated “existing”	1.513–1.947
Manuherikia at Ophir	Modelled natural	3.200 (±600)
	Existing	2.197
Manuherikia at Campground	Modelled natural	3.900 (±800)
	Existing	0.915
Dunstan Creek at Gorge	Natural (gaps filled)	0.692
Dunstan Creek at Loop Road Bridge	Naturalised	0.779
Dunstan Creek at Beattie Road	Naturalised	0.934
	Existing	0.35

The Manuherikia River supports a regionally significant brown trout fishery and is among the most popular river fisheries in the Otago region. Dunstan Creek is categorised as backcountry fishery and contains both brown and rainbow trout.

[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.

Nine native fish are present in the Manuherikia catchment, including three threatened species of non-migratory galaxias: Central Otago roundhead galaxias and alpine galaxias (Manuherikia) are classified as “nationally endangered”, while the Clutha flathead galaxias is classified as “nationally critical”, the highest threat classification available (Goodman et al., 2014). Koaro and longfin eels are present in the catchment and are listed as “at risk, declining” in the most recent threat classification (Goodman et al., 2014). Koura (freshwater crayfish) are also present and are classified as “at risk, declining” (Granger et al., 2014).

The highest conservation values – the alpine galaxias and the Clutha flathead galaxias – are not found within the reach of the main stem affected by flow alteration and were not considered as part of this instream habitat assessment. Although Central Otago roundhead galaxias are not found within the main stem of the Manuherikia River, they are present within the main stem of the Dunstan Creek and are considered in instream habitat analyses for Dunstan Creek.

Instream habitat modelling was conducted to determine how changes in flow affect habitat for fish, macroinvertebrates and algae at three locations in the Manuherikia catchment: upper and lower Manuherikia River and Dunstan Creek. Two flow baselines were used in this analysis: 1) naturalised flows and 2) existing flows. Naturalised flows estimate what the flow in the river would be in the absence of Falls Dam or other storage or water races, and without any abstraction. In contrast, the existing flows are those currently experienced in the river, which are influenced by the management of Falls Dam and current abstractions from the river.

The outcomes of instream habitat analyses are summarised in the following table:

		Units	Manuherikia at Ophir	Manuherikia at Campground	Dunstan Creek at Beattie Road
Naturalised 7-d MALF		m^3/s	3.200	3.900	0.934
Existing 7-d MALF		m^3/s	2.197	0.915	0.350
Aquatic ecosystem flow recommendation based on:	Naturalised flow baseline	m^3/s	2.500	2.500	0.750
	Existing flow baseline	m^3/s	1.750	0.750	-
Flow providing twice brown trout adult habitat available at existing flow		m^3/s	-	1.500	-
Flow providing three times brown trout adult habitat available at existing flow		m^3/s	-	2.000	-

The results of instream habitat modelling for the lower Manuherikia vary markedly depending on the baseline flow used for calculation of habitat retention. The differences between the flow recommendations, based on the two baselines, highlight the difficulty associated with using the habitat retention approach in a river with such a modified hydrology.

An alternative approach would be to choose a flow that would improve habitat relative to the existing baseline, but may be lower than that recommended based on the naturalised baseline.

Contents

Otago Regional Council

List of figures

List of tables

1. Introduction

The Regional Plan: Water for Otago (2013) (the Water Plan) sets out as one of its objectives 'to retain flows in rivers sufficient to maintain their life-supporting capacity for aquatic ecosystems and their natural character'. As a means of achieving this objective, the Water Plan provides for the setting of minimum flows in Otago's rivers.

The Manuherikia River (catchment area: 3,033 km^2) is located in Central Otago. Its headwaters are in the Hawkdun and Saint Bathans Ranges and Dunstan Mountains, and it flows in a south-west direction, joining the Clutha River at the township of Alexandra (Figure 1.1). The northern part of the catchment borders the Waitaki catchment and forms the boundary of Otago with Canterbury. Western tributaries of the Manuherikia drain the Dunstan Ranges, while the Raggedy Range forms the eastern boundary of the Manuherikia Valley. In addition to the Manuherikia Valley itself, the Ida Valley lies directly to the east and is connected to the Manuherikia Valley via the Pool Burn Gorge, which has carved its way through the dividing block of the Raggedy Range.

The climate of the Manuherikia catchment is considered to be the most continental in the country and is characterised by cold winters and warm, dry summers, with an even distribution of rain through the year. Surface water in the catchment is heavily allocated due to a combination of limited rainfall and high water demand. There are currently 213 water takes in the Manuherikia catchment, with a combined permitted maximum instantaneous rate of take of 32 m^3/s. To meet the water needs of the community, several reservoirs have been constructed, including Ida Burn, Pool Burn and Moa Creek Manor Burn. Falls Dam (Figure 1.1) is the largest and is located in the main stem of the Manuherikia River. These reservoirs are operated by several irrigation companies that convey water both via races and, mainly, using the natural watercourses. The companies also capture flows from a number of tributaries transporting water from one catchment into another, generally resulting in highly modified flows in watercourses.

The flow regime of the Manuherikia River itself is heavily influenced by the augmentation of water from Falls Dam during the irrigation season. Completed in 1935, Falls Dam is 34 m high and provides storage of water for irrigation (capacity 10 Mm^3). The operation of the dam is controlled by a needle valve and a 'morning glory' type spillway. In 1955 the crest of the dam was raised by an additional 0.6 m. In 2003 Pioneer Generation completed the installation of a small hydroelectric station, which uses water that is surplus to irrigation and the discharge from the dam for irrigation schemes.

Schedule 1A of the Water Plan[2] identifies the ecosystem values that must be sustained in Otago catchments. In Manuherikia River, these include spawning, juvenile rearing and adult habitat for trout, as well as significant habitat for longfin eels. Further to these values, the Manuherikia catchment supports populations of threatened non-migratory galaxias: the described Central Otago roundhead galaxias (*Galaxias anomalus*) and two indeterminate non-migratory galaxiids – the Clutha flathead galaxias (*Galaxias* sp. D) and alpine galaxias (Manuherikia) (*G.* aff. *paucispondylus 'Manuherikia'*).

[2] Schedule 1A of the Regional Plan: Water for Otago (2013), p. 20–6.

The Manuherikia catchment also supports populations of riverine bird species, particularly in the headwaters above Falls Dam where banded dotterel, black-fronted terns and wrybills have been recorded. Black-backed gulls, little shags and black shags are found in the reaches of the river downstream of Falls Dam.

1.1. Objectives

This report presents information on the main stem of the Manuherikia River and Dunstan Creek that is relevant to determining the flows required to sustain the river's aquatic habitat. That information includes freshwater values, hydrology (including flow statistics), the distribution of water resources within the catchment and the results of instream habitat modelling.

This report builds on the analyses presented in ORC (2006). The hydrological analyses presented in the current report are based on considerably longer flow datasets (measured and synthetic) for two sites in the upper catchment with natural or near-natural flows (Dunstan Creek at Gorge and Manuherikia River downstream of Fork) (Figure 2.1). The values assessment presented in this report has been updated to reflect changes in the taxonomy of non-migratory galaxiids and improved understanding of their conservation status, as well as updated estimates of angler usage. Finally, instream analyses are presented for two sites on the main stem of the Manuherikia River and one site in Dunstan Creek. Instream habitat modelling for the upper Manuherikia (between Falls Dam and Ophir) was conducted by NIWA in the summer of 2015/16 (Duncan & Bind, 2016), while instream habitat modelling for the lower Manuherikia was originally conducted by Jowett & Wilding (2003). Instream habitat modelling for Dunstan Creek is based on the analysis of Golder Associates (2008).

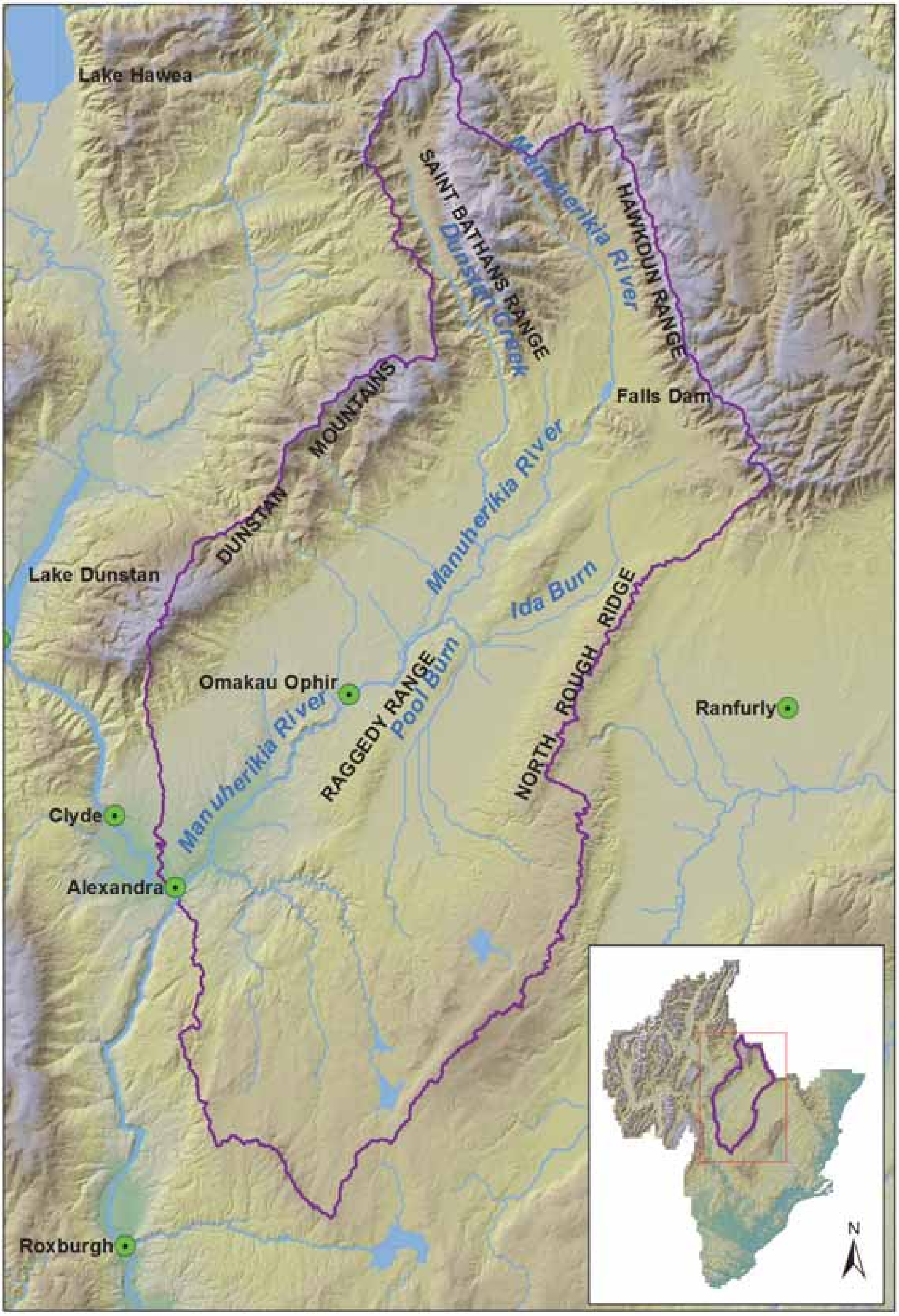


Figure 1.1 **The Manuherikia catchment.**

2. The Manuherikia catchment

The Manuherikia catchment (3,033 km^2) is located in Central Otago. Its headwaters are in the Hawkdun and Saint Bathans Ranges and the Dunstan Mountains, and it flows in a south-west direction, joining the Clutha River at the township of Alexandra (Figure 2.1). The northern part of the catchment borders the Waitaki catchment and forms the boundary of Otago with Canterbury. Western tributaries of the Manuherikia drain the Dunstan Ranges, while the Raggedy Range forms the eastern boundary of the Manuherikia Valley (Figure 2.1). The Ida Valley lies directly to the east and is connected to the Manuherikia Valley via the Poolburn Gorge, which has carved its way through the dividing block of the Raggedy Range (Figure 2.1).

2.1. Vegetation and land use

The dominant land use in both the Ida Burn and Manuherikia Valleys is agriculture, with pasture grasslands dominating the catchment (Figure 2.2). The level of production by grasslands (agricultural intensity) is largely dependent on the availability of water for irrigation, with high-producing pastures mainly found at lower elevations in the Manuherikia and Ida Valleys (Figure 2.2, Table 2.1).

The original vegetation of the catchment can still be seen in many of the headwater tributaries and in parts above Falls Dam where tussock grassland dominates the river and creek terraces, with snow tussock occupying the higher mountain faces (Figure 2.2, Table 2.1). Scrub (including matagouri or grey scrub, mixed exotic shrublands, manuka, kanuka, gorse, broom and subalpine shrubland) covers about 98 km^2, or 3% of the catchment (Table 2.1).

There has been a relatively small amount of land use change in the Manuherikia catchment over the period 1996–2012, based on the Land Cover Database (LCDB) v. 4 cover class change layer[3]. The majority of this change saw the conversion of low-producing grassland to high-producing exotic grassland (68 ha) and the harvest of exotic forest (44 ha), of which almost half was converted to high-producing exotic grassland (18 ha). Other land use changes include clearance of gorse/broom to high-producing exotic grassland (8 ha), conversion of high-producing exotic grassland to orchards, vineyards or other perennial crops (2.4 ha), and clearance of deciduous hardwoods to high-producing exotic grassland (1.5 ha).

[3] https://lris.scinfo.org.nz/layer/413-land-cover-database-lcdb-v40-change/

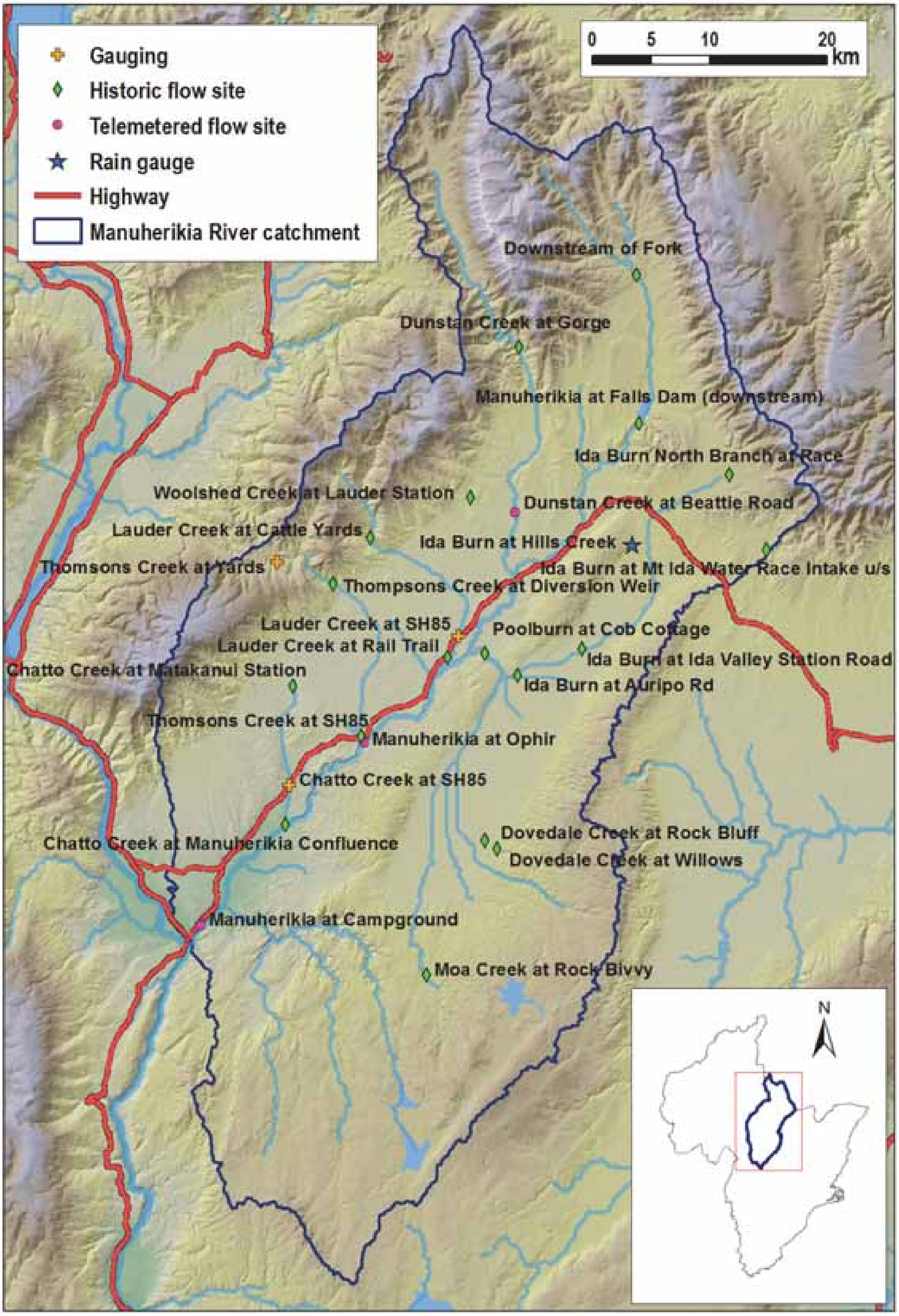


Figure 2.1 **The Manuherikia catchment showing the location of the hydrological monitoring sites.**

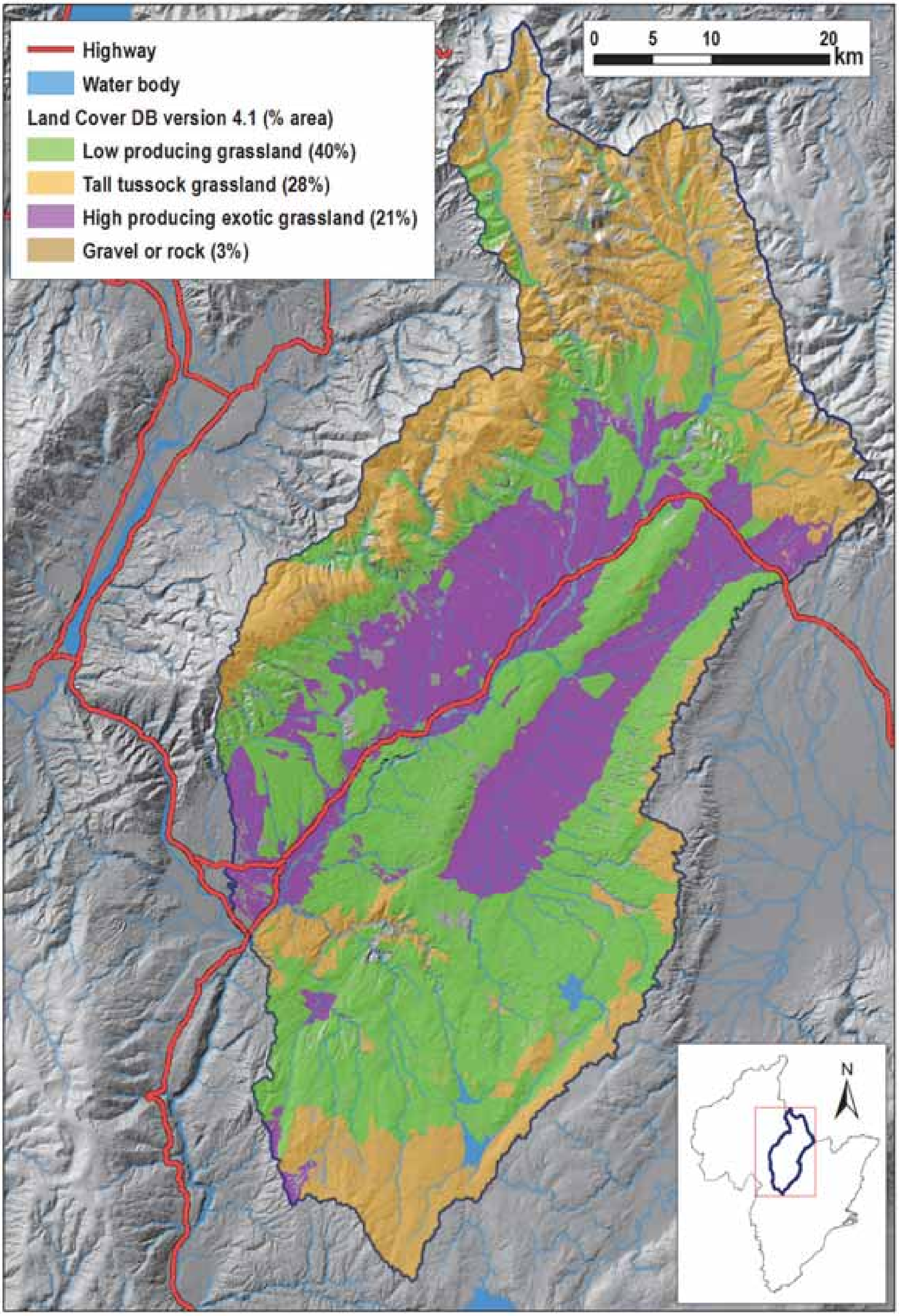


Figure 2.2 **Land cover in the Manuherikia catchment, based on the Land Cover Database (LCDB, version 4.1).**

Table 2.1 Land cover types in the Manuherikia catchment, based on the LCDB (v.4).

Land use type	Area (km^2)	%
High-producing exotic grassland	636	21
Low-producing grassland	1,222	40
Tall tussock grassland	835	28
Scrub	98	3
Other	242	8

2.2. Rainfall

The Manuherikia Valley is considered to have the most continental climate in the country, with cold winters and warm dry summers. The valley floor is classified as semi-arid as it receives between 350 mm and 500 mm rainfall (Figure 2.4). The median annual rainfall in the Dunstan Mountains is as high as 1,000 mm, while the Raggedy Range to the east receives 350 mm to 600 mm of rainfall annually (Figure 2.4). Mean monthly rainfall varies from 65 mm in January to 30 mm in July/August (Figure 2.3).

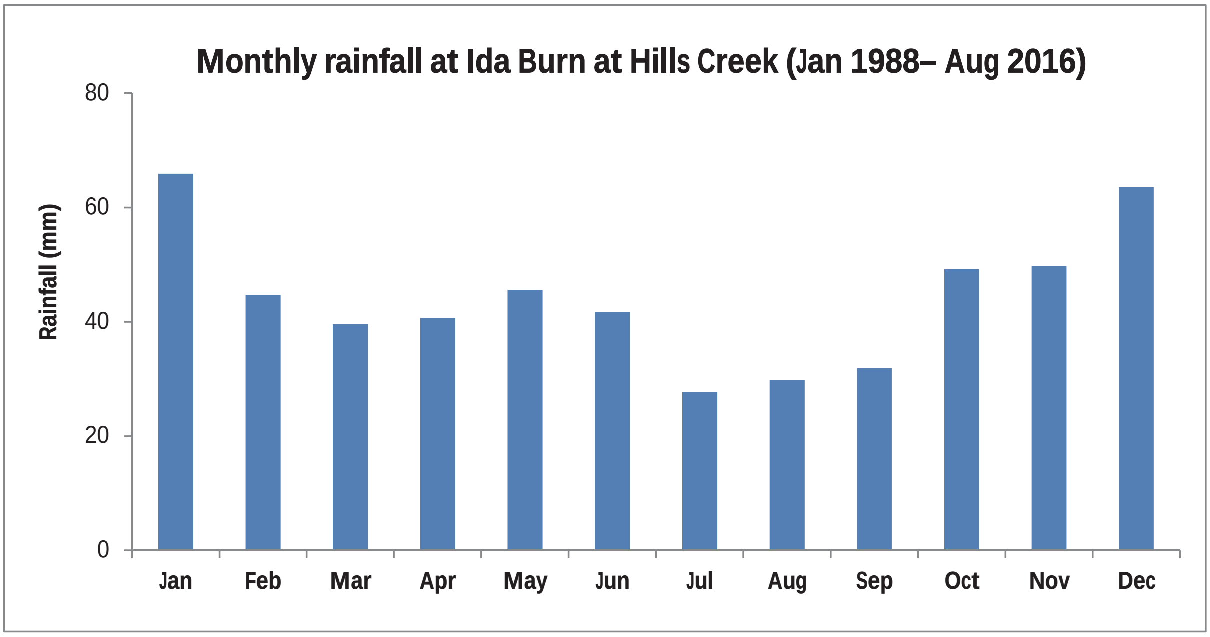


Figure 2.3 Mean monthly rainfall at Ida Burn at Hills Creek (see Figure 2.1 for locations).

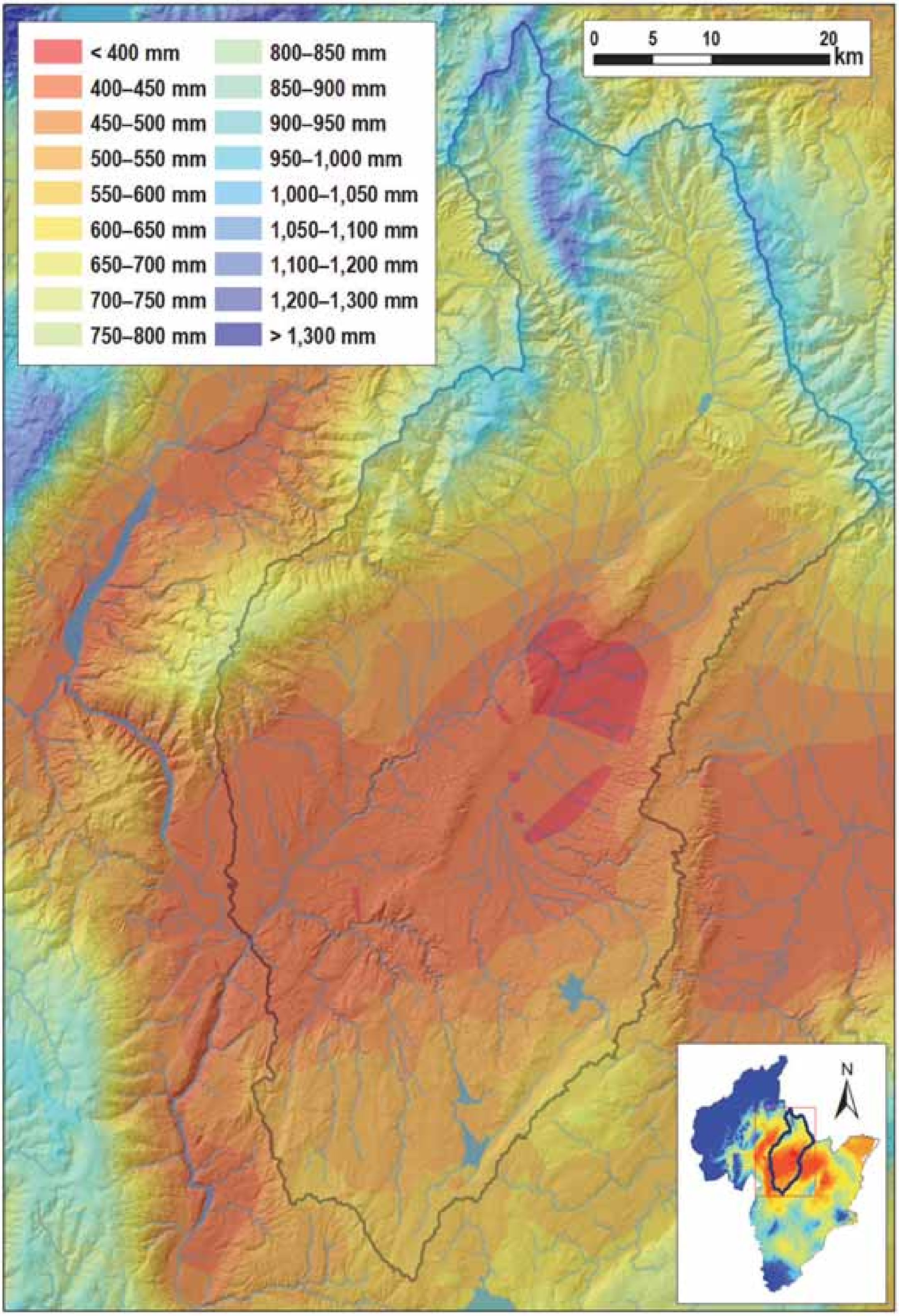


Figure 2.4 **Median annual rainfall over the Manuherikia catchment (from Grow Otago).**

3. Water allocation

There are 213 existing surface water takes in the Manuherikia catchment (Figure 3.1), with a total allocation of approximately 32 m^3/s (including connected groundwater takes) (Figure 3.1). However, the actual usage is likely to be considerably lower than this, especially at low flows. Aqualinc (2012b) estimated that the maximum combined take is about 16 m^3/s when river flows are favourable.

There are several irrigation schemes in the Manuherikia catchment that transport water from one sub-catchment to another via water races. There are also several storage reservoirs that have been constructed to store water during winter, which is to be used when there is high irrigation demand during the irrigation season.

There are six farmer cooperative irrigation companies in the catchment:

- Omakau
- Manuherikia
- Galloway
- Blackstone Hill
- Hawkdun Idaburn
- Ida Valley.

The first four have shared governance of the Falls Dam Company, which operates Falls Dam. The dam structure itself is owned by the Omakau Irrigation Company.

3.1. Storage

3.1.1. Falls Dam

Falls Dam was constructed by the Public Works Department, with work underway in the early 1930s and the reservoir filled late in 1935. The dam is a rock-filled structure 34 m high and has storage capacity of approximately 10 Mm^3 [4]. In 1955 the height of the entry lip of the spillway was raised an additional 0.6 m, which increased the dam's storage capacity.

Pioneer Generation installed a small hydroelectric station at Falls Dam in 2003. This uses water that is surplus to irrigation requirements, as well as water discharged from the dam, to supply irrigation schemes on the Manuherikia River (Ellis, 2009).

The dam's outflow is operated by a needle valve and a 'morning glory' type spillway, which operates almost continuously outside of the irrigation season. Four major irrigation schemes are dependent on Falls Dam to provide a secure supply of water: Omakau, Manuherikia, Blackstone Hills and Galloway. Water is released from the dam when the natural flow within the river is insufficient to meet irrigation requirements. The operators of Falls Dam are required to release at least 500 l/s from Falls Dam to the Manuherikia River (Consent 98306).

[4] Mm^3 = Mega cubic meters, a volume equivalent to a million cubic meters, or a billion litres. For comparison, an Olympic-sized swimming pool (25 m wide, 50 m long and at least 2 m deep) has a volume of 2,500 m^3.

3.1.2. Additional dams

Other water storage reservoirs are located within several sub-catchments. There are two dams in the Manor Burn catchment, a dam and a diverting weir in the Pool Burn, a diverting weir in Moa Creek and a small dam in the Ida Burn catchment. They have varying storage capacities and potentially supplement river flows during the irrigation season.

3.2. Major irrigation races

Several major irrigation water races transport water throughout, and out of, the catchment. The following summarises information about these races.

Mt Ida Race

This irrigation scheme extracts water from the sub-catchment bounded by the Hawkdun Range and the upper Manuherikia River, and delivers it to the upper catchment of the Ida Valley and into the Ewe Burn area. The race is approximately 100 km in length. The race provided water for early mining and supplied water to Naseby gold mining fields (Reid & Grant, 1980).

Blackstone Race

The Blackstone water race extracts water downstream of Falls Dam and negotiates the slope of the Blackstone Hills. It provides water for approximately 530 ha over a total length of approximately 14 km (Reid & Grant, 1980).

Downs Race

The race serves the Downs settlement and takes its water from Dunstan Creek. The water serves 600 ha over 9 km (Reid & Grant, 1980).

Omakau scheme

This race takes its water from the main stem of the Manuherikia River, immediately upstream of the confluence with Dunstan Creek. The race crosses the Manuherikia River downstream of the intake and extends to the Tiger Hills. Additional races belonging to this scheme include the Dunstan, Thomson, Lauder and Devonshire races (ORC, 2006).

Manuherikia scheme

This 30 km long race serves the lower valley areas downstream of Tiger Hills, extracting its water from the Manuherikia Gorge.

Galloway scheme

This scheme serves 1,200 ha using water from the Manorburn Dam for its upper portion. Return flows from other schemes are pumped from the Manuherikia River to irrigate its lower areas.

Ida Valley scheme

The scheme makes use of several old mining races, in addition to the storage of Poolburn and Manorburn. The total available storage provides water for 5,600 ha, in addition to 600 ha in the upper Galloway area. The upper area of the Ida Valley is served partly by the Mt Ida Race and partly by a small storage dam in the Ida Burn (ORC, 2006).

Private irrigation

There are several small, privately-owned schemes that are dependent on a variety of water races, including old mining privileges, to secure water for irrigation.

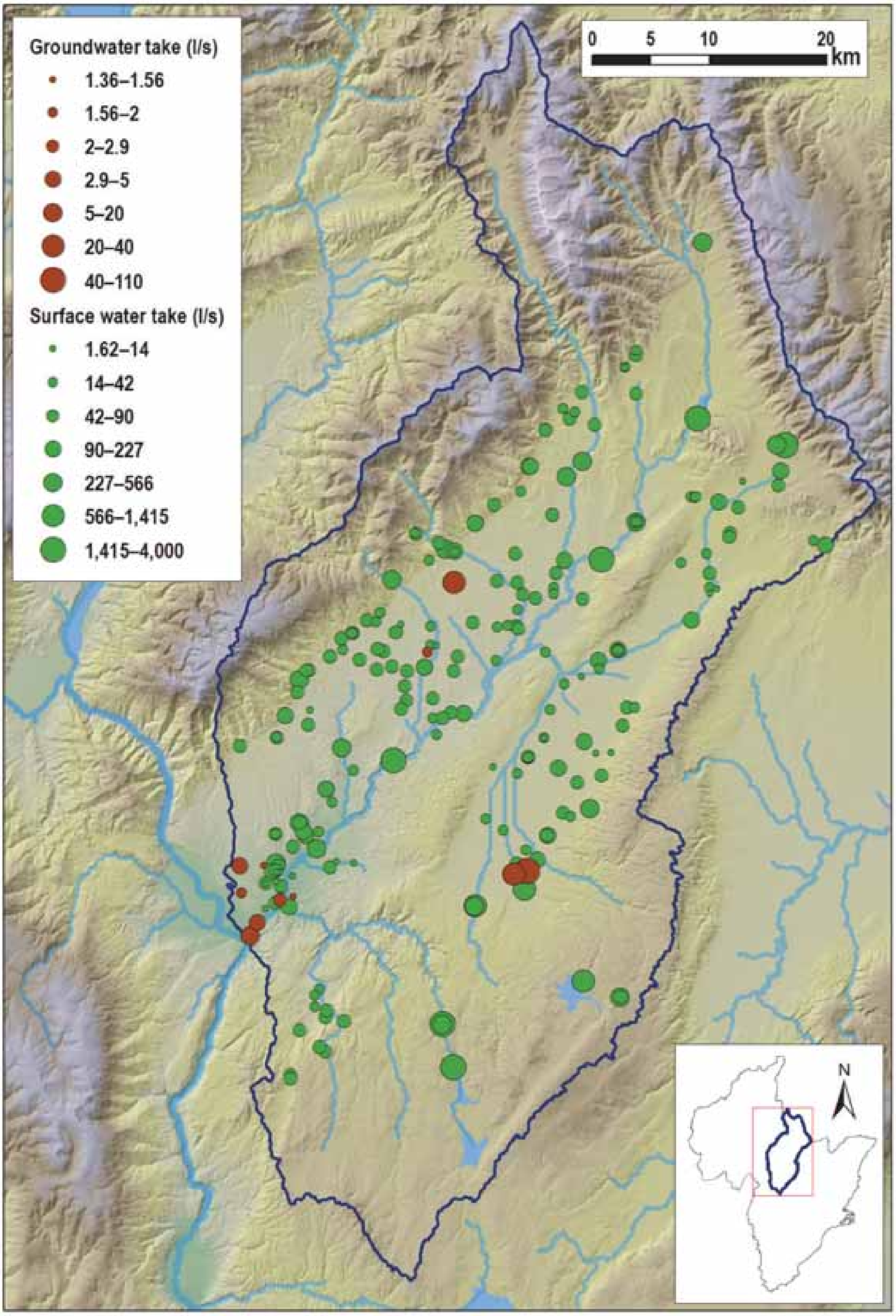


Figure 3.1 **Groundwater and surface water takes (maximum consented rate of take) in the Manuherikia catchment.**

4. River hydrology

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 Manuherikia River and Dunstan Creek. Understanding the low flow hydrology of the Manuherikia River is an essential step in achieving this objective.

Understanding the natural (unaltered) hydrology of the Manuherikia catchment is a complex task because of the long history of flow alteration with storage reservoirs, augmented flows, transport of water via water races and severe over-allocation of water resources. These challenges were also noted in Aqualinc (2012a).

Hydrological analyses prepared for the Manuherikia Catchment Water Strategy Group have focused on inflows to Falls Dam and irrigation scenarios (Stewart, 2012; Aqualinc, 2012a). Stewart (2012) estimated that the mean inflow to Falls Dam was 5.252 m^3/s, the median inflow was 3.870 m^3/s and the 7-d MALF was 1.362 m^3/s. Aqualinc (2012a) estimated the naturalised mean flow of the Manuherikia River at the Clutha confluence to be 18.5 m^3/s.

Natural (or naturalised) low-flow statistics are regularly used as a baseline when calculating habitat retention as part of instream habitat analysis (see Section 7). In this report, levels of habitat retention were calculated relative to both naturalised and existing flows (see Section 7). Additionally, naturalised low-flow statistics were estimated at the key locations within the Upper Manuherikia catchment (listed in Table 4.2, Figure 4.1 shows their locations). The details of hydrological analyses are given in Appendix A. The recorded flows in Dunstan Creek at Gorge are natural due to the absence of upstream water takes. Flows in the Manuherikia River downstream of Fork are affected to a small extent by water captured by the Mt Ida Race, although it is possible to estimate the magnitude of this effect and compensate for it. Therefore, flow data from these two sites (Figure 4.2) were used as the key reference flow sites for estimating the naturalised low-flow statistics for other locations within the catchment.

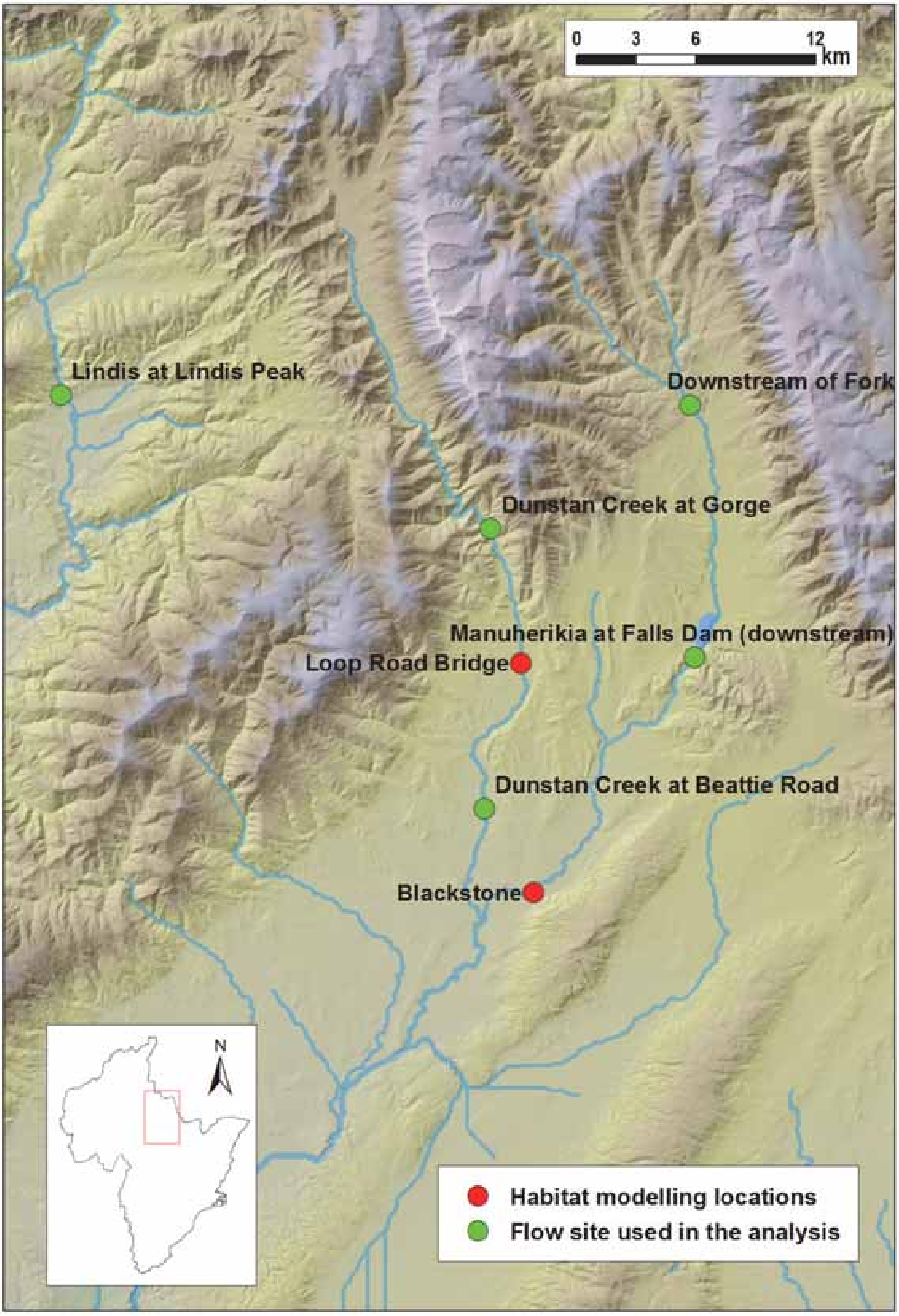


Figure 4.1 **Flow sites in the upper Manuherikia catchment used for flow naturalisation and habitat modelling locations.**

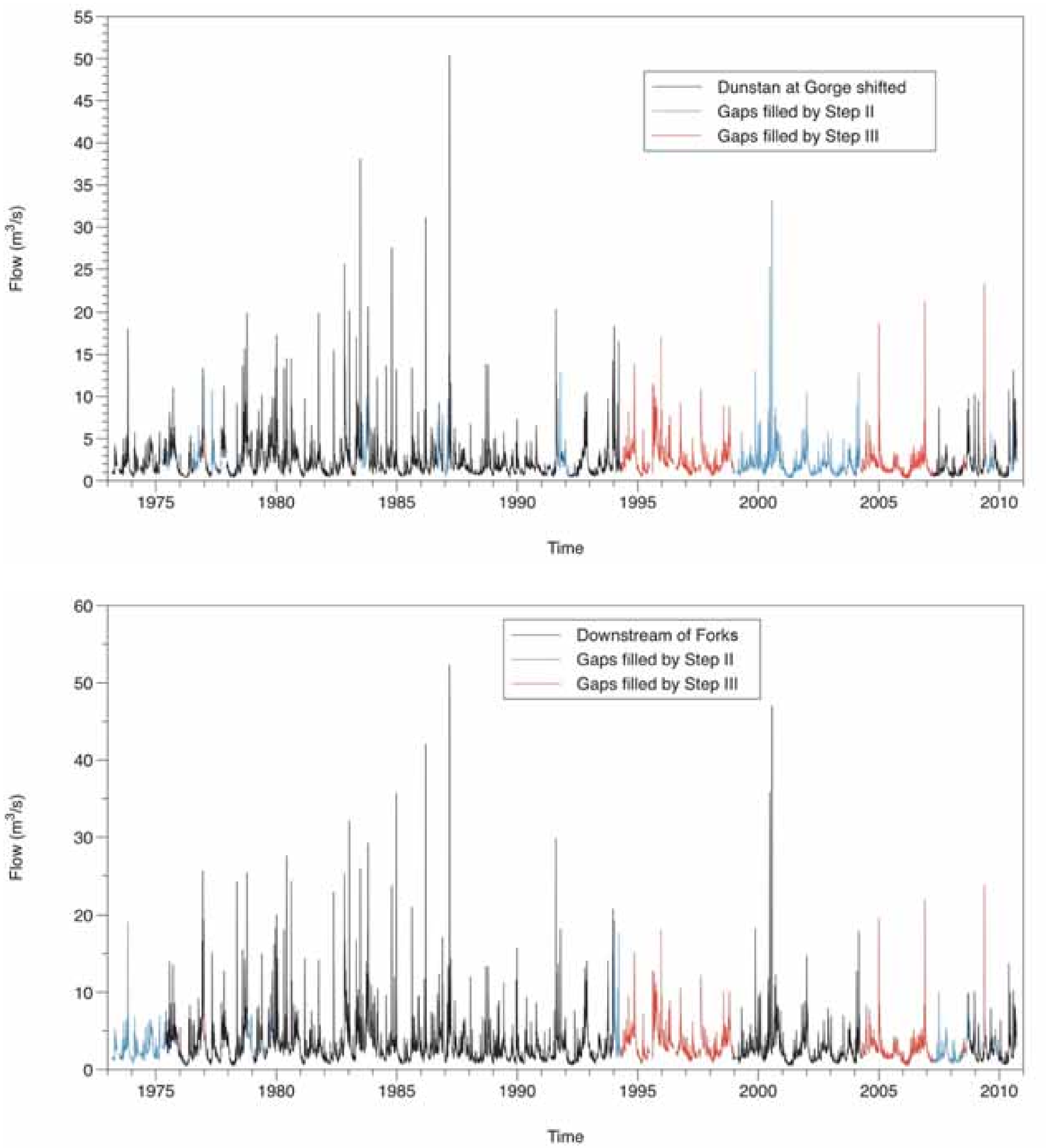


Figure 4.2 **Gap-filled datasets for Dunstan Creek at Gorge and the upper Manuherikia River downstream of Fork.**

4.1.1. Naturalised 7-d MALF estimations

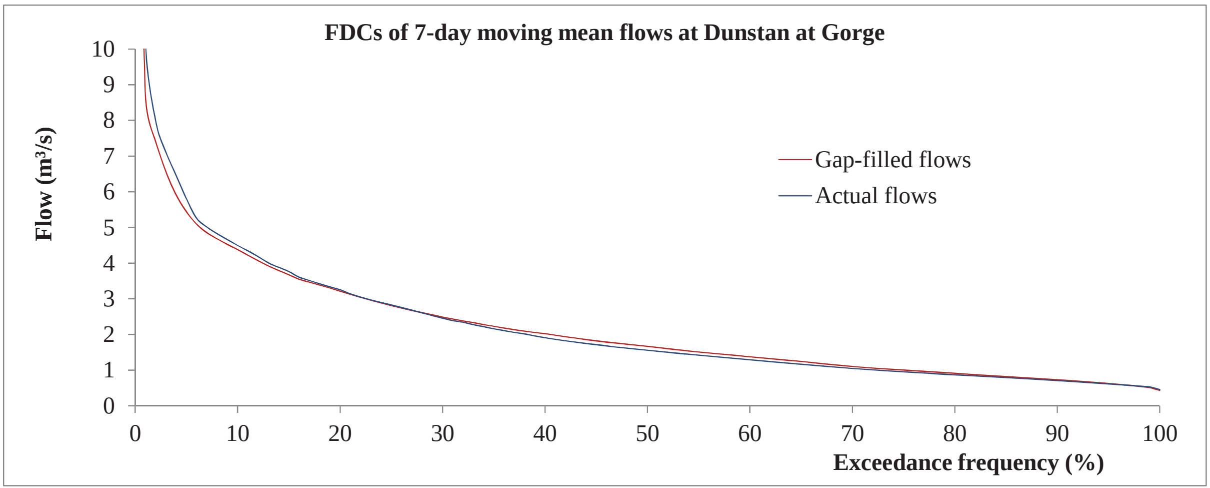
Gap-filled datasets for the Gorge and Forks flow sites produced by the process outlined in Appendix A were used to calculate 7-d MALFs[5] (October–April), which are summarised in Table 4.1.

Table 4.1 Calculated 7-d MALFs (October–April, inclusive) for sites of interest in the upper Manuherikia catchment.

Location	Data used for analysis	Flow data type	No. of complete seasons	7-d MALF (m^3/s)
Dunstan Creek at Gorge	8/3/1973–28/9/2010	Natural (gaps filled)	34	0.692
downstream of Fork	8/3/1973–28/9/2010	Naturalised (gaps filled)	34	1.009
Dunstan Creek at Beattie Road	14/11/2002–28/7/2016	Existing	10	0.350
Manuherikia River at Falls Dam (downstream)	4/2/1999–2/6/2014	Existing	15	1.737

[5] The average of the lowest arithmetic mean of seven consecutive daily values of flows within the irrigation season (October–April, inclusive).

To examine how good the gap-filled flow data is compared to the respective existing flows at Dunstan Creek at Gorge and downstream of Fork, the flow duration curves (FDCs) of seven-day moving mean flows were plotted for both sites (Figure 4.3).



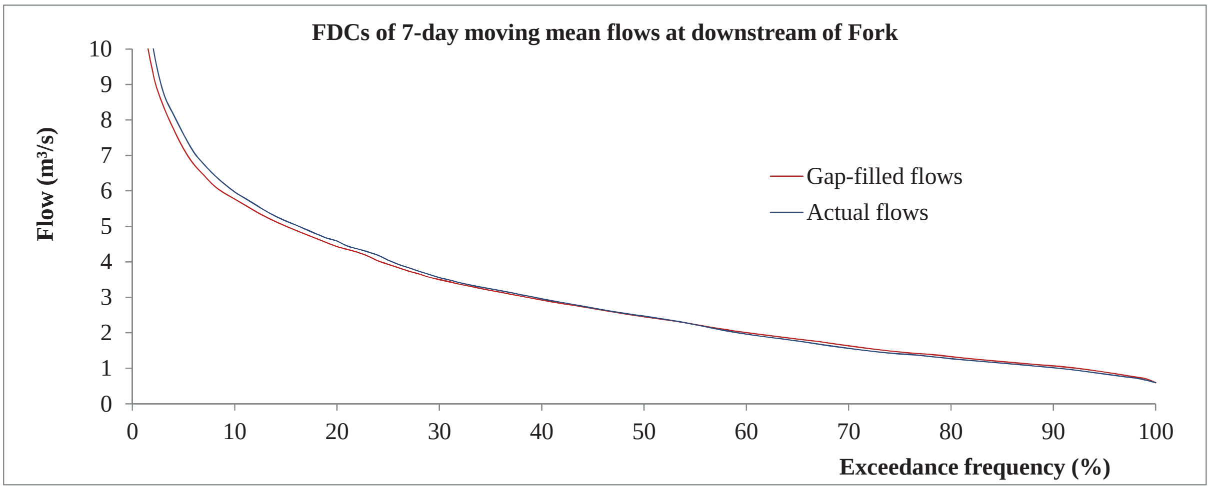


Figure 4.3 **FDCs for 7-day moving mean flows at Dunstan at Gorge and downstream of Fork.**

Figure 4.3 illustrates that there is an excellent match between the flow distribution curves for measured and gap-filled flow data for both sites at low-flow ranges (almost identical). Therefore, the low-flow statistics summarised from both gap-filled flow data are assumed to be representative.

4.1.2. Estimated naturalised 7-d MALF for sites with modified hydrology

Low-flow statistics were estimated for the following three locations to inform instream habitat modelling (Figure 4.1):

- Manuherikia River at Falls Dam (downstream)
- Manuherikia River upstream of Blackstone Bridge (upstream of water take 2001.702)
- Dunstan Creek at Loop Road Bridge.

Naturalised 7-d MALFs at these locations were estimated from the two reference flow datasets for the Gorge and Forks sites using the method outlined in Appendix A. The calculated 7-d MALFs (October–April, inclusive) at the three locations of interest are summarised in Table 4.2.

Table 4.2 Naturalised 7-d MALFs (October–April, inclusive) at the three locations of interest in the upper Manuherikia River.

Location	Data availability	Flow data type	No. of complete low-flow seasons	7-d MALF (m^3/s)
Dunstan Creek at Loop Road Bridge	8/3/1973–28/9/2010	Naturalised	34	0.779
Manuherikia River at Falls Dam (downstream)	8/3/1973–28/9/2010	Naturalised	34	1.532
Manuherikia River upstream of Blackstone Bridge (upstream of water take 2001.702)	8/3/1973–28/9/2010	Naturalised	34	1.779

4.1.3. The “existing” 7-d MALF at Blackstone Bridge

The “existing” flows at Falls Dam for the period 8 March 1973 to 28 September 2010 were estimated, using the ‘improved combined ratio method’ outlined in Appendix A, to simulate flows in the Manuherikia River upstream of Blackstone Bridge in the absence of water takes between Falls Dam and Blackstone Bridge (7-d MALF = 2.017 m^3/s). Then, the “existing” flows at Blackstone Bridge were estimated by subtracting estimated water use based on water take data for all takes between Falls Dam and Blackstone Bridge.

The upper and lower rate of water take at low flows (Table 4.3) was assessed using water metering data for each permit. Available water take data was plotted against the corresponding flow in the Manuherikia at Falls Dam (downstream) to assess the upper and lower limits to the rate of take for each water take at low flows (less than 4 m^3/s). Water taken under Permit 2003.917.V1 was not included in these calculations, as this is a retake of irrigation water released upstream in Waterfall Creek. Similarly, 94675, 99281 and WR5152N were not included in these calculations, as these takes are all from the upper reaches of Williamsons Creek, which is augmented by water from the Ida Hawkdun irrigation race.

The combined rate of take between Falls Dam and the Blackstone Bridge during periods of low flow is estimated to be between 0.070 m^3/s and 0.504 m^3/s. This was affected by the wide variation in take observed for Permits 2000.516.V1, 2000.517.V1 and RM15.063.01, which ranged from 0.060 m^3/s to 0.380 m^3/s over the period January 2015 to July 2016. However, there was a limited period of overlap between the usable water use record for these permits and available flow at Falls Dam (downstream), so these minimum and maximum rates of take for the period January 2015 to July 2016 were used in the analysis. Therefore, the estimated “existing” 7-d MALF at Blackstone Bridge is between 1.947 m^3/s and 1.513 m^3/s.

Table 4.3 Water use between Falls Dam and just above water take of 2001.702.

Permit number(s)	Data availability	Consented maximum rate of take (m^3/s)	Estimated rate of take (m^3/s)	
			Lower	Upper
2000.516.V1, 2000.517.V1, RM15.063.01	3/9/2008–22/7/2016	0.403	0.060	0.380
2002.503.V1	2/05/2010–8/08/2016	0.042	0	0.004
2002.504.V1	3/01/2004–26/10/2012	0.014	0	0.008
96208	9/08/2013–26/01/2015	0.056	0.010	0.056
RM11.013.02	2/07/2012–30/06/2014	0.056	0	0.056

4.1.4. Naturalised flows for the Manuherikia at Ophir and Campground flow sites

The long history of flow alteration in the Manuherikia catchment, including storage reservoirs, augmented flows, transport of water via water races and severe over-allocation of the catchment, makes obtaining estimates of low-flow statistics for sites in the lower catchment extremely challenging, if not impossible. Given this, advice was sought from NIWA on approaches to derive estimates of the natural 7-d MALF for the Manuherikia River at Ophir and Campground. The approach chosen involved taking estimates for these sites, derived from national maps of 7-d MALF as described in Booker and Woods (2013), and “correcting” these values. These “corrections” were based on the relationship between modelled MALF estimates for a number of nearby flow sites with available natural or near-natural records (see Appendix B for details).

The estimate of 7-d MALF derived using this approach for Ophir was 3.2 m^3/s and the uncertainty associated with this estimate was ±20%, meaning the 7-d MALF for Ophir is 2.6–3.8 m^3/s. The estimate of 7-d MALF derived using this approach for the Campground site was 3.9 m^3/s and, with uncertainty of ±20%, the 7-d MALF for this site is 3.1–4.7 m^3/s.

4.2. Summary of the hydrology of the Manuherikia catchment

Hydrological results were calculated using the combined ratio method, alongside annual rainfall and actual evapotranspiration spatial data, at the two reference sites (Gorge and downstream of Fork). Table 4.4 presents the respective 7-d MALFs for the locations of interest.

Table 4.4 Summary of 7-d MALFs (low-flow season) at key locations in the Manuherikia River and Dunstan Creek.

Location	Flow data type	7-d MALF (m^3/s)
Upper Manuherikia River downstream of Fork	Naturalised (gaps filled)	1.009
Manuherikia River at Falls Dam (downstream)	Naturalised	1.532
	Existing	1.737
Manuherikia River at Blackstone Bridge	Naturalised	1.779
	Estimated “existing” (range)	1.513–1.947
Manuherikia River at Ophir	Modelled natural	3.200 (±600)
	Existing	2.197
Manuherikia River at Campground	Modelled natural	3.900 (±800)
	Existing	0.915
Dunstan Creek at Gorge	Natural (gaps filled)	0.692
Dunstan Creek at Loop Road Bridge	Naturalised	0.779
Dunstan Creek at Beattie Road	Naturalised	0.934
	Existing	0.35

5. Water temperature

Water temperature is one of the key considerations when assessing the effects of various flows on instream values, as the volume of water in the river has a direct effect on water temperature. Generally, as river flows increase there is less diurnal fluctuation[6], and average and maximum water temperatures are reduced. However, this pattern may not hold in streams with substantial inputs of groundwater, as such inputs may reduce water temperatures and the amount of diurnal fluctuation.

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 Manuherikia 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 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).

Most native fish species with available thermal tolerance data are more tolerant of high temperatures than trout. Olsen et al. (2012) developed interim thermal criteria for native species for which sufficient information was available. No acute criteria are available for the native fish species present in the Manuherikia catchment, but chronic thermal criteria are available for longfin eels (34ºC for adults, 28ºC for elvers (juveniles)) and common bully (24ºC in upland sites) (Olsen et al., 2012).

Water temperature data was available for five sites in the Manuherikia catchment (Figure 5.1).

[6] Diurnal fluctuation is the variation between a high temperature and a low temperature that occurs during the same day.

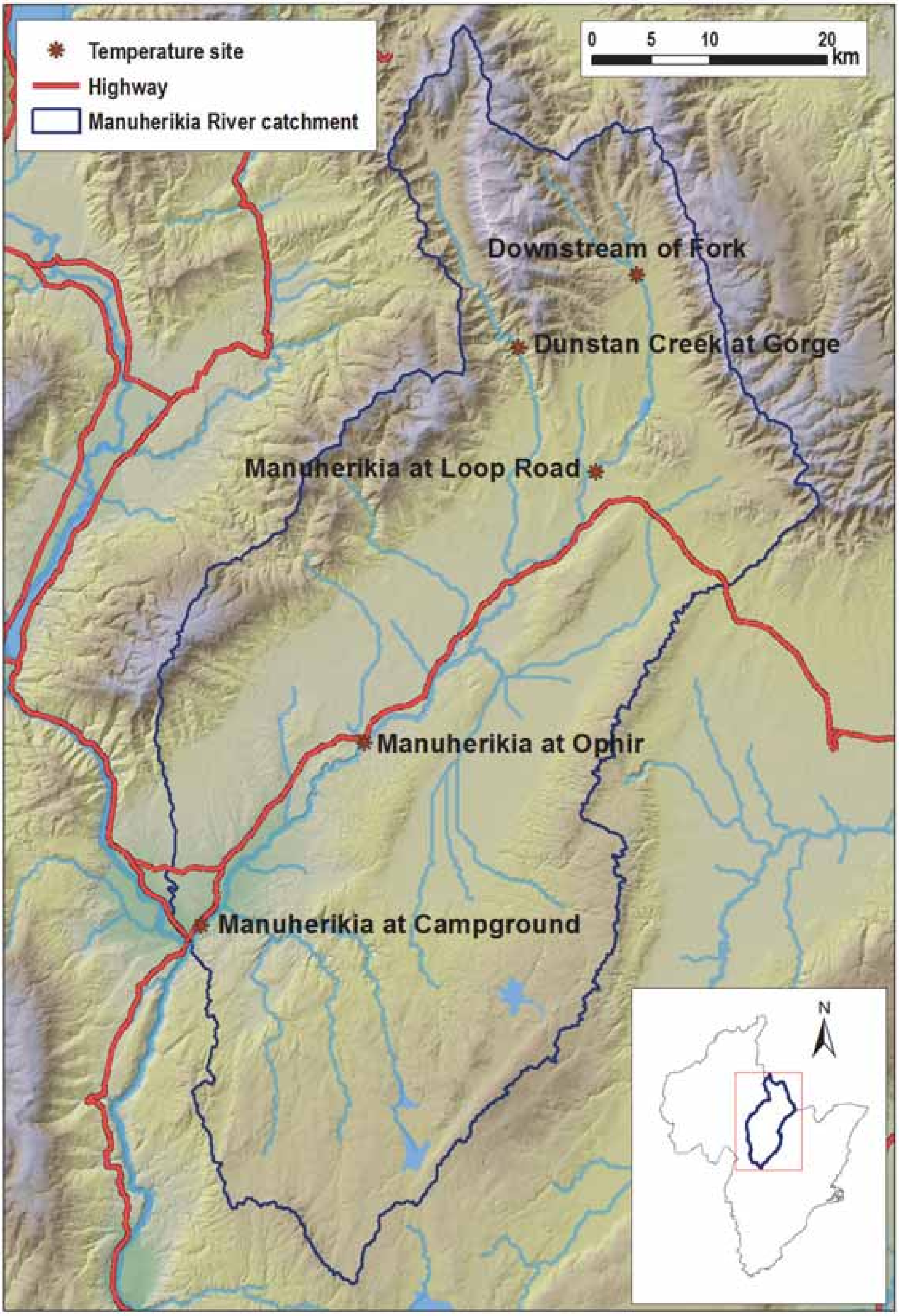


Figure 5.1 **Manuherikia catchment locations for which water temperature data was available.**

5.1. Manuherikia River

5.1.1. Downstream of Fork

Water temperatures in the upper Manuherikia River downstream of Fork vary from near freezing during the winter months to summer maxima of less than 23°C (Figure 5.2). Water temperatures at this site were well within the thermal tolerances of brown and rainbow trout, although the low winter temperatures observed are likely to limit growth rates during winter months (Figure 5.2).

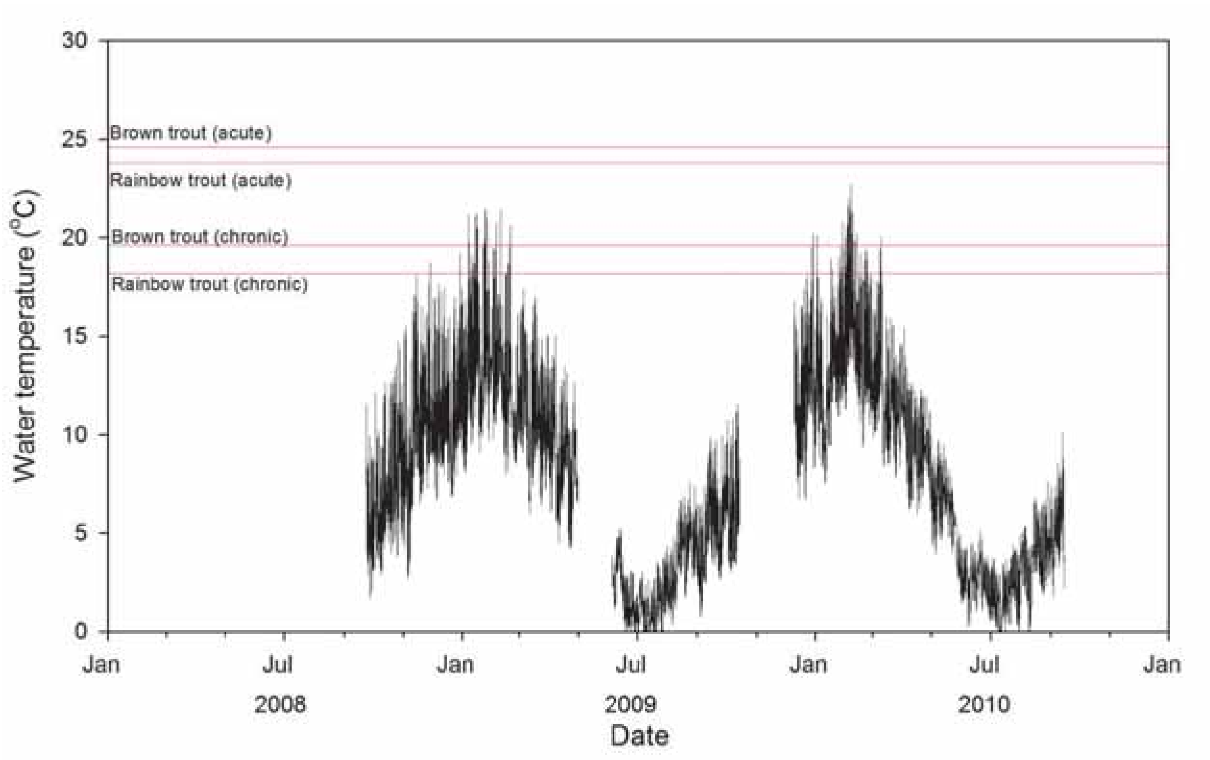


Figure 5.2 **Water temperature from the upper Manuherikia River at the flow site downstream of Fork.**

5.1.2. Loop Road

Water temperatures in the Manuherikia River at Loop Road (6.5 km below Falls Dam) approached the chronic thermal criterion for rainbow trout in summer (Figure 5.3). Winter water temperatures at Loop Road were around 5°C (Figure 5.3), with the more moderate temperatures observed at this site – compared to those above Falls Dam – likely to result from the moderating influence of water released from Falls Dam.

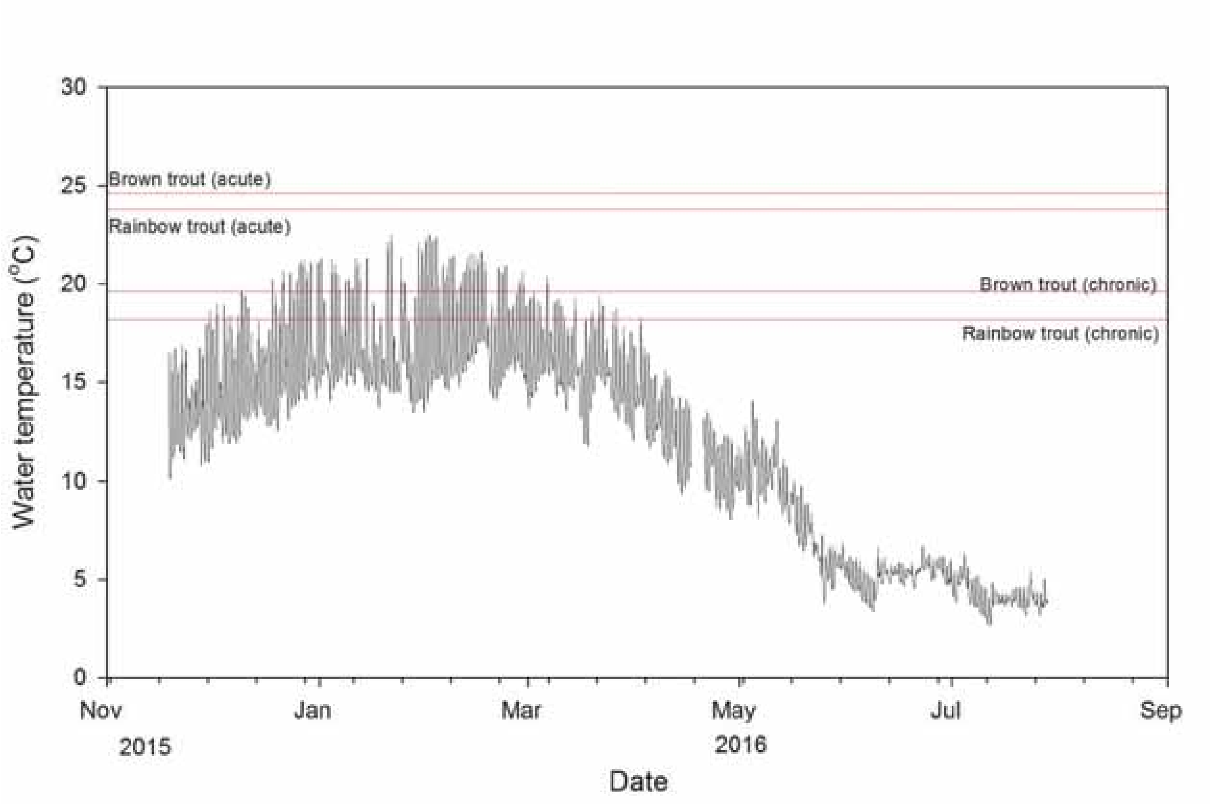


Figure 5.3 **Water temperature from the upper Manuherikia River at Loop Road for 2015–2016.**

5.1.3. Ophir

Water temperatures in the Manuherikia River at Ophir reached as high as 26.5°C (Figure 5.4). Water temperatures in excess of 24°C have been recorded when flows at Ophir have ranged between 1.4 and 3.4 m^3/s. Winter water temperatures at Ophir are cooler than those observed at Loop Road (Figure 5.3), most likely because the moderating influence of water released from Falls Dam is reduced by the longer time required for water to reach Ophir, alongside inputs of cold water from tributaries such as Dunstan Creek. Water temperature readings from the logger installed at Ophir are able to be validated using readings taken with a handheld meter (Appendix C).

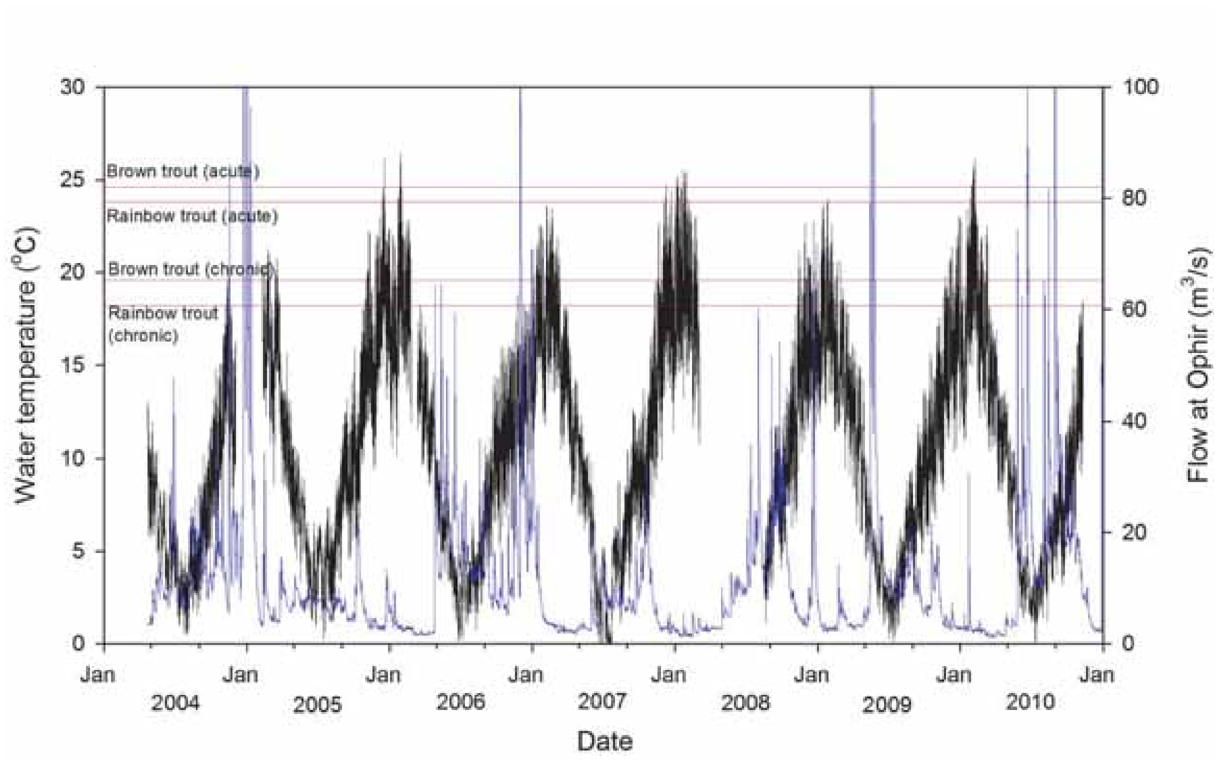


Figure 5.4 **Water temperature (black line) from the Manuherikia River at the Ophir flow site between 2004 and 2010. The blue line is the flow at the Ophir flow recorder.**

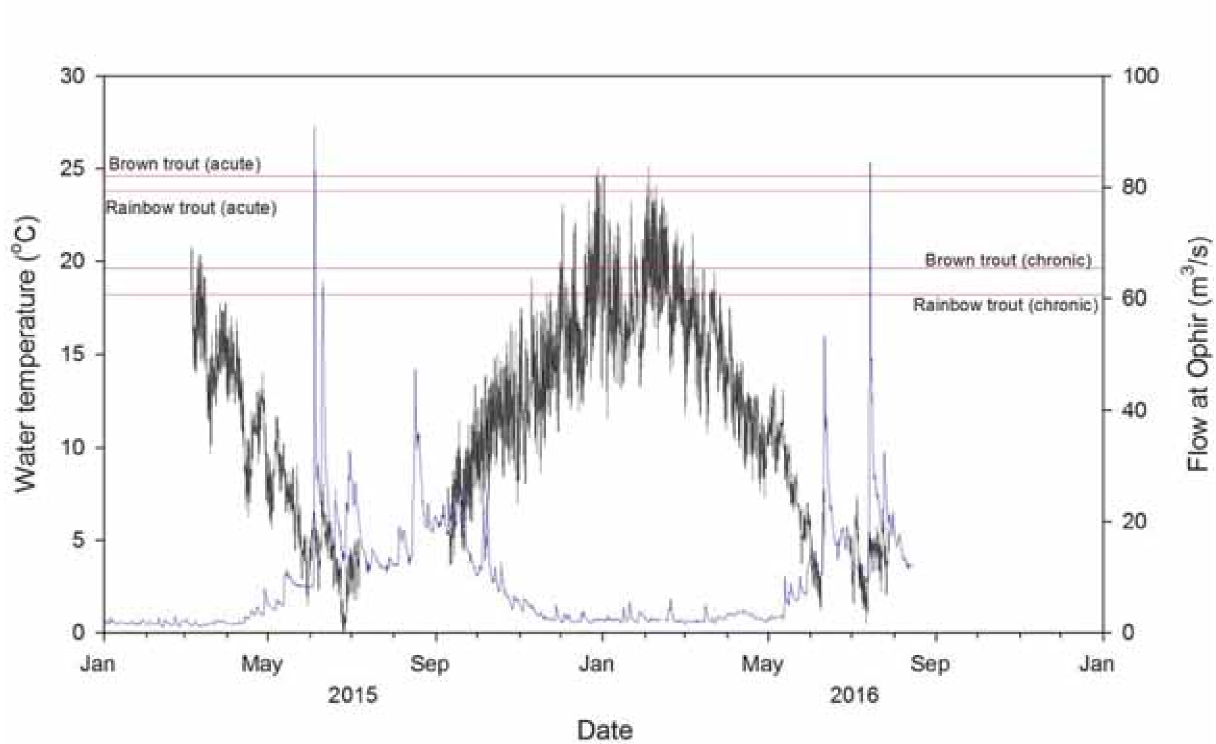


Figure 5.5 **Water temperature (black line) from the Manuherikia River at the Ophir flow site between 2015 and 2016. The blue line is the flow at the Ophir flow recorder.**

5.1.4. Campground

Water temperatures in the Manuherikia River at the Campground flow monitoring site reached as high as 28°C in the period December 2013 to June 2016 (Figure 5.6). Water temperatures in excess of 24°C were recorded when flows at the Campground ranged between 0.45 and 8.0 m^3/s. Winter water temperatures at Campground were generally around 3°C, although they approached 0°C on occasion (Figure 5.6).

Water temperature readings from the logger installed at the Campground site were able to be validated using handheld meter readings taken at the Galloway water quality monitoring site 3 km upstream (Appendix C).

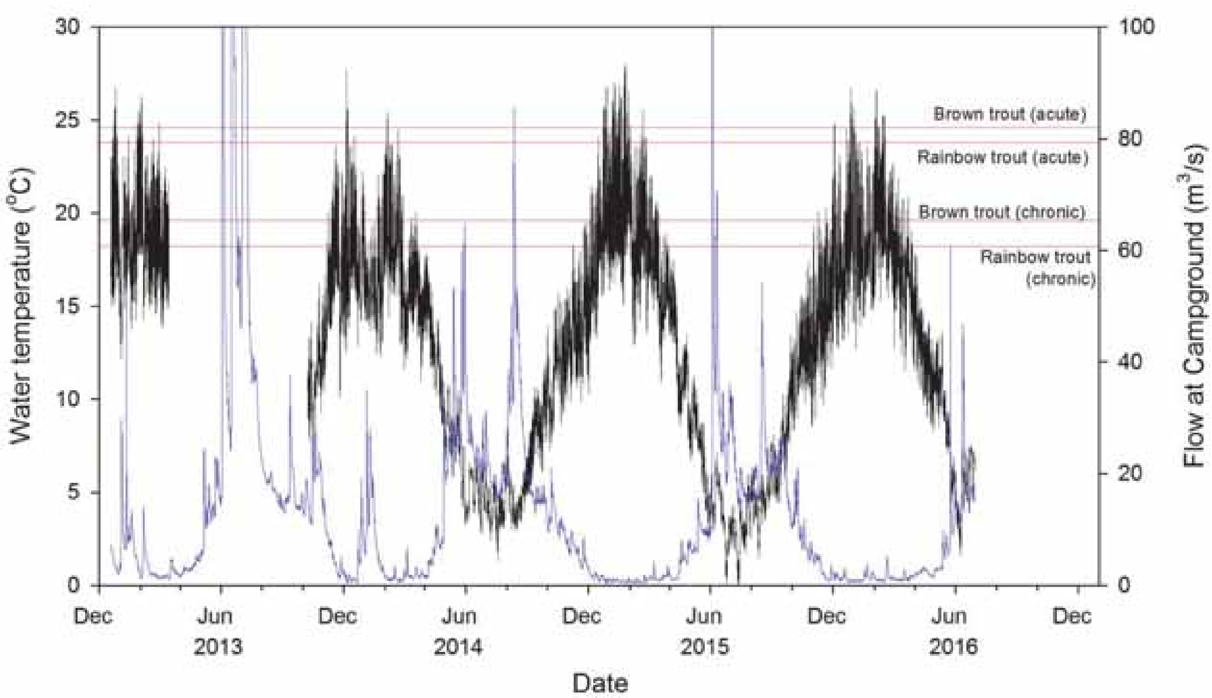


Figure 5.6 Water temperature (black line) from the Manuherikia River at the Campground flow site between 2012 and 2016. The blue line is the flow at the Campground flow recorder.

5.2. Dunstan Creek at Gorge

Water temperatures in Dunstan Creek at Gorge vary from near freezing during the winter months to summer maxima of less than 24°C (Figure 5.7). Water temperatures at this site were well within the thermal tolerances of brown and rainbow trout, although, as for the upper Manuherikia at the downstream of Fork flow site, the low winter temperatures observed are likely to limit growth rates during winter months.

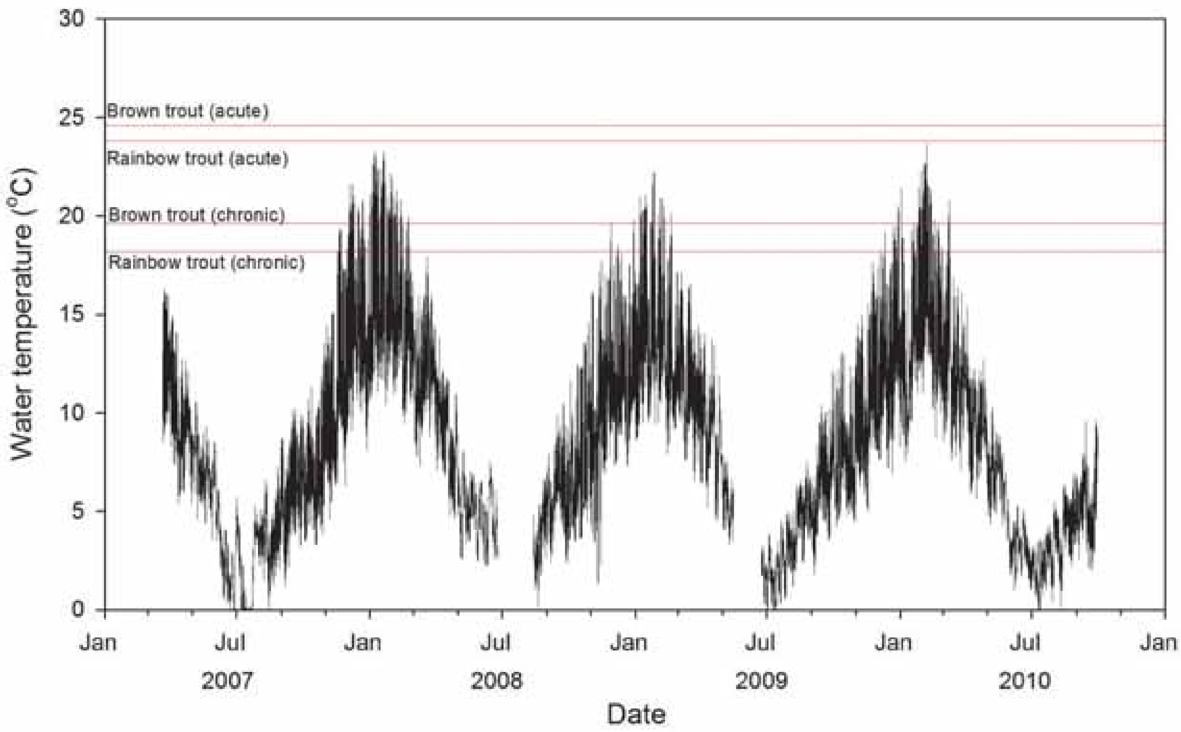


Figure 5.7 **Water temperature from Dunstan Creek at the Gorge flow site between 2007 and 2010.**

5.3. Implications of observed water temperatures

Water temperatures at all sites in the Manuherikia catchment considered in these analyses were well within the thermal criteria for longfin eels and common bully.

Water temperatures at most sites in the upper Manuherikia catchment (including Dunstan Creek at the Gorge monitoring site) were suitable for rainbow and brown trout throughout the periods for which temperature data was available (Table 5.1).

The most extensive temperature record available was for Ophir, with six hydrological years of temperature records (2005/06–2009/10 and 2015/16). Water temperatures at Ophir exceeded acute criteria for rainbow trout on between one (2008/09) and 17 days (2007/08) in a hydrological year, and on between two (2015/16) and nine days for brown trout. The chronic criteria for rainbow trout were exceeded on between nine (2008/09) and 63 days (2007/08), and on between 11 (2009/10) and 19 days (2015/16) for brown trout. Water temperatures in excess of 24°C were recorded when flows at Ophir ranged between 1.4 and 3.4 m^3/s.

Water temperatures at the Campground site in the lower Manuherikia River exceeded acute criteria for rainbow trout on between seven (2013/14) and 30 days (2014/15) in a hydrological year, and on between four (2013/14) and 22 days for brown trout. The chronic criteria for rainbow trout were exceeded on between 39 (2013/14) and 69 days (2014/15), and on between seven (2013/14) and 30 days (2014/15) for brown trout. Water temperatures in excess of 24°C were recorded when flows at Campground ranged between 0.45 and 7.8 m^3/s.

These results indicate that both rainbow and brown trout in the Manuherikia, in the vicinity of Ophir and the Campground site, experience thermal stress at times, unless they are able to find cold water refugia (such as cool tributary inflows or groundwater springs). This thermal stress is likely to result in increased rates of mortality and reduced rates of growth and fitness.

Table 5.1 Summary of the number of days exceeding acute and chronic thermal criteria for the protection of rainbow and brown trout at five sites in the Manuherikia catchment.

Site	Start of record	End of record	Total record (d)	Number of days exceeding thermal criteria			
				Acute (max. 2 h average)		Chronic (weekly average)	
				Rainbow trout	Brown trout	Rainbow trout	Brown trout
				23.8°C	24.6°C	18.2°C	19.6°C
Manuherikia downstream of Fork	23/09/2008	15/09/2010	633	-	-	-	-
Manuherikia at Loop Road	18/11/2015	28/07/2016	252	-	-	-	-
Manuherikia at Ophir	22/04/2004	28/07/2016	2,576	44	21	181	60
Manuherikia at Campground	18/12/2012	29/06/2016	633	72	49	224	89
Dunstan Creek at Gorge	21/03/2007	29/09/2010	1,202	-	-	-	-

6. Aquatic ecosystem values of the Manuherikia catchment

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

- plant, boulder, gravel, sand, silt and rock bed composition of importance to resident biota
- absence of aquatic pest plants identified in the Pest Plant Management Strategy for the Otago region
- presence of indigenous fish species threatened with extinction
- significant presence of trout and eel
- significant habitat – area of importance to internationally uncommon species – black-fronted terns above Falls Dam.

6.1. Ecological values

6.1.1. Native fish

Nine native fish species have been recorded from the Manuherikia catchment as well as koura/freshwater crayfish (*Paranephrops zealandicus*). Native fish include three non-migratory galaxiids, koaro, two bully species (upland and common bully) and longfin eels. Of these, koaro, longfin eels and koura are listed as "at risk, declining" in the most recent threat classification publications (Goodman et al., 2014; Grainger et al., 2014).

The three non-migratory galaxiids are the Central Otago roundhead galaxias (*Galaxias anomalus*) and two indeterminate non-migratory galaxias, namely the Clutha flathead galaxias (*G.* sp. D) and alpine galaxias (Manuherikia) (*G.* aff. *paucispondylus* 'Manuherikia'). These all have highly significant conservation values due to their threatened status.

The Central Otago roundhead galaxias is ranked as "nationally endangered" due to the small area of habitat in which it is found (≤100 ha) and predicted decline in numbers (50–70%) (Goodman et al., 2014). There are historic records of the Central Otago roundhead galaxias for the main stem of the Manuherikia River. This species is highly likely to have been displaced from the main stem and is now considered to persist in residual pockets in several tributaries within the catchment. Overall, this species has undergone considerable range shrinkage, and there are now 35 known sub-populations.

The Clutha flathead galaxias is classified as "nationally critical" by Goodman et al. (2014) due to the high predicted or ongoing rate of decline in numbers (>70%). In the Manuherikia catchment, the Clutha flathead galaxias is confined to several isolated tributaries in the upper Pool Burn–Manor Burn area. This is a highly threatened species and has lost 20% of known sub-populations over the past decade. The Clutha flathead galaxias has never been recorded in the main stem of the Manuherikia River or any tributaries outside of the Pool Burn–Manor Burn area.

The alpine galaxias (Manuherikia) is ranked as "nationally endangered" due to the small area of habitat in which it is found (≤10 ha) and predicted decline in numbers (10–50%) (Goodman et al., 2014). It has a single known population, located in the main stem of the Manuherikia River above Falls Dam. The fish has a confined distribution, with an upper limit of the exit of the Gorge to approximately 1.5 km above the footprint of the Falls Dam, and persists in a couple of small headwater creeks.

6.1.2. Sports fish

Four sport fish species have been recorded within the Manuherikia catchment: brown and rainbow trout, brook char and perch. Rainbow and brown trout provide angling opportunities throughout the catchment. Brook char are located high in the headwater streams and tend to form self-sustaining populations of small, stunted fish. Perch have been observed in the Ida Burn immediately below the Ida Burn Dam and could potentially be occupying irrigation reservoirs within the catchment.

The Manuherikia River is considered to be a regionally important brown trout fishery (Otago Fish & Game Council, 2015). Table 6.1 presents angler effort on the Manuherikia River, recorded during National Angler Surveys conducted in 1994/95, 2001/2002, 2007/08 and 2014/15. There appeared to be a declining trend in angler use in the Manuherikia River between the 2001/2002 survey and the two subsequent survey periods.

Table 6.1 Angler effort on the Manuherikia River and Dunstan Creek (angler days ± standard error), based on the national angler survey (Unwin, 2016).

River	Angler usage (angler days ± SE)			
	1994/1995	2001/2002	2007/2008	2014/15
Manuherikia River	3,570 ± 840	5,630 ± 2,060	2,070 ± 650	2,140 ± 830
Dunstan Creek	360 ± 200	40 ± 40	160 ± 140	210 ± 150

Dunstan Creek and the upper Manuherikia River are considered to have backcountry characteristics. Both are considered to be regionally significant sports fishery (Otago Fish and Game Council, 2015).

The Manorburn and Poolburn Reservoirs, as well as Falls Dam, offer a backcountry type of angling experience and are regionally significant (Tierney et al., 1984; Otago Fish and Game Council, 2015). The Poolburn Reservoir receives a large amount of angling effort and is becoming increasingly popular with anglers (Table 6.2). Manor Burn is unusual for Otago as it supports a reasonable population of medium-sized rainbow trout.

Table 6.2 Angler effort on the reservoirs in the Manuherikia catchment (angler days ± standard error), based on the national angler survey (Unwin, 2016).

Reservoir	Angler usage (angler days ± SE)			
	1994/1995	2001/2002	2007/2008	2014/15
Falls Dam	30 ± 30	130 ± 80	170 ± 80	50 ± 30
Poolburn	2,270 ± 540	2,810 ± 600	3,650 ± 700	5,090 ± 90
Manorburn	510 ± 130	2,350 ± 540	3,220 ± 610	1,240 ± 110

6.1.3. Riverine birds

Nineteen species of birds have been recorded from the Manuherikia catchment, 16 of which are native (Schweigman, 1992). The upper Manuherikia River and the mid to lower reaches provide two quite distinct types of habitat. The upper reaches are a braided river system, whereas the mid to lower sections are willow-lined and confined to a single thread. Excessive broom and gorse growth on the gravel beaches of the streambed were noted as reducing river bird habitat (Schweigman, 1992).

The upper reaches (upstream of Falls Dam) provide ideal habitat for wading birds. Banded dotterels, pied stilts and South Island oyster catchers, as well as the occasional wrybill, have been observed in this upper reach of the river (Ravenscroft, 2014). Black-fronted terns have also been recorded from braided river habitats upstream of Falls Dam (O'Donnell & Hoare, 2011; Wildland Consultants Ltd, 2014). Of these, the wrybill and banded dotterel have a conservation status of "nationally vulnerable", while the black-fronted tern is "nationally endangered" (Robertson et al., 2013). The pied stilt and South Island oyster catcher are "at risk" and "declining" (Robertson et al., 2013).

Black-backed gulls, little and black shags, pied stilts and South Island oyster catchers are present in the reach of river downstream of Falls Dam. Both the black and little shag have a conservation status of "naturally uncommon" (Robertson et al., 2013).

6.2. Summary of aquatic ecosystem values

The Manuherikia River is a regionally significant brown trout fishery and has been in the top five most popular river fisheries in the Otago region in all national angler surveys conducted to date (Unwin, 2016). Dunstan Creek is categorised as a backcountry fishery, containing both brown and rainbow trout (Table 6.3). Nine native fish species are present in the Manuherikia catchment. This includes three threatened species of non-migratory galaxias, two of which are classified as "nationally endangered" (Central Otago roundhead galaxias and alpine galaxias (Manuherikia)) and the other is classified as "nationally critical", the highest threat classification available (Clutha flathead galaxias) (Goodman et al., 2014). Koaro and longfin eels are also present in the catchment and are listed as "at risk, declining" in the most recent threat classification (Goodman et al., 2014) (Table 6.3). In addition, koura (freshwater crayfish) are also present and have a threat classification of "at risk, declining" (Granger et al., 2014).

The highest conservation values, such as the alpine galaxias and the Clutha flathead galaxias, are not found within the reach of the main stem affected by flow alteration and are not considered as part of this instream habitat assessment. Central Otago roundhead galaxias, although not found within the main stem of the Manuherikia River, are present within the main stem of the Dunstan Creek. As a result, they are considered in instream habitat analyses for Dunstan Creek.

Table 6.3 **Assessment of instream habitat values at sites in the Manuherikia River and Dunstan Creek, with recommended levels of habitat retention (based on the approach of Jowett & Hayes, 2004).**

Instream value	Fishery or conservation value	Recommended % habitat retention
Manuherikia River		
Brown trout – adult	Regionally significant†	80
Brown trout – juvenile rearing	Regionally significant†	80
Brown trout – spawning (May–August)	Regionally significant†	80
Longfin eel	Declining‡	80
Upland bully	Low	60
Black-fronted tern (upstream of Falls Dam)	Nationally endangered[¥]	-
Macroinvertebrates	Life-supporting capacity	80
Periphyton (especially cyanobacteria, long filamentous algae)	Nuisance	<150
Dunstan Creek		
Brown trout – adult	Regionally significant†	80
Brown trout – juvenile rearing	Regionally significant†	80
Brown trout – spawning (May–August)	Regionally significant†	80
Rainbow trout – adult	Regionally significant†	80
Rainbow trout – juvenile rearing	Regionally significant†	80
Rainbow trout – spawning (September–November)	Regionally significant†	80
Central Otago roundhead galaxias	Nationally endangered ‡	90
Upland bully	Low	60
Macroinvertebrates	Life-supporting capacity	80
Periphyton (especially cyanobacteria, long filamentous algae)	Nuisance	<150

† Based on the assessment in Otago Fish & Game Council (2015).
‡ Based on Goodman et al. (2014).
¥ Based on Robertson et al. (2012).

7. Instream habitat assessment

Instream habitat assessments have been conducted for two reaches of the Manuherikia River (upper: Duncan & Bind, 2016; lower: Jowett & Wilding, 2003) and for one reach in Dunstan Creek (Golder Associates, 2008). These survey reaches are shown in Figure 7.1.

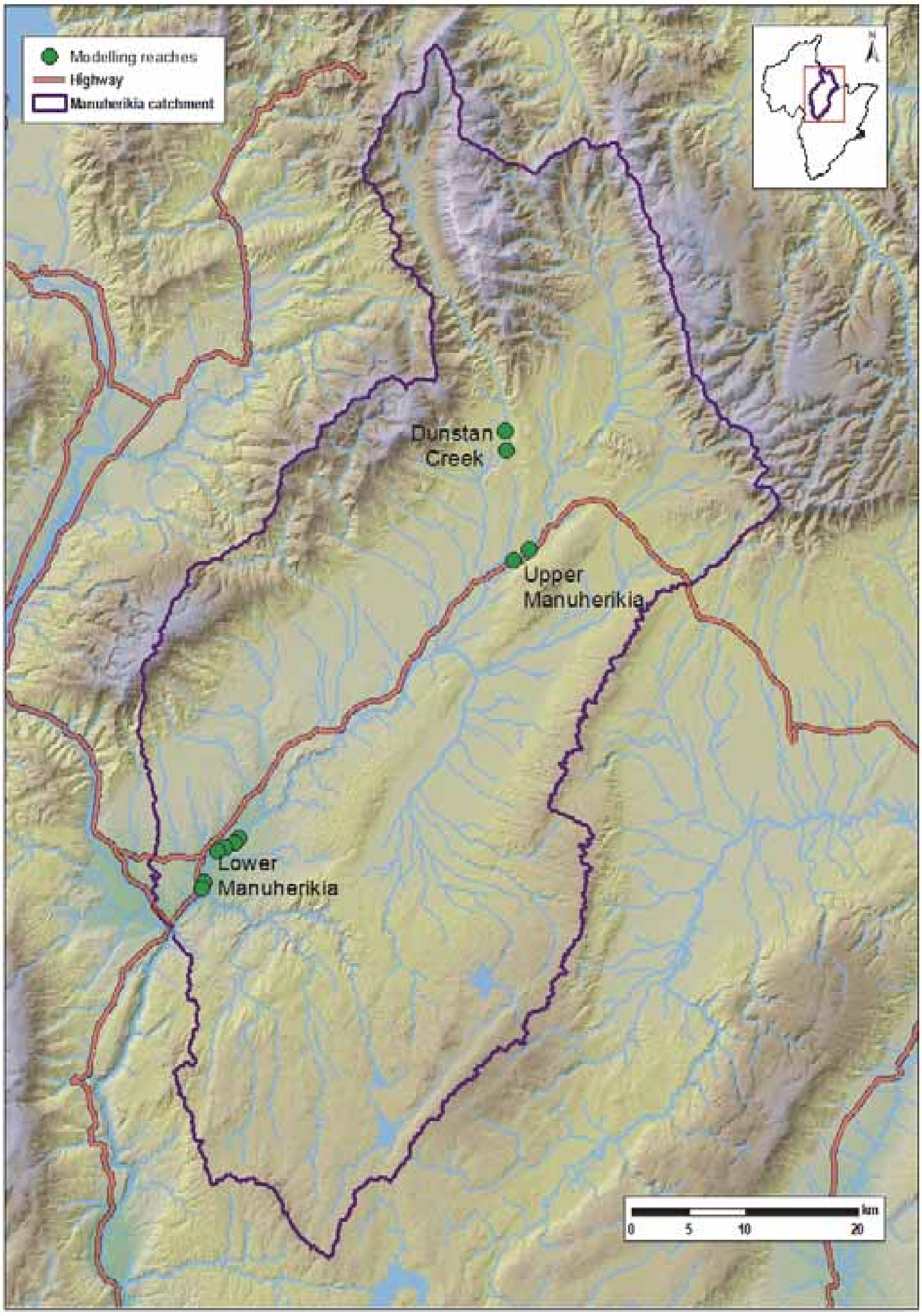


Figure 7.1 **The location of instream habitat modelling reaches in the Manuherikia catchment. Points represent the upstream or downstream boundaries of each survey reach.**

7.1. 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 & Wilding, 2003). 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 as square metres per metre (m^2/m). The reach-averaged Combined Suitability Index (CSI) is another metric 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).

7.1.1. Habitat preferences and suitability curves

Habitat suitability curves (HSC) for a range of organisms present in the Manuherikia catchment were modelled (Table 7.1) to understand the full range of potential effects of flow regime changes in the Manuherikia catchment – from changes in the cover and type of periphyton, to changes in the availability of macroinvertebrate prey, to changes in the habitat for fish and birds. It should be noted that the HSC used in these analyses may differ from those presented in the original reports, as the analyses were re-run using the most up to date HSC to ensure consistency between the three modelled reaches.

Table 7.1 Habitat suitability curves used in instream habitat modelling in the Manuherikia catchment.

Group	HSC name	HSC source	Manuherikia River		Dunstan Creek
			Upper	Lower	
Periphyton	Cyanobacteria	Ex Heath et al. (2013)	Y	Y	Y
	Diatoms	Unpublished NIWA data	Y	Y	Y
	Didymo (Waitaki)	Jowett	Y	Y	Y
	Long filamentous	Unpublished NIWA data	Y	Y	Y
	Short filamentous	Unpublished NIWA data	Y	Y	Y
Macro-invertebrates	Food producing	Waters (1976)	Y	Y	Y
	Cased caddis fly (*Pycnocentrodes*)	Jowett et al. (1991)	Y	Y	Y
	Mayfly nymphs (*Deleatidium*)	Jowett et al. (1991)	Y	Y	Y
	Net-spinning caddis fly (*Aoteapsyche*)	Jowett et al. (1991)	Y	Y	Y
Fish	Central Otago roundhead galaxias	Jowett & Richardson (2008)	Y	N	Y
	Longfin eel > 300 mm	Jowett & Richardson (2008)	Y	Y	Y
	Upland bully	Jowett & Richardson (2008)	Y	Y	Y
	Brown trout adult	Hayes & Jowett (1994)	Y	Y	Y
	Brown trout yearling	Raleigh et al. (1986)	Y	Y	Y
	Brown trout spawning	Shirvell & Dungey (1983)	Y	N	Y
	Rainbow trout adult lies	Jowett et al. (1991)	N	N	Y

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 7.2). These periphyton classes were included in these analyses to consider how changes in flow in the modelled reaches may affect periphyton cover and composition, and the potential impacts on other instream values.

Cyanobacteria were included because some types may produce toxins that pose a health risk to humans and animals. 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).

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 7.2c) that can affect recreational and ecosystem values, as well as water use (ORC, 2007; Larned et al., 2007).

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

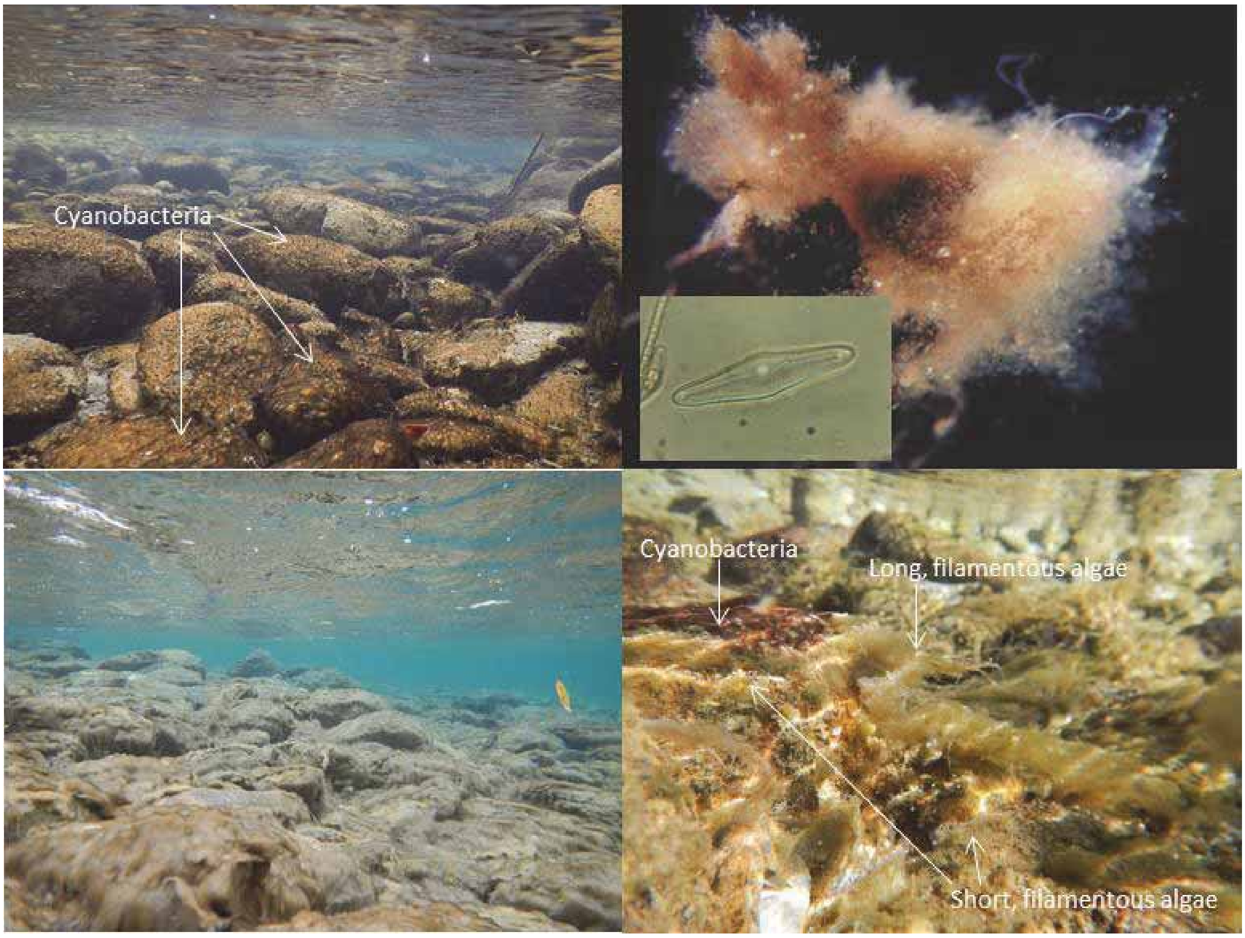


Figure 7.2 **Periphyton types considered in these analyses: a) benthic cyanobacteria (*Phormidium*), b) native diatoms, c) underwater photograph showing an extensive growth of didymo in the Hawea River and d) long and short filamentous algae (and cyanobacteria).**

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 four widespread and common macroinvertebrate taxa were included in this analysis. *Deleatidium* has been among the most abundant invertebrates in the Manuherikia River and Dunstan Creek on almost all long-term monitoring occasions. The other taxa included in these analyses (cased and net-spinning caddis fly larvae) are often abundant in the Manuherikia River and Dunstan Creek.

Figure 7.3 Common macroinvertebrate taxa in the Manuherikia catchment: 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*).

Native fish

HSC for native fish found in the main stem of the Manuherikia River and Dunstan Creek were included in these analyses to consider how changes in flow in the modelled reaches will affect habitat availability. Central Otago roundhead galaxias were included for Dunstan Creek, as they are present in the main stem in this sub-catchment. Longfin eel habitat was modelled for all reaches, although habitat is not currently the main factor affecting the distribution and abundance of this species in the catchment. Recruitment of longfin eels to the Manuherikia catchment (and the rest of the Clutha catchment upstream) is low due to the presence of Roxburgh Dam. Upland bullies are among the most widespread and abundant fish species in the catchment and were modelled for all model reaches.

It should be noted that the habitat suitability curves available for koaro (Richardson & Jowett, 1995) were not included in these analyses, as they were based on data from steep cascade habitat in the Onekaka River (Golden Bay) and are not applicable to the type of habitat present in the Manuherikia River or Dunstan Creek.

Sports fish

Brown trout are found throughout the Manuherikia catchment and rainbow trout are particularly abundant in Dunstan Creek. 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 reaches will affect habitat availability for sports fish.

7.1.2. Approaches to flow setting

There are a number of approaches to determining the appropriate flows 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 7-d MALF.

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 7-d MALF.

However, for the Manuherikia River there are two potential baseline flows: the existing flows and the naturalised flows. The former represents the existing environment influenced by the management of Falls Dam (completed in 1935) and current abstractions from the river, which will generally mean that flows in the upper catchment (above the Gorge downstream of Ophir) are augmented (i.e., higher than natural) during dry periods, while flows in the lower river are reduced as a result of the large amount of water abstracted from the main stem and tributaries. In contrast, the naturalised flows estimate what the flow in the river would be in the absence of Falls Dam and without any abstraction.

In this report, habitat retention values are presented for each of these baseline flows (i.e., existing and naturalised) for the upper site on the main stem of the Manuherikia River. However, there were no major water takes upstream of the modelling reach for Dunstan Creek, so the naturalised flow was the baseline used for calculation of habitat retention.

7.2. Instream habitat modelling in the Upper Manuherikia River

Instream habitat modelling was undertaken in the upper Manuherikia by NIWA (Duncan & Bind, 2016), using the hydraulic and instream habitat model RHYHABSIM (Jowett, 1989). Calibration measurements were undertaken on two different occasions in addition to the initial survey (Table 7.2). Duncan & Bind (2016) present more details of the methods employed in these surveys and the results of the analyses.

Table 7.2 Survey flows and calibration flows for the survey reach of upper Manuherikia River (Duncan & Bind, 2016) and estimated naturalised and existing 7-d MALF values.

Survey flow	Calibration flow 1	Calibration flow 2	Naturalised 7-d MALF	Existing 7-d MALF
3/2/16	14/4/16	2/5/16		
(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
2.200	2.049	1.390	1.779	1.513–1.947

7.2.1. Physical characteristics

The hydraulic component of instream habitat modelling made predictions about how water depth, channel width and water velocity will change with changes in flow (Figure 7.4). The most notable pattern is that there is a gradual decline in channel width, depth and water velocity with declining flows down to 0.5 m^3/s, below which width and velocity drop rapidly (Figure 7.4).

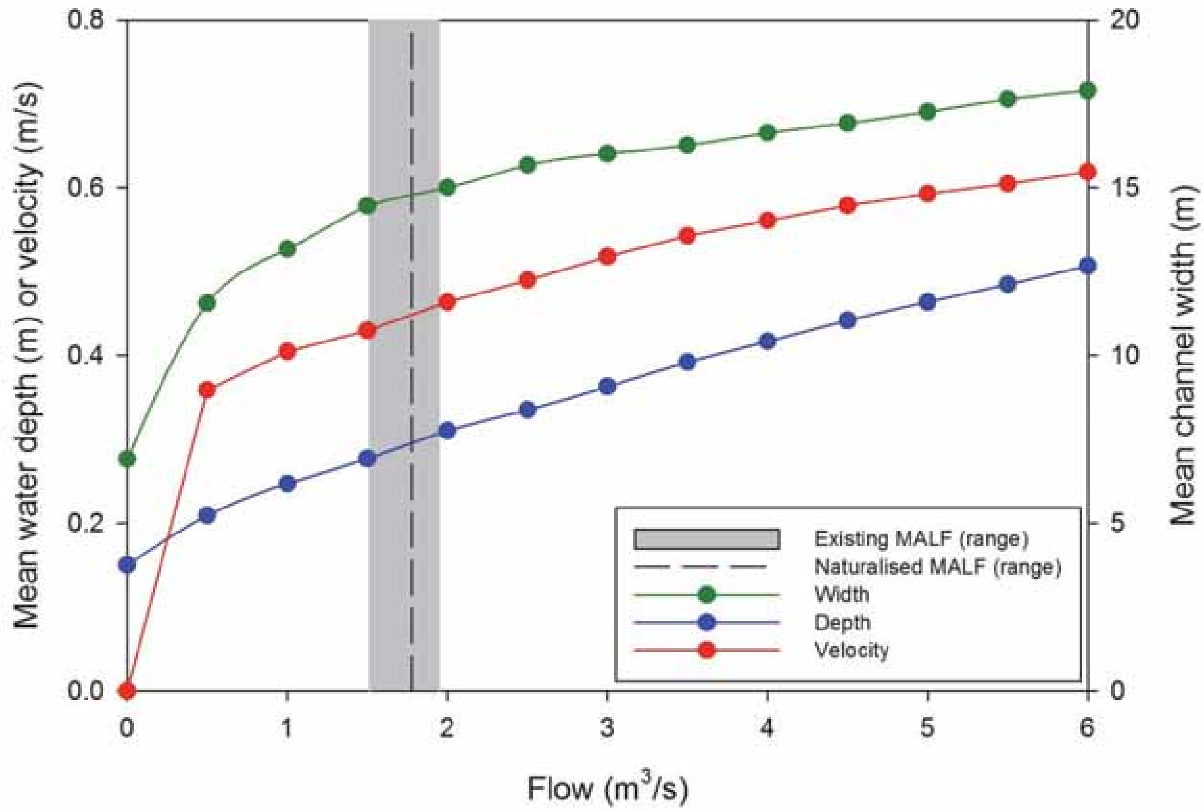


Figure 7.4 **Changes in mean channel width, wetted perimeter, mean water depth and mean water velocity with changes in flow in the survey reach in the upper Manuherikia River at Blackstone Bridge.**

7.2.2. 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 periphyton, and the relative contribution of the different types of periphyton to the overall community. Given this, it is the percentage of the wetted channel covered by periphyton, not the total area of suitable habitat, that is of interest. For this reason, the habitat suitability index (reach-averaged CSI) was used instead of weighted usable area (RAWS) in instream habitat analyses for periphyton.

Flow was predicted to have little effect on habitat quality for cyanobacteria (*Phormidium*) and the invasive diatom didymo, with a decline in habitat quality for both species predicted below 0.5 m^3/s (Figure 7.5). Habitat quality for native diatoms was predicted to increase across the modelled flow range (Figure 7.5). Habitat quality for short filamentous algae was predicted to increase with increasing flows to 2.5 m^3/s, before declining at higher flows, while habitat quality for long filamentous algae was predicted to be highest in the absence of flow and to decline across the modelled flow range (Figure 7.5).

This analysis suggests that when flows are less than 0.784 m^3/s in the upper Manuherikia there is a significantly higher risk of proliferation of long filamentous algae, compared with naturalised flows, and this risk is predicted to rise further at flows of less than 0.345 m^3/s (Table 7.3). Compared with existing flows, there would be a significantly higher risk of proliferation of long filamentous algae when flows are less than 0.577–0.912 $m^3/$, with this risk rising further at flows of less than 0.212–0.428 m^3/s (Table 7.3).

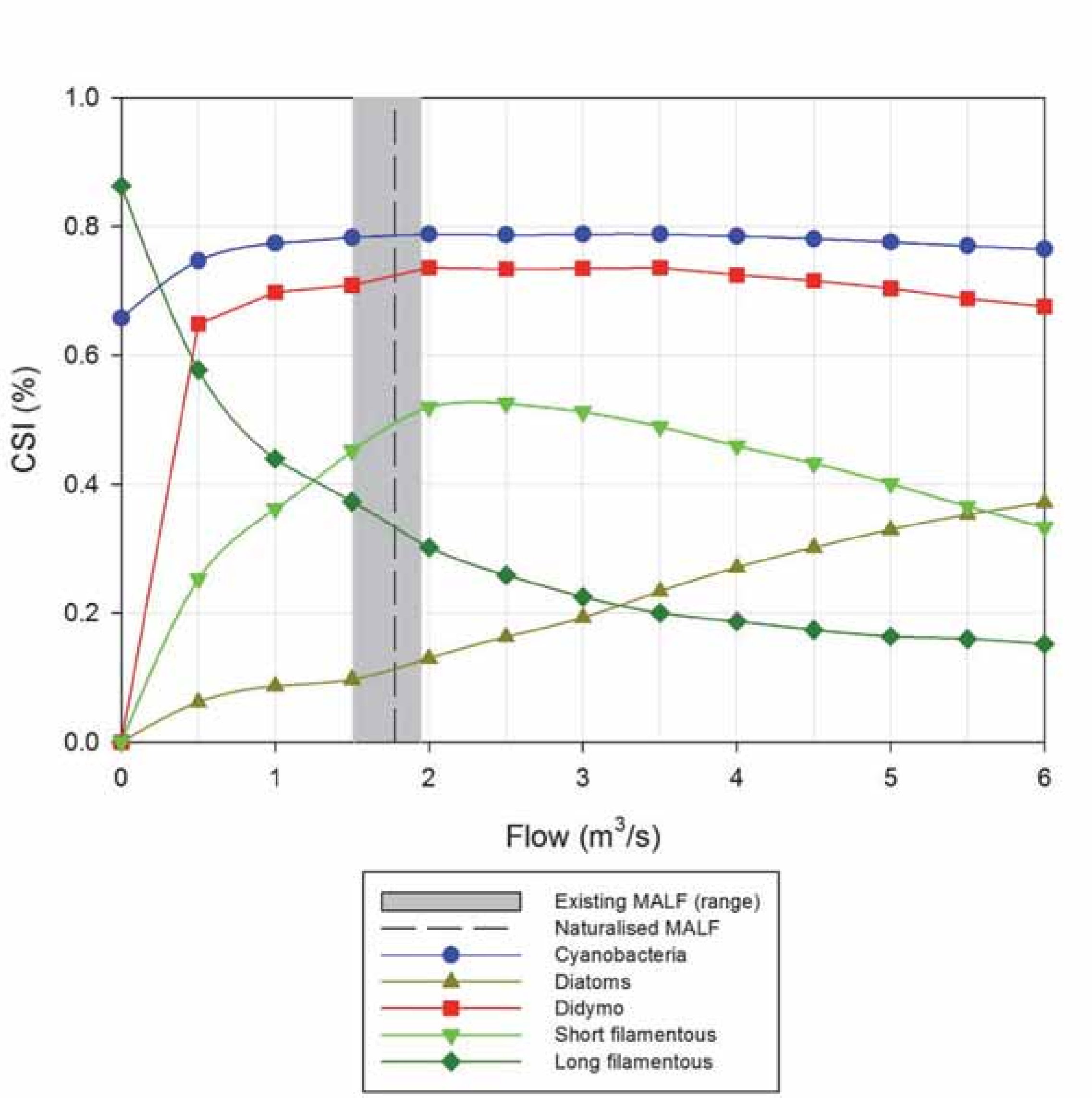


Figure 7.5 **Variation in instream habitat quality (reach-averaged CSI) for periphyton classes relative to flow in the survey reach of the upper Manuherikia River. The dotted lines represent the naturalised (long dash) and existing (grey bar) MALF.**

Table 7.3 Flow requirements for periphyton habitat in the upper Manuherikia River, based on the analysis of Duncan & Bind (2016). Flows required for the various habitat retention values are given relative to existing flows (i.e., with current operation of Falls Dam) and naturalised flows (i.e., flows predicted in the absence of Falls Dam and all abstraction).

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly declines (m^3/s)	Flow at which % habitat retention occurs (m^3/s)		
			150%	200%	300%
Compared to existing flows					
Cyanobacteria	1.5–3.5	1.0	-	-	-
Diatoms	>6.0	-	-	-	-
Didymo	2–3.5	0.5	-	-	-
Short filamentous	2.5	2.0	-	-	-
Long filamentous	0	-	0.577–0.912	0.212–0.428	-
Compared to naturalised flows					
Cyanobacteria	1.5–3.5	1.0	-	-	-
Diatoms	>6.0	-	-	-	-
Didymo	2–3.5	0.5	-	-	-
Short filamentous	2.5	2.0	-	-	-
Long filamentous	0	-	0.782	0.344	-

7.2.3. Invertebrate habitat

Food producing habitat rose with increasing flow to 3 m^3/s, above which habitat remained relatively stable (Figure 7.6). Habitat for net-spinning caddis fly larvae was predicted to increase with increasing flow up to 5.5 m^3/s (Figure 7.6). Habitat for the common mayfly *Deleatidium* and the cased caddis *Pycnocentrodes* was predicted to rise with increasing flows, reaching a peak at 3.5 m^3/s, above which habitat was predicted to gradually decline (Figure 7.6). For most of the macroinvertebrate species modelled, habitat was predicted to decline rapidly as flows dropped below 2 m^3/s (Table 7.4).

Flows of between 0.978 m^3/s (*Deleatidium*) and 1.312 m^3/s (*Aoteapsyche*) were predicted to retain 80% of the habitat available in the upper Manuherikia River relative to naturalised flows (Table 7.4). Flows of 0.883 m^3/s (*Deleatidium*) to 1.404 m^3/s (food producing habitat) were predicted to retain 80% of the habitat available in the upper Manuherikia River relative to existing flows (Table 7.4).

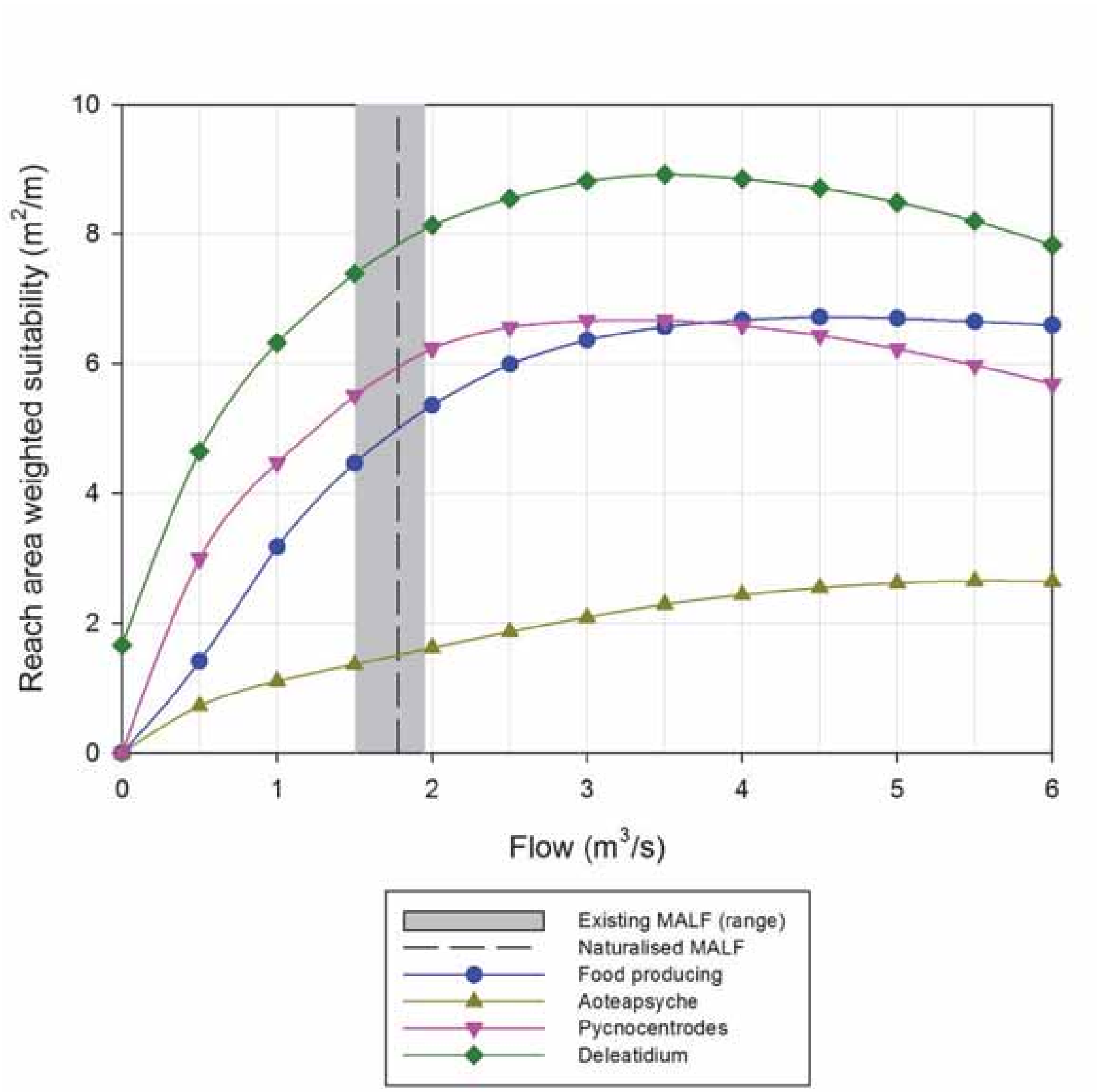


Figure 7.6 **Variation in instream habitat for common macroinvertebrates relative to flow in the survey reach of the upper Manuherikia River. The dotted lines represent the naturalised (long dash) and existing (grey bar) MALF .**

Table 7.4 Flow requirements for macroinvertebrate habitat in the upper Manuherikia River, based on the analysis of Duncan & Bind (2016). Flows required for the various habitat retention values are given relative to existing flows (i.e., with current operation of Falls Dam) and naturalised flows (i.e., flows predicted in the absence of Falls Dam and all abstraction).

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly declines (m^3/s)	Flow at which % habitat retention occurs (m^3/s)			
			60%	70%	80%	90%
Compared to existing flows						
Food producing	4.5	2.0	0.864–0.998	0.992–1.201	1.163–1.404	1.336–1.654
Mayfly nymphs (*Deleatidium*)	3.5	2.0	0.467–0.557	0.662–0.797	0.883–1.058	1.163–1.435
Net-spinning caddis fly (*Aoteapsyche*)	5.5	-	0.631–0.803	0.810–1.015	0.988–1.324	1.247–1.634
Cased caddis fly (*Pycnocentrodes*)	3	2.0	0.611–0.738	0.797–0.945	0.983–1.219	1.243–1.522
Compared to naturalised flows						
Food producing	4.5	2.0	0.946	1.119	1.311	1.503
Mayfly nymphs (*Deleatidium*)	3.5	2.0	0.512	0.745	0.978	1.330
Net-spinning caddis fly (*Aoteapsyche*)	5.5	-	0.737	0.933	1.191	1.483
Cased caddis fly (*Pycnocentrodes*)	3	2.0	0.689	0.888	1.125	1.410

7.2.4. Native fish habitat

Adult roundhead galaxias had the lowest flow preference, with optimum habitat predicted to occur at 0.5 m^3/s, followed by upland bully (1 m^3/s) (Figure 7.7, Table 7.5). In contrast, habitat for longfin eels (>300 mm) increased rapidly as flows increased to 1 m^3/s, but were relatively stable at flows between 1 and 6 m^3/s (Figure 7.7).

A flow of 0.370 m^3/s was predicted to retain 90% of the Central Otago roundhead galaxias habitat available, compared with naturalised flows in the upper Manuherikia River, while a flow of 0.676 m^3/s was predicted to retain 80% of the longfin eel habitat (Table 7.5). In comparison, a flow of 0.350–0.402 m^3/s was predicted to retain 90% of the Central Otago roundhead galaxias habitat available, compared with existing flows in the upper Manuherikia River, while flows of 0.350–0.402 m^3/s were predicted to retain 80% of the longfin eel habitat, compared with existing flows (Table 7.5).

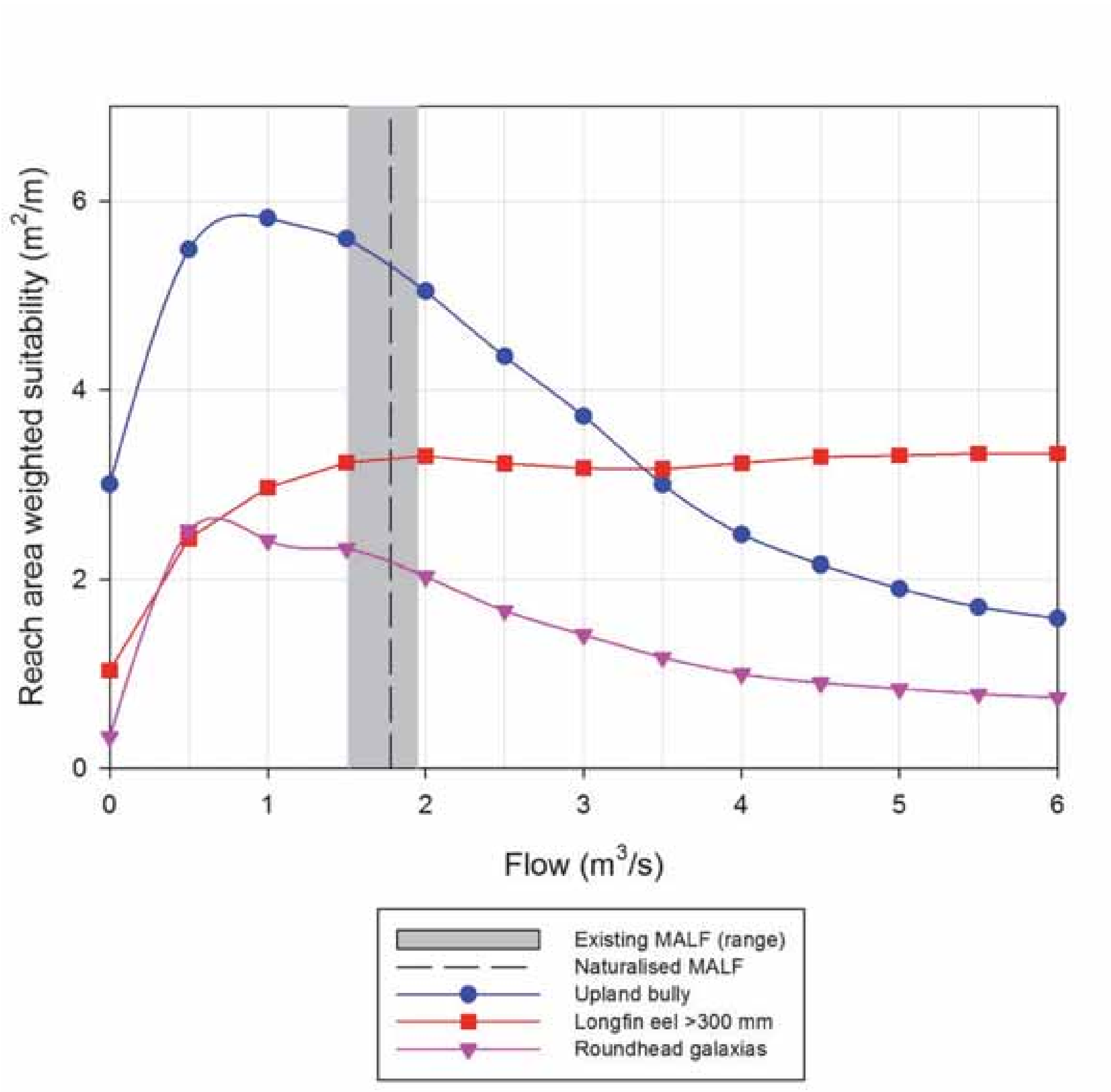


Figure 7.7 **Variation in instream habitat of native fish relative to flow in the survey reach of the upper Manuherikia River. The dotted lines represent the naturalised (long dash) and existing (grey bar) MALF .**

Table 7.5 Flow requirements for native fish habitat in the upper Manuherikia River, based on the analysis of Duncan & Bind (2016). Flows required for the various habitat retention values are given relative to existing flows (i.e., with current operation of Falls Dam) and naturalised flows (i.e., flows predicted in the absence of Falls Dam and all abstraction).

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly declines (m^3/s)	Flow at which % habitat retention occurs (m^3/s)			
			60%	70%	80%	90%
Compared to existing flows						
Central Otago roundhead galaxias	0.5	0.5	0.243–0.208	0.296–0.255	0.349–0.303	0.402–0.350
Longfin eel >300 mm	-	1.0	0.326–0.339	0.442–0.457	0.649–0.694	0.947–0.998
Upland bully	1.0	0.5	0.071–0.013	0.183–0.116	0.296–0.218	0.408–0.321
Compared to naturalised flows						
Central Otago roundhead galaxias	0.5	0.5	0.222	0.271	0.320	0.370
Longfin eel >300 mm	-	1.0	0.334	0.451	0.676	0.978
Upland bully	1.0	0.5	0.036	0.142	0.248	0.355

7.2.5. Brown trout habitat

Habitat for adult brown trout was predicted to increase across the modelled range of flows (Figure 7.8). Habitat for yearling brown trout was also predicted to increase across the modelled flow range, although habitat was predicted to drop rapidly below 1 m^3/s, with minor increases as flows increased above this (Figure 7.8). In contrast, predicted spawning habitat increased rapidly with increasing flows to 1 m^3/s and was predicted to be optimum at 2 m^3/s, above which the amount of suitable habitat was predicted to decline (Figure 7.8).

A flow of 1.412 m^3/s was predicted to retain 80% of the adult brown trout habitat compared with naturalised flows in the upper Manuherikia River, while flows of 0.679 m^3/s and 0.959 m^3/s retained 80% of the habitat available compared with naturalised flows in the upper Manuherikia River for brown trout yearlings and spawning, respectively (Table 7.6). In comparison, flows of 1.214–1.536 m^3/s were predicted to retain 80% of the adult brown trout habitat compared with naturalised flows in the upper Manuherikia River, and flows of 0.587–0.736 m^3/s and 0.943–0.968 m^3/s retained 80% of the habitat available compared with naturalised flows in the upper Manuherikia River for brown trout yearlings and spawning, respectively (Table 7.6).

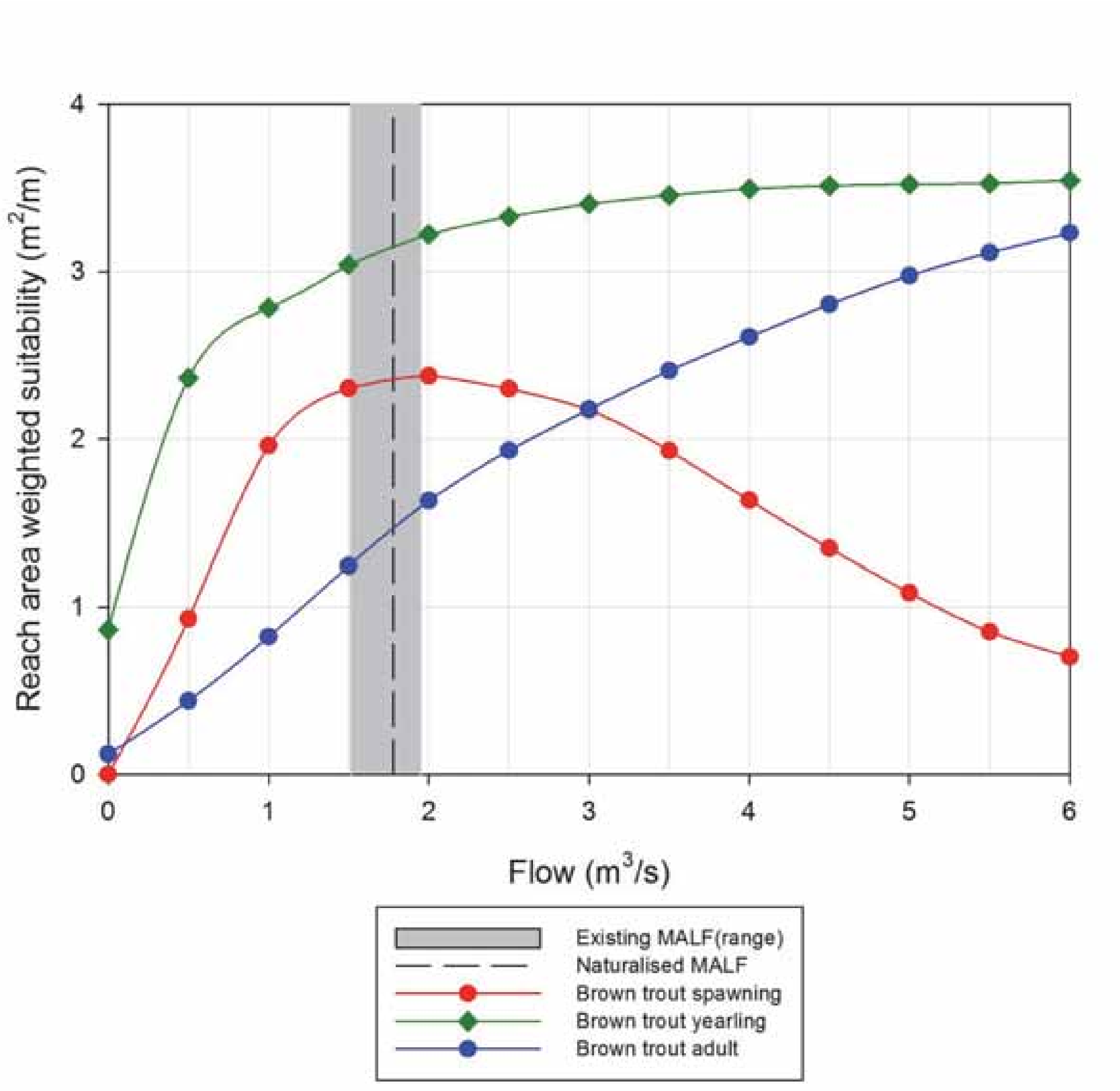


Figure 7.8 **Variation in instream habitat of various life stages of brown trout relative to flow in the upper Manuherikia River. The dotted lines represent the naturalised (long dash) and existing (grey bar) MALF.**

Table 7.6 **Flow requirements for brown trout habitat in the upper Manuherikia River, based on the analysis of Duncan & Bind (2016). Flows required for the various habitat retention values are given relative to existing flows (i.e., with current operation of Falls Dam) and naturalised flows (i.e., flows predicted in the absence of Falls Dam and all abstraction).**

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly declines (m^3/s)	Flow at which % habitat retention occurs (m^3/s)		
			70%	80%	90%
Compared to existing flows					
Brown trout adult	>6.0	-	1.065–1.345	1.214–1.536	1.363–1.742
Brown trout yearling	>6.0	1.0	0.423–0.459	0.587–0.736	0.951–1.192
Brown trout spawning	2.0	1.0	0.831–0.854	0.943–0.968	1.166–1.252
Compared to naturalised flows					
Brown trout adult	>6.0	-	1.237	1.410	1.591
Brown trout yearling	>6.0	1.0	0.445	0.679	1.087
Brown trout spawning	2.0	1.0	0.845	0.959	1.218

7.3. Instream habitat modelling in the Lower Manuherikia River

Instream habitat modelling was undertaken in the lower Manuherikia by NIWA (Jowett & Wilding, 2003), using the hydraulic and instream habitat model RHYHABSIM (Jowett, 1989). The data files for this site were reanalysed by Ian Jowett (Jowett Consulting Ltd) in July 2016 using SEFA software to ensure that the HSC used were up to date and consistent across all modelling reaches presented in this report. Calibration measurements were undertaken on two different occasions in addition to the initial survey (Table 7.7). Jowett & Wilding (2003) presents more details of the methods employed in these surveys and the results of the analyses.

The instream habitat modelling in the lower Manuherikia is representative of the lower river from where the river exits the Tiger Hill gorge to its confluence with the Clutha, a length of approximately 15 km. However, Contact Energy has a land use consent (2001.398.V1) “to disturb and alter the bed of the lower Manuherikia River” to just upstream of the Galloway Bridge. These works affect the morphology of the lower 6 km of the Manuherikia River; therefore, there is some uncertainty regarding the applicability of instream habitat modelling conducted for the lower Manuherikia to the reach affected by these works. However, it is likely that the morphological effects of the gravel removal from this reach are of greater consequence for instream habitat than the flow. The results of instream habitat modelling remain applicable to the remaining 9 km of the lower Manuherikia River.

Table 7.7 Survey flows and calibration flows for the survey reach of lower Manuherikia River (Jowett & Wilding, 2003) and naturalised and existing 7-d MALF values.

Survey flow	Calibration flow 1	Calibration flow 2	Naturalised 7-d MALF	Current 7-d MALF
(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
7.4	1.4	1.0	3.900 (3.100–4.700)	0.915

7.3.1. Physical characteristics

The hydraulic component of instream habitat modelling made predictions over how water depth, channel width and water velocity will change with changes in flow (Figure 7.9).

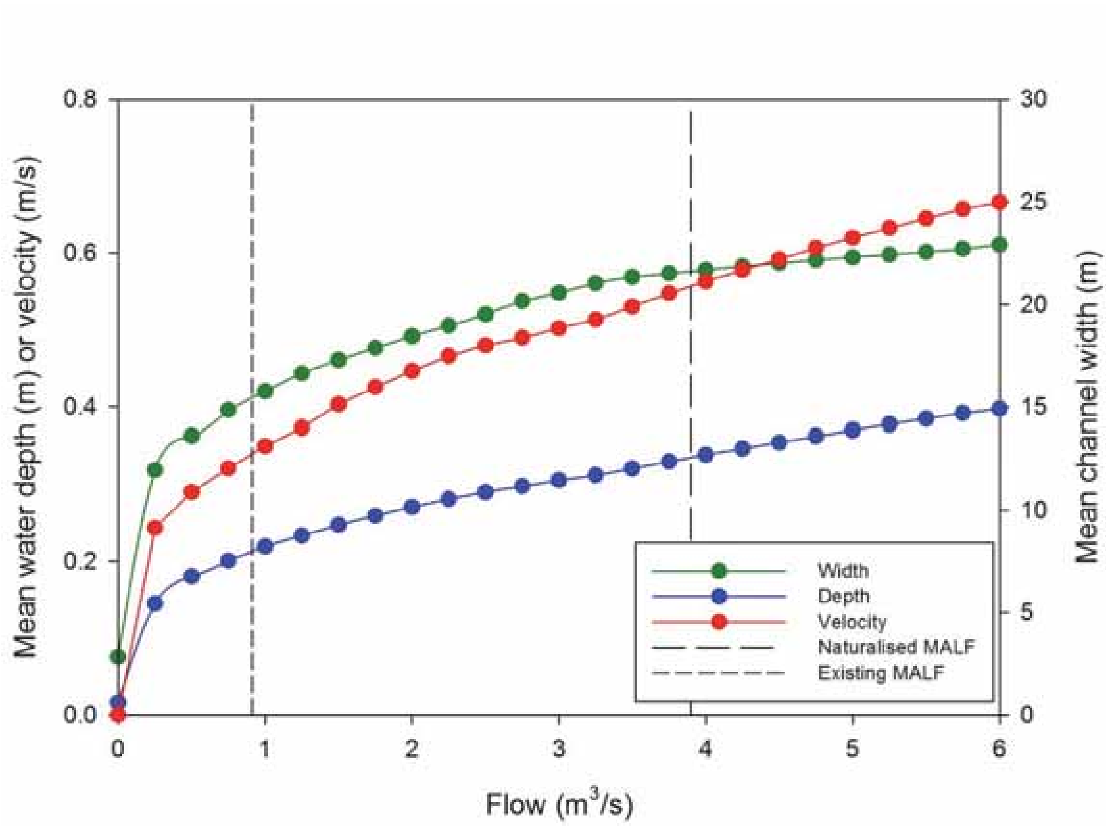


Figure 7.9 **Changes in mean channel width, wetted perimeter, mean water depth and mean water velocity with changes in flow in the survey reach of the lower Manuherikia River.**

7.3.2. Periphyton

Flow was predicted to have little effect on habitat quality for cyanobacteria and the invasive diatom didymo, with a decline in habitat quality for both species predicted below 0.5 m^3/s (Figure 7.10). Habitat quality for native diatoms was predicted to increase across the modelled flow range (Figure 7.10). Habitat quality for short filamentous algae was predicted to increase with increasing flows to 1.5 m^3/s (Figure 7.10). Habitat quality for short filamentous algae was similar between 1.5 and 4.5 m^3/s, but declined at higher flows (Figure 7.10). Habitat quality for long filamentous algae was predicted to be highest in the absence of flow and to decline across the modelled flow range (Figure 7.10). This analysis suggests that there would be a significantly higher risk of proliferation of long filamentous algae when flows are less than 0.161 m^3/s than under the existing flows in the lower Manuherikia, as indicated by the habitat quality for long filamentous algae being 150% of that predicted at the existing 7-d MALF (Table 7.8).

This analysis also suggests that there would be a significantly higher risk of proliferation of long filamentous algae when flows are less than 2.5 m^3/s (range: 1.9–3.4 m^3/s) than under the natural flows expected in the lower Manuherikia, as indicated by the habitat quality for long filamentous algae being 150% of that predicted at the naturalised 7-d MALF (Table 7.8).

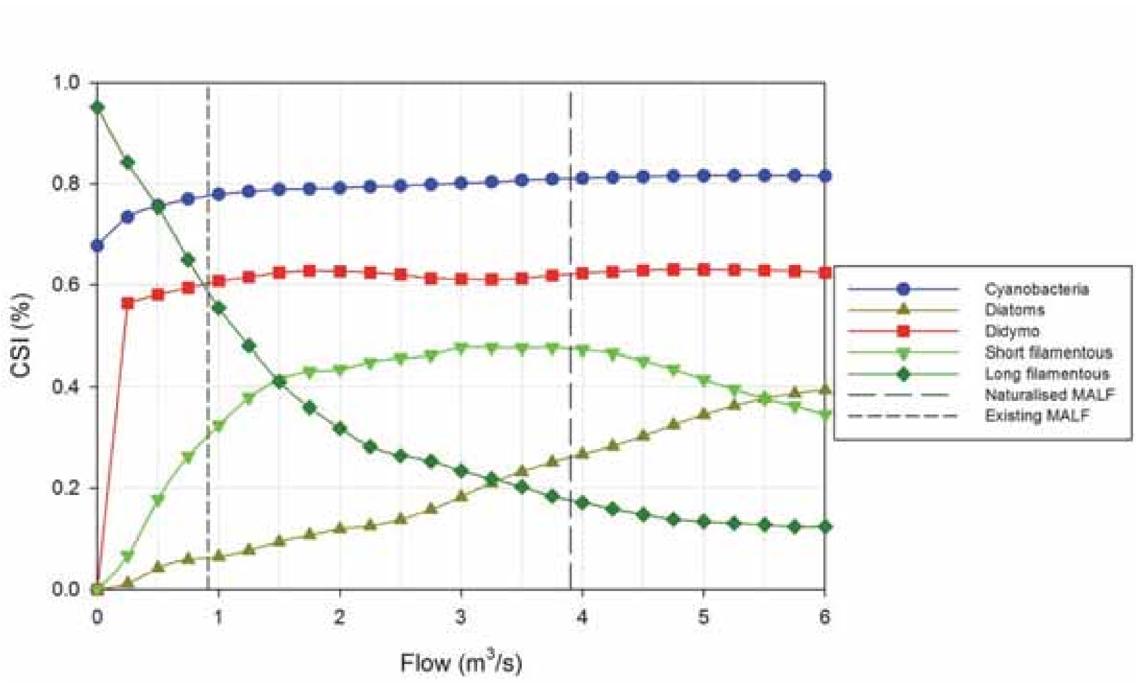


Figure 7.10 **Variation in instream habitat quality (reach-averaged CSI) for periphyton classes relative to flow in the survey reach of the lower Manuherikia River. The dotted lines represent the naturalised (long dash) and existing (short dash) MALF.**

Table 7.8 **Flow requirements for periphyton habitat in the lower Manuherikia River, based on the analysis of Jowett & Wilding (2003). Flows that result in the given increase in habitat relative to existing flows (i.e., with current operation of Falls Dam) and naturalised flows (i.e., flows predicted in the absence of Falls Dam and all abstraction).**

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly increases (m^3/s)	Flow at which % habitat retention occurs (m^3/s)		
			150%	200%	300%
Compared to existing flows					
Cyanobacteria	-	-	-	-	-
Diatoms	>6.00	-	-	-	-
Didymo	-	-	-	-	-
Short filamentous	3.0–3.75	1.50	-	-	-
Long filamentous	0.00	-	0.161	-	-
Compared to naturalised flows					
Cyanobacteria	-	-	-	-	-
Diatoms	>6.00	-	-	-	-
Didymo	-	-	-	-	-
Short filamentous	3.0–3.75	1.50	-	-	-
Long filamentous	0.00	-	2.490 (1.850–3.381)	1.785 (1.335–2.278)	1.085 (0.667–1.465)

7.3.3. Invertebrate habitat

Food producing habitat rose across the modelled flow range. The greatest rate of increase with increasing flow occurred at flows of less than 3 m^3/s (Figure 7.11). Habitat for net-spinning caddis flies was predicted to increase across the modelled range (Figure 7.11). Habitat for the common mayfly *Deleatidium* was predicted to rise with increasing flows, reaching a peak at 4.75 m^3/s, with little change in habitat availability between 4.75 and 6 m^3/s (Figure 7.11). Habitat for the cased caddis *Pycnocentrodes* was predicted to increase with increasing flow to a peak at 4.25 m^3/s, above which habitat was predicted to gradually decline (Figure 7.11).

Flows of between 0.555 m^3/s (*Deleatidium*) and 0.733 m^3/s (food producing habitat) retained 80% of the habitat available in the lower Manuherikia River at the existing MALF (Table 7.9). In comparison, flows of between 1.912 m^3/s (*Deleatidium*, range: 1.606–2.022 m^3/s) and 3.149 m^3/s (*Aoteapsyche,* range: 2.506–3.713 m^3/s) retained 80% of the habitat available in the lower Manuherikia River at the naturalised MALF (Table 7.9).

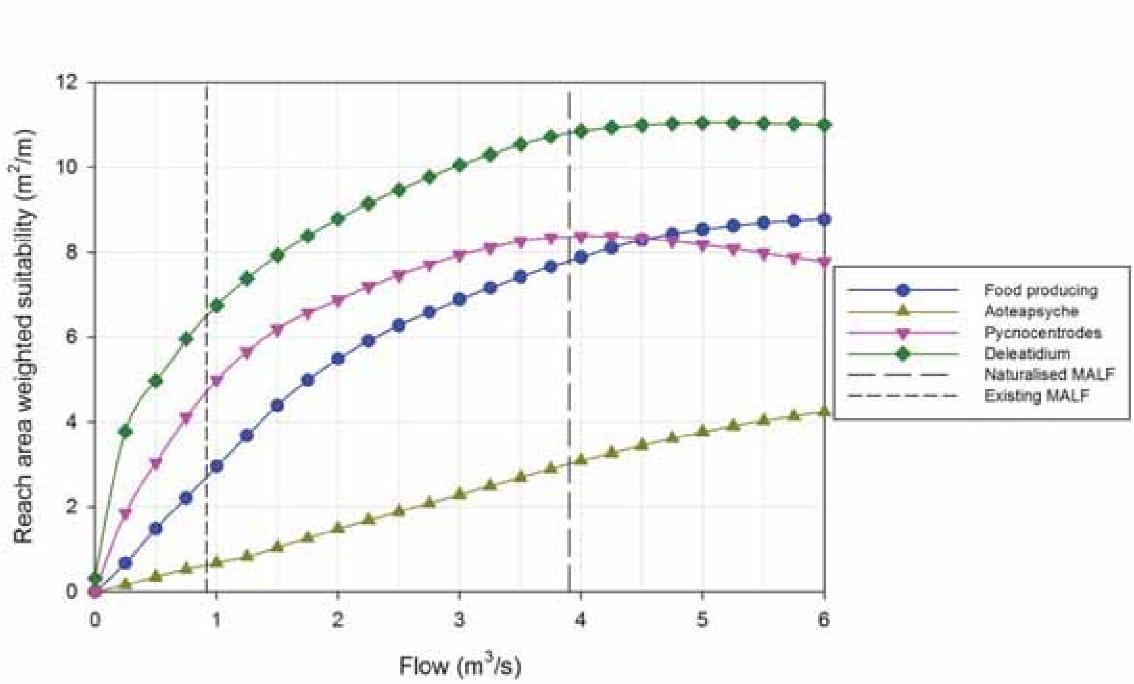


Figure 7.11 **Variation in instream habitat for common macroinvertebrates relative to flow in the survey reach of the lower Manuherikia River. The dotted lines represent the naturalised (long dash) and existing (short dash) MALF .**

Table 7.9 Flow requirements for macroinvertebrate habitat in the lower Manuherikia River, based on the analysis of Jowett & Wilding (2003). Flows required for the various habitat retention values are given relative to existing flows (i.e., with current operation of Falls Dam) and naturalised flows (i.e., flows predicted in the absence of Falls Dam and all abstraction).

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly declines (m^3/s)	Flow at which % habitat retention occurs (m^3/s)			
			60%	70%	80%	90%
Compared to existing flows						
Food producing	>6.0	3.00	0.548	0.641	0.733	0.824
Mayfly nymphs (*Deleatidium*)	4.50–>6.0	2.50	0.272	0.409	0.555	0.719
Net-spinning caddis fly *(Aoteapsyche)*	>6.00	-	0.536	0.624	0.712	0.810
Cased caddis fly (*Pycnocentrodes*)	4.25	1.50	0.452	0.556	0.666	0.782
Compared to naturalised flows						
Food producing	>6.0	3.00	1.622 (1.433–1.779)	1.986 (1.714–2.230)	2.474 (2.064–2.862)	3.119 (2.517–3.647)
Mayfly nymphs (*Deleatidium*)	4.50–>6.0	2.50	0.916 (0.793–0.956)	1.333 (1.141–1.401)	1.912 (1.606–2.022)	2.713 (2.242–2.881)
Net-spinning caddis fly (*Aoteapsyche)*	>6.00	-	2.398 (1.930–2.828)	2.776 (2.216–3.267)	3.149 (2.506–3.713)	3.520 (2.805–4.186)
Cased caddis fly (*Pycnocentrodes*)	4.25	1.50	1.011 (0.949–0.994)	1.339 (1.230–1.312)	1.843 (1.640–1.789)	2.561 (2.270–2.488)

7.3.4. Native fish habitat

Upland bully had the lowest flow preference, with optimum habitat predicted to occur at 0.5 m^3/s (Figure 7.12, Table 7.10). In contrast, habitat for longfin eels (>300 mm) increased rapidly as flows increased to 1 m^3/s, but was relatively stable at flows up to 4 m^3/s, above which habitat gradually declined (Figure 7.12).

A flow of 0.468 m^3/s was predicted to retain 80% of the longfin eel habitat available in the lower Manuherikia River at the existing MALF (Table 7.10). In comparison, 0.592 m^3/s (range: 0.600–0.481 m^3/s) was predicted to retain 80% of the longfin eel habitat available in the lower Manuherikia River at the naturalised MALF (Table 7.10).

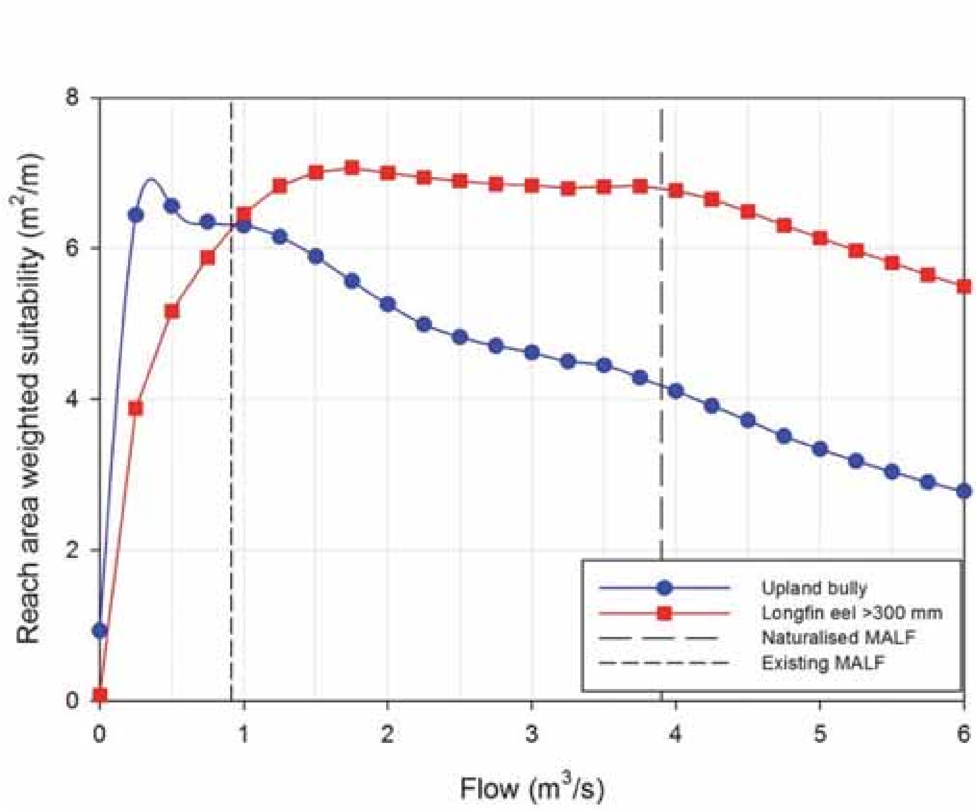


Figure 7.12 **Variation in instream habitat of native fish relative to flow in the survey reach of the lower Manuherikia River. The dotted lines represent the naturalised (long dash) and existing (short dash) MALF.**

Table 7.10 **Flow requirements for native fish habitat in the lower Manuherikia River, based on the analysis of Jowett & Wilding (2003). Flows required for the various habitat retention values are given relative to existing flows (i.e., with current operation of Falls Dam) and naturalised flows (i.e., flows predicted in the absence of Falls Dam and all abstraction).**

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly declines (m^3/s)	Flow at which % habitat retention occurs (m^3/s)			
			60%	70%	80%	90%
Compared to existing flows						
Longfin eel >300 mm	1.75	1.00	0.242	0.348	0.468	0.664
Upland bully	0.50	0.25	0.130	0.159	0.187	0.216
Compared to naturalised flows						
Longfin eel >300 mm	1.75	1.00	0.288 (0.292–0.245)	0.419 (0.423–0.359)	0.592 (0.600–0.481)	0.850 (0.862–0.691)
Upland bully	0.50	0.25	0.072 (0.082–0.055)	0.091 (0.103–0.071)	0.110 (0.124–0.087)	0.128 (0.145–0.103)

7.3.5. Brown trout habitat

Habitat for adult brown trout was predicted to increase with increasing flows up to 4.5 m^3/s, above which it gradually declined (Figure 7.13), and a flow of 0.711 m^3/s was predicted to retain 80% of the adult brown trout habitat available in the lower Manuherikia River compared with the existing MALF (Table 7.11). In comparison, a flow of 2.652 m^3/s (range: 2.357–2.693 m^3/s) was predicted to retain 80% of the adult brown trout habitat available in the lower Manuherikia River compared with the naturalised MALF (Table 7.11). Habitat for yearling brown trout was predicted to increase with increasing flows up to an optimum of 1.5–2 m^3/s, above which it gradually declined (Figure 7.13). Predicted spawning habitat increased rapidly with increasing flows to an optimum at 1–2 m^3/s, above which the amount of suitable habitat was predicted to decline (Figure 7.13).

Flows of 0.419 m^3/s and 0.576 m^3/s retained 80% of the habitat available in the lower Manuherikia River at the existing MALF for brown trout yearlings and spawning, respectively (Table 7.9). In comparison, flows of 0.594 m^3/s (range: 0.674–0.528 m^3/s) and 0.471 m^3/s (range: 0.548–0.417 m^3/s) retained 80% of the habitat available in the lower Manuherikia River at the naturalised MALF for brown trout yearlings and spawning, respectively (Table 7.9).

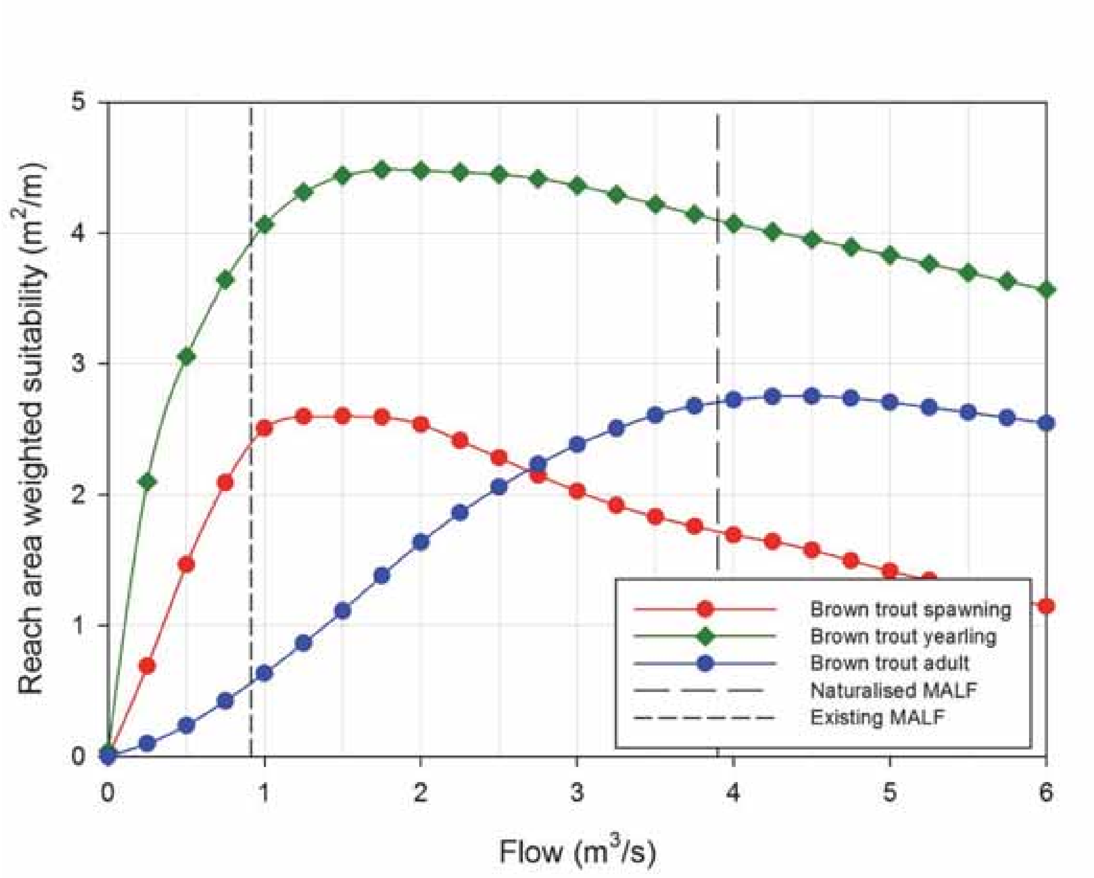


Figure 7.13 **Variation in instream habitat of various life stages of brown trout relative to flow in the lower Manuherikia River. The dotted lines represent the naturalised (long dash) and existing (short dash) MALF.**

Table 7.11 **Flow requirements for brown trout habitat in the lower Manuherikia River, based on the analysis of Jowett & Wilding (2003). Flows required for the various habitat retention values are given relative to existing flows (i.e., with current operation of Falls Dam) and naturalised flows (i.e., flows predicted in the absence of Falls Dam and all abstraction).**

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly declines (m^3/s)	Flow at which % habitat retention occurs (m^3/s)		
			70%	80%	90%
Compared to existing flows					
Brown trout adult	4.50	3.00	0.636	0.711	0.782
Brown trout yearling	1.50–2.00	1.00	0.316	0.419	0.534
Brown trout spawning	1.00–2.00	1.00	0.485	0.576	0.671
Compared to naturalised flows					
Brown trout adult	4.50	3.00	2.292 (2.074–2.324)	2.652 (2.357–2.693)	3.107 (2.686–3.172)
Brown trout yearling	1.50–2.00	1.00	0.451 (0.494–0.415)	0.594 (0.674–0.528)	0.776 (0.903–0.694)
Brown trout spawning	1.00–2.00	1.00	0.415 (0.475–0.369)	0.471 (0.548–0.417)	0.532 (0.627–0.466)

7.4. Instream habitat modelling in Dunstan Creek

Instream habitat modelling was undertaken in Dunstan Creek by Golder Associates (2008), using the hydraulic and instream habitat model RHYHABSIM (Jowett, 1989). Calibration measurements were undertaken on two different occasions in addition to the initial survey (Table 5.1). Golder Associates (2008) presents more details of the methods employed in these surveys and the results of the analyses. The data files for this site were reanalysed by Ian Jowett (Jowett Consulting Ltd) in July 2016 using SEFA software to ensure that the HSC used were up to date and consistent across all modelling reaches presented in this report.

Table 7.12 Survey flows and calibration flows for the survey reach of Dunstan Creek (Golder Associates, 2008) and estimate of naturalised 7-d MALF.

Survey flow	Calibration flow 1	Calibration flow 2	Naturalised 7-d MALF
(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
0.622	0.567	0.490	0.779

7.4.1. Physical characteristics

The hydraulic component of instream habitat modelling made predictions over how water depth, channel width and water velocity will change with changes in flow (Figure 7.14).

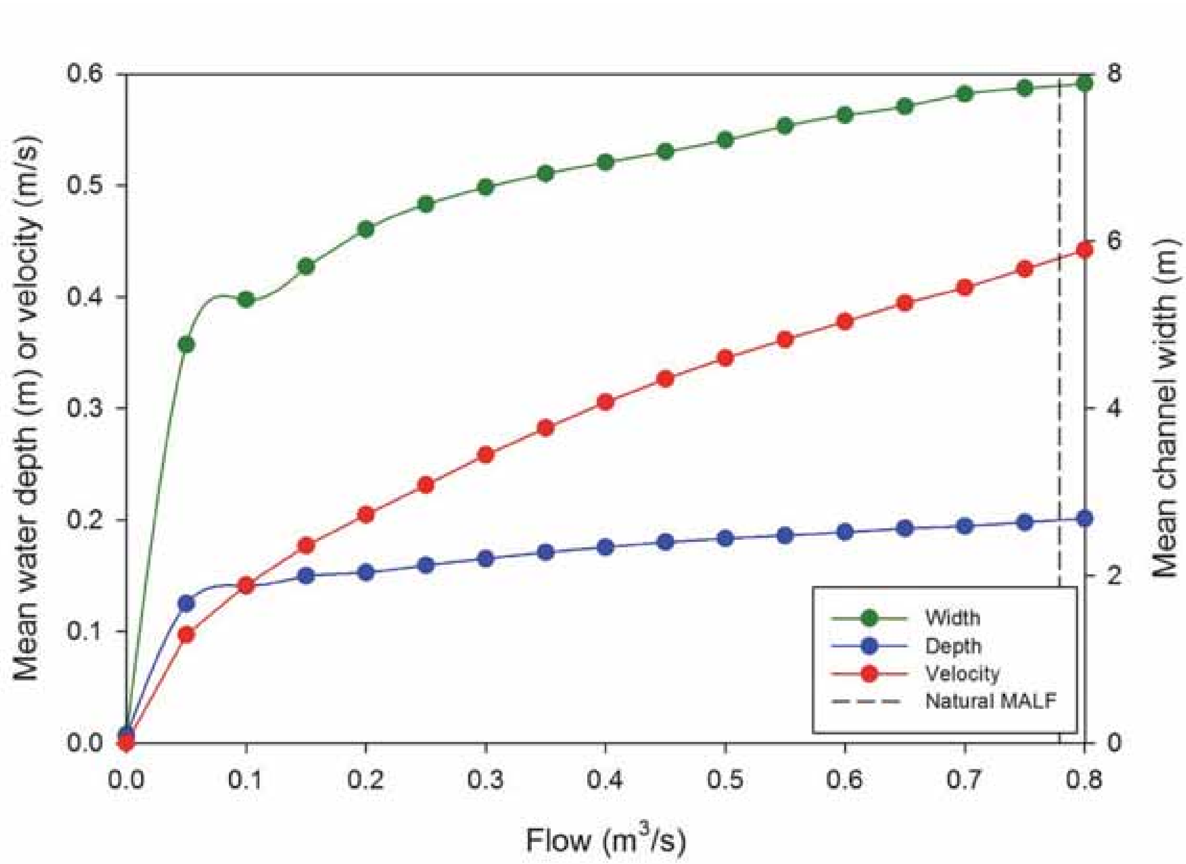


Figure 7.14 Changes in mean channel width, wetted perimeter, mean water depth and mean water velocity with changes in flow in the survey reach in Dunstan Creek.

7.4.2. Periphyton

Flow was predicted to have little effect on habitat quality for cyanobacteria, with a slight decline in habitat quality predicted below 0.05 m^3/s (Figure 7.15). Habitat quality for native diatoms was predicted to increase across the modelled flow range, while flow was predicted to have little effect on habitat quality for didymo until flows dropped below 0.1 m^3/s (Figure 7.15). Habitat quality for short filamentous algae was predicted to increase with increasing flows to 0.650 m^3/s (Figure 7.15).

Habitat quality for long filamentous algae was predicted to be highest at 0.05 m^3/s and to decline across the modelled flow range (Figure 7.15). This analysis suggests that there would be a significantly higher risk of proliferation of long filamentous algae when flows are less than 0.453 m^3/s than under naturalised flows in Dunstan Creek, as indicated by the habitat quality for long filamentous algae being 150% of that predicted at the naturalised 7-d MALF (Table 7.13). This risk is predicted to rise further at flows of less than 0.290 m^3/s, as indicated by the habitat quality for long filamentous algae being 200% of that predicted at the naturalised 7-d MALF (Table 7.13).

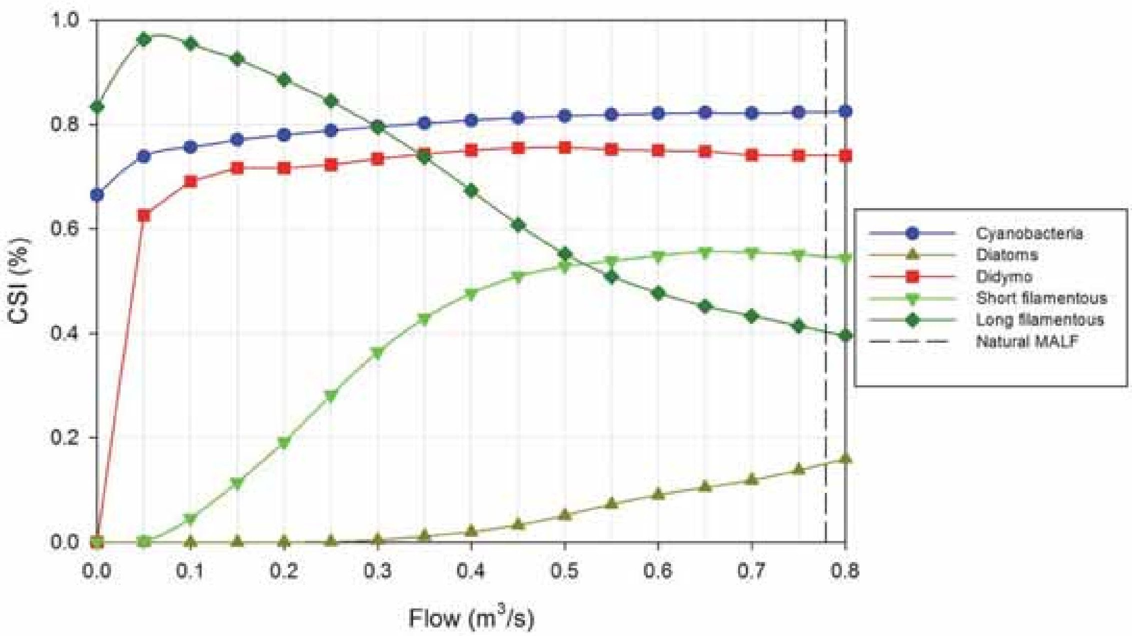


Figure 7.15 **Variation in instream habitat quality (reach-averaged CSI) for periphyton classes relative to flow in the survey reach of Dunstan Creek. The dashed line represents the naturalised 7-d MALF.**

Table 7.13 **Flow requirements for periphyton habitat in Dunstan Creek, based on the analysis of Golder Associates (2008). Flows that result in the given increase in habitat relative to naturalised 7-d MALF.**

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly increases (m^3/s)	Flow at which % habitat retention occurs (m^3/s)		
			150%	200%	300%
Compared to naturalised flows					
Cyanobacteria	0.65	-	-	-	-
Diatoms	>0.70	-	-	-	-
Didymo	0.5	-	-	-	-
Short filamentous	0.65	-	-	-	-
Long filamentous	0.05	0.55	0.453	0.290	-

7.4.3. Invertebrate habitat

Habitat for all invertebrate taxa (including food producing habitat) rose across the modelled flow range (Figure 7.11). Flows of between 0.382 m^3/s (*Pycnocentrodes*) and 0.681 m^3/s (*Aoteapsyche*) retained 80% of the habitat available in Dunstan Creek at the naturalised MALF (Table 7.14).

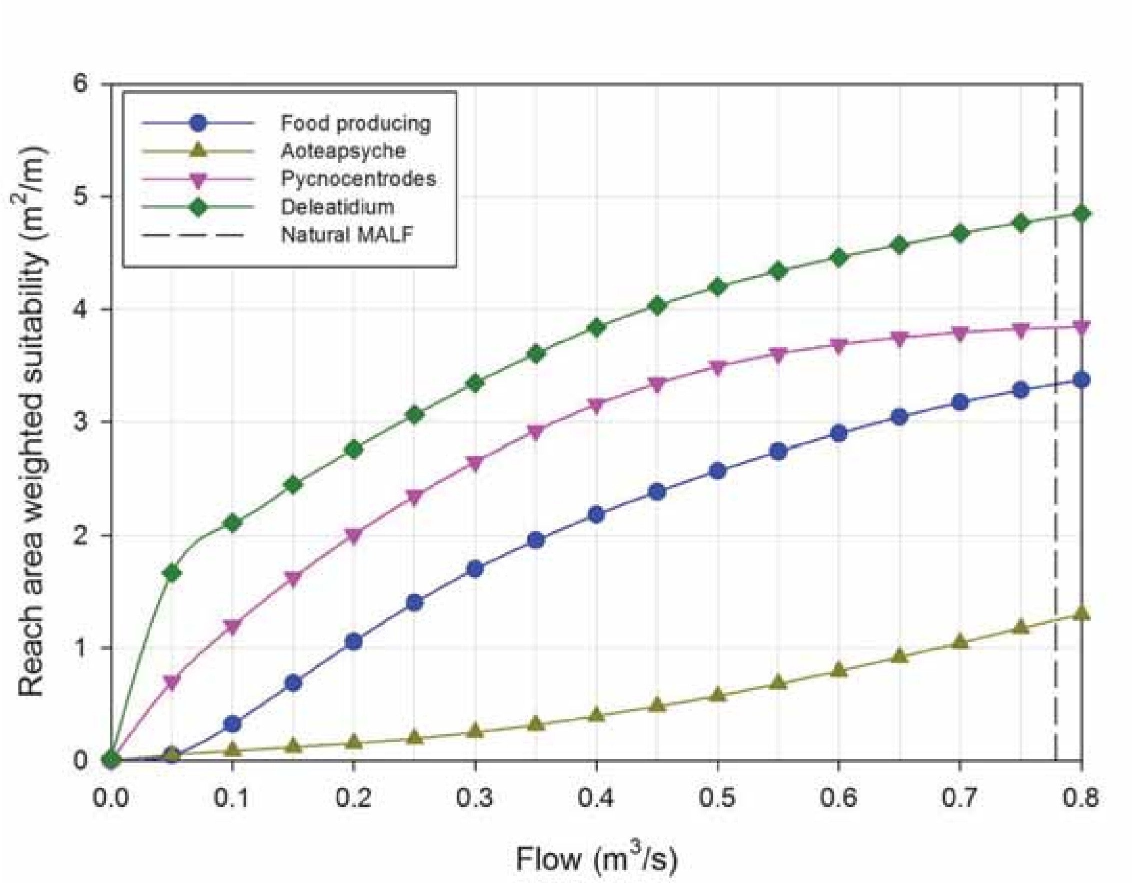


Figure 7.16 **Variation in instream habitat for common macroinvertebrates relative to flow in the survey reach of Dunstan Creek. The dashed line represents the naturalised 7-d MALF.**

Table 7.14 Flow requirements for macroinvertebrate habitat in Dunstan Creek, based on the analysis of Golder Associates (2008). Flows required for the various habitat retention values are given relative to the naturalised MALF.

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly declines (m^3/s)	Flow at which % habitat retention occurs (m^3/s)			
			60%	70%	80%	90%
Compared to naturalised flows						
Food producing	>0.70	-	0.360	0.437	0.528	0.635
Mayfly nymphs (*Deleatidium*)	>0.70	-	0.221	0.305	0.404	0.548
Net-spinning caddis fly (*Aoteapsyche)*	>0.70	-	0.579	0.631	0.681	0.730
Cased caddis fly (*Pycnocentrodes*)	>0.70	-	0.243	0.306	0.382	0.487

7.4.4. Native fish habitat

The optimum flow for upland bully was predicted to occur at 0.35 m^3/s, although there was little change in predicted habitat across the rest of the modelled flow range (Figure 7.17). Habitat for upland bully was predicted to decline steeply as flows dropped below 0.1 m^3/s (Figure 7.17). Habitat for Central Otago roundhead galaxias was predicted to rise rapidly with increasing flow to an optimum at 0.1–0.2 m^3/s, above which habitat gradually declined (Figure 7.17). A flow of 0.034 m^3/s was predicted to maintain 90% of the Central Otago roundhead galaxias habitat available in Dunstan Creek at the naturalised MALF (Table 7.15). Habitat for longfin eels rose with rising flows to an optimum at 0.25–0.40 m^3/s, above which it gradually declined (Figure 7.17). A flow of 0.092 m^3/s was predicted to maintain 80% of the habitat available for large longfin eels in Dunstan Creek at the naturalised MALF (Table 7.15).

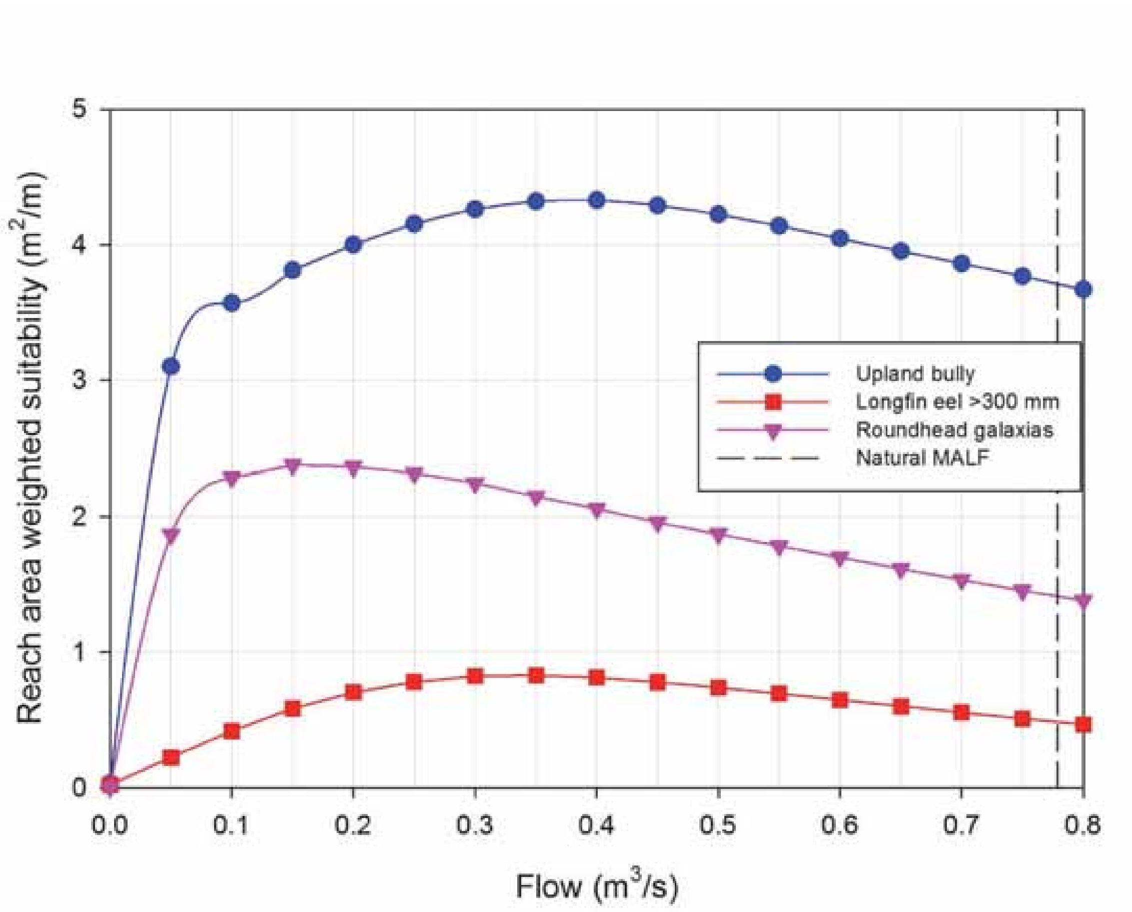


Figure 7.17 **Variation in instream habitat of native fish relative to flow in the survey reach of Dunstan Creek. The dashed line represents the naturalised 7-d MALF.**

Table 7.15 **Flow requirements for native fish habitat in Dunstan Creek, based on the analysis of Golder Associates (2008). Flows required for the various habitat retention values are given relative to the naturalised MALF.**

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly declines (m^3/s)	Flow at which % habitat retention occurs (m^3/s)			
			60%	70%	80%	90%
Compared to naturalised flows						
Central Otago roundhead galaxias	0.10–0.20	0.10	0.023	0.026	0.030	0.034
Longfin eel >300 mm	0.25–0.40	-	0.067	0.080	0.092	0.106
Upland bully	0.35	0.10	0.036	0.042	0.048	0.075

7.4.5. Brown trout habitat

Habitat for adult brown trout increased across the entire modelled flow range, although the rate of increase lessened above 0.5 m^3/s (Figure 7.18), and a flow of 0.398 m^3/s was predicted to retain 80% of the adult brown trout habitat available in Dunstan Creek at the naturalised MALF (Figure 7.18). Habitat for yearling brown trout was predicted to increase rapidly with increasing flows up to 0.2 m^3/s, reaching a maximum at 0.3–0.45 m^3/s, before declining at higher flows (Figure 7.18). Brown trout spawning habitat was expected to rise rapidly to 0.3 m^3/s, reaching a maximum at 0.35–0.50 m^3/s, before gradually declining (Figure 7.18). Flows of 0.087 m^3/s and 0.168 m^3/s retained 80% of the habitat available in Dunstan Creek at the naturalised MALF for brown trout yearlings and spawning, respectively (Table 7.16).

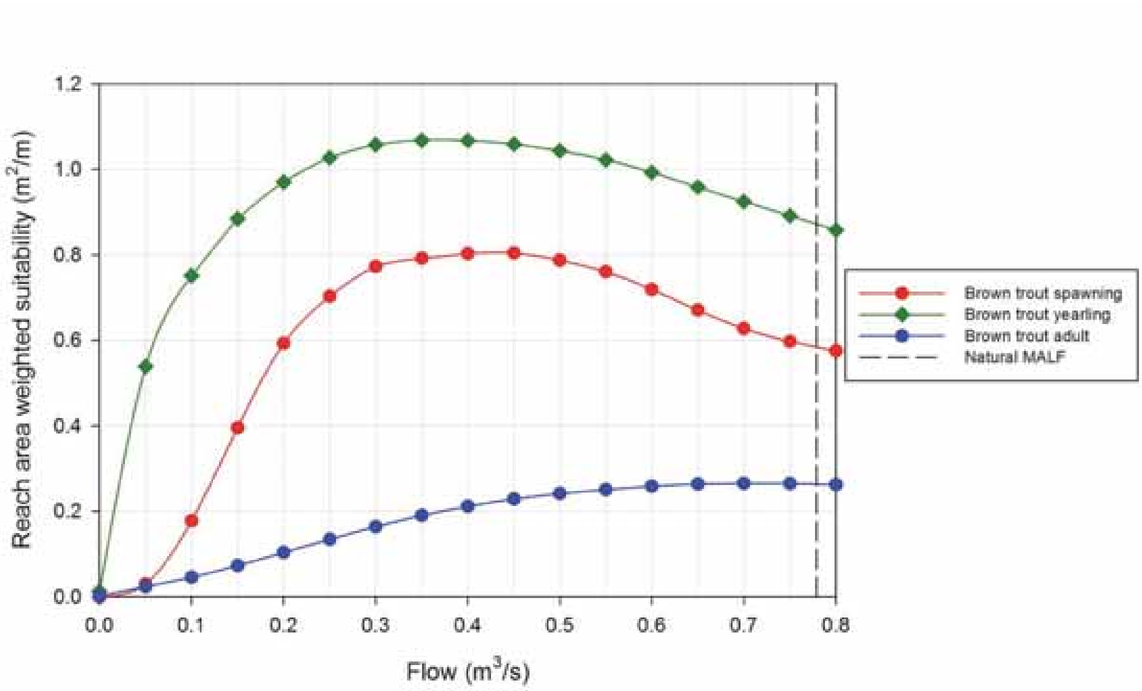


Figure 7.18 **Variation in instream habitat of various life stages of brown trout relative to flow in Dunstan Creek. The dashed line represents the naturalised 7-d MALF.**

Table 7.16 **Flow requirements for brown trout habitat in Dunstan Creek, based on the analysis of Golder Associates (2008). Flows required for the various habitat retention values are given relative to the naturalised MALF.**

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly declines (m^3/s)	Flow at which % habitat retention occurs (m^3/s)		
			70%	80%	90%
Compared to naturalised flows					
Brown trout adult	0.35	0.25	0.339	0.398	0.483
Brown trout yearling	0.30–0.45	0.2	0.067	0.087	0.113
Brown trout spawning	0.35–0.50	0.25	0.153	0.168	0.183

7.4.6. Rainbow trout habitat

Little or no habitat for adult rainbow trout was predicted to occur at flows below 0.5 m^3/s (Figure 7.19). A flow of 0.753 m^3/s was predicted to retain 80% of the rainbow trout feeding habitat available in Dunstan Creek at the existing MALF (Table 7.17). However, the analysis of adult rainbow trout flow requirements in Dunstan Creek should be interpreted with caution given the very low amount of habitat predicted within the modelled flow range.

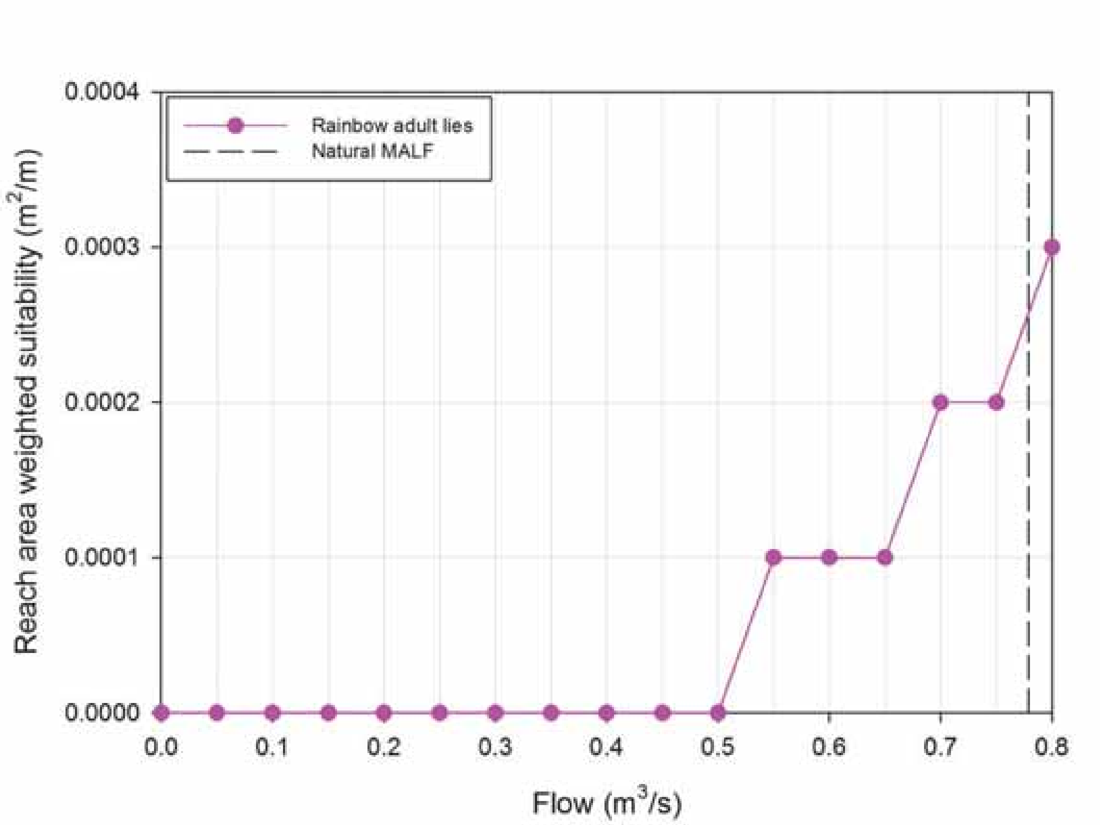


Figure 7.19 **Variation in instream habitat of adult rainbow trout relative to flow in Dunstan Creek. The dashed line represents the naturalised 7-d MALF.**

Table 7.17 **Flow requirements for rainbow trout habitat in Dunstan Creek, based on the analysis of Golder Associates (2008). Flows required for the various habitat retention values are given relative to the naturalised MALF.**

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly declines (m^3/s)	Flow at which % habitat retention occurs (m^3/s)		
			70%	80%	90%
Compared to naturalised flows					
Rainbow trout adult lies	>0.70	-	0.690	0.753	0.766

7.5. Consideration of the current minimum flow for the Manuherikia River at Ophir

The current minimum flow for the Manuherikia River at Ophir is 0.820 m^3/s. The ratio of the naturalised 7-d MALF at Ophir to that for the upper Manuherikia modelling reach was used to estimate the flow in the modelling reach, equivalent to 0.820 m^3/s at Ophir. The ratio of the naturalised 7-d MALF at Ophir to that for the upper Manuherikia modelling reach was 1.80 (range: 1.5–2.1). Based on these ratios, the flow in the modelling reach equivalent to 0.820 m^3/s at Ophir was estimated to be 0.456 m^3/s (range: 0.561–0.384 m^3/s). In the analyses presented in this section, these values are used to estimate the level of habitat retention offered by the current minimum flow at Ophir relative to the natural flows at this site.

The results of comparisons with habitat available at naturalised or existing MALFs are very similar (Table 7.18). The current minimum flow at Ophir is predicted to significantly increase the risk of the proliferation of long filamentous algae, but reduce habitat quality for short filamentous algae, diatoms and didymo, and have little effect on habitat quality for benthic cyanobacteria (Table 7.18). Habitat for invertebrates is predicted to be significantly reduced compared to naturalised or existing flows (Table 7.18). The effect on habitat for upland bully is predicted to be negligible, while habitat for large longfin eels is predicted to be significantly reduced (Table 7.18). Habitats for adult and juvenile brown trout, as well as spawning habitat, are predicted to be significantly reduced at flows equating to the current minimum flow at Ophir compared to naturalised flows (Table 7.18).

At present, water is released from Falls Dam, travels downstream in the Manuherikia River and is taken by irrigators downstream. This means that, since 1998, it has been extremely rare that flows at Ophir have dropped to below 0.820 m^3/s (0.3% of the period 28 February 1998 to 17 November 2015). In the future, if water is distributed from near Falls Dam by water race or pipes, these flows will not augment flows in the upper Manuherikia River. This will result in the river approaching or dropping to the minimum flow more frequently. The results of the instream habitat analyses presented here suggest that this will result in significant reductions in habitat for fish and invertebrates, alongside a markedly higher risk of the proliferation of long filamentous algae compared with the existing or naturalised flows in this section of the Manuherikia River.

Table 7.18 **Habitat retention for various species/life stages of species present in the upper Manuherikia River at the flow that corresponds to the minimum flow expressed as a percentage of habitat available at the naturalised and existing 7-d MALF. Values in brackets represent the range of habitat retention estimates resulting from the uncertainties associated with 7-d MALF estimates.**

Species/life stage	% habitat retention compared with naturalised 7-d MALF	% habitat retention compared with existing 7-d MALF
Cyanobacteria	94% (95–92%)	94% (92–96%)
Diatoms	49% (56–41%)	51% (38–66%)
Didymo	82% (69–90%)	81% (68–92%)
Short filamentous algae	47% (54–40%)	48% (38–59%)
Long filamentous algae	181% (168–193%)	179% (151–208%)
Food producing	26% (33–22%)	28% (21–36%)
Deleatidium (mayfly)	56% (62–51%)	57% (49–65%)
Pycnocentrodes (stony-cased caddis)	46% (54–39%)	45% (35–56%)
Aoteapsyche (net-spinning caddis)	44% (51–37%)	47% (37–57%)
Longfin eel	70% (76–64%)	70% (64–77%)
Upland bully	100% (104–93%)	98% (88–108%)
Brown trout adult	28% (33–25%)	30% (23–39%)
Brown trout yearling	71% (77–64%)	71% (63–79%)
Brown trout spawning	36% (45–30%)	37% (30–46%)

7.6. Summary of instream habitat assessments

From an aquatic ecosystem perspective, appropriate ecosystem management objectives for both the upper Manuherikia and Dunstan Creek modelling reaches are to maintain the regionally significant brown trout fishery and macroinvertebrate populations, and limit the risk of proliferation of long filamentous algae. Instream habitat modelling suggests that 1.4 m^3/s in the upper Manuherikia modelling reach and 0.400 m^3/s in Dunstan Creek would achieve these objectives (Table 7.19). To transfer the results for the upper Manuherikia modelling reach to the Ophir flow site, the aquatic ecosystem flow recommendation in the upper Manuherikia was adjusted based on the ratio of the MALFs at these two sites, resulting in a flow recommendation of 2.5 m^3/s (estimate range: 2.0–3.0) at Ophir.

The current minimum flow at this site is 0.820 m^3/s. Instream habitat modelling in the upper Manuherikia River suggests that 0.820 m^3/s at Ophir provides significantly reduced habitat for brown trout, macroinvertebrates and longfin eel, and significantly increases the risk of proliferation of long filamentous algae in the upper Manuherikia River compared with natural or existing flows. However, since 1998, it has been extremely rare that flows at Ophir have dropped to below 0.820 m^3/s (0.3% of the period 28 February 1998 to 17 November 2015).

The results of instream habitat modelling for the lower Manuherikia vary markedly depending on the baseline flow used for calculation of habitat retention. Analysis using the existing flows suggests that 0.750 m^3/s would maintain an appropriate level of habitat retention for the regionally significant brown trout fishery it supports, as well as maintaining sufficient macroinvertebrate habitat and presenting a low risk of proliferation of long filamentous algae (Table 7.19). In comparison, analyses using the naturalised flows suggest that 2.5 m^3/s would provide an appropriate level of habitat retention for trout fishery, maintain sufficient macroinvertebrate habitat and present a low risk of proliferation of long filamentous algae (Table 7.19).

The differences between the flow recommendations based on the two baselines highlight the difficulty associated with using the habitat retention approach in a river with such a modified hydrology.

One alternative approach would be to choose a flow that would improve habitat relative to the existing baseline, but may be lower than that recommended based on the naturalised baseline. For example, in the case of the lower Manuherikia, a flow of 2 m^3/s represents a very large increase in the available habitat for adult brown trout (190% increase) compared with existing low flows and near optimal habitat for juvenile trout. For adult brown trout, 1.2 m^3/s was predicted to provide a 50% increase in habitat compared with existing low flows and 1.5 m^3/s was predicted to provide double the habitat compared with existing low flows.

Table 7.19 Flow requirements to maintain the values of the upper and lower Manuherikia and Dunstan Creek, based on the instream habitat assessments of Jowett & Wilding (2003), Golder Associates (2008) and Duncan & Bind (2016).

Value	Season	Significance	Suggested level of habitat retention	Flow to maintain suggested level of habitat retention (m^3/s) Naturalised	Existing	Flow below which habitat rapidly declines (m^3/s)
Upper Manuherikia						
Brown trout	All year	Regionally significant†	80%	1.410	1.214–1.536	1.000
Food producing	All year	Life-supporting capacity	80%	1.311	1.163–1.404	2.000
Long filamentous algae	Summer	Nuisance	<150%	0.782	0.577–0.912	-
Lower Manuherikia						
Brown trout	All year	Regionally significant†	80%	2.652 (2.357–2.693)	0.782	3.250
Longfin eel	All year	At risk, declining	80%	0.592 (0.600–0.481)	0.468	1.000
Food producing	All year	Life-supporting capacity	80%	2.474 (2.064–2.862)	0.733	-
Long filamentous algae	Summer	Nuisance	<150%	2.491 (1.850–3.381)	0.161	-
Dunstan Creek						
CO roundhead galaxias	All year	Nationally endangered	90%	0.034	-	0.500
Brown trout	All year	Regionally significant†	80%	0.398	-	0.250
Rainbow trout	All year	Regionally significant†	80%	0.753	-	-
Food producing	All year	Life-supporting capacity	80%	0.528	-	-
Deleatidium mayfly	All year	Life-supporting capacity	80%	0.404		0.050
Long filamentous algae	Summer	Nuisance	<150%	0.453	-	-

† Based on the assessment in Otago Fish & Game Council (2015).
* Based on Robertson et al. (2012).
‡ Based on Goodman et al. (2014).
¥ The suggested level of habitat retention for black-fronted terns takes into account their threat classification, the size of the population using these reaches of river and use of these reaches by black-fronted terns for foraging, but not breeding.

Habitat for trout spawning was not included in this summary. The spawning season for brown trout (May–September) occurs during winter months when water demand is low and flows are unlikely to be affected by abstraction. Similarly, rainbow trout spawning occurs in spring (September–November). In addition, it is likely that flows sufficient to protect habitat availability for adult trout will also be sufficient to protect spawning and juvenile rearing habitat, as these have lower flow requirements than adult trout.

8. Conclusions: Flow requirements for aquatic ecosystems in the Manuherikia catchment

Under the Water Plan, 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 provide information on the Manuherikia 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 213 existing surface water takes in the Manuherikia catchment, with a total allocation of approximately 32 m^3/s, although the actual usage is likely to be considerably lower than this, especially at low flows. The high level of allocation, long history of water use and flow alteration due to the numerous storage reservoirs and transport of water via water races makes understanding the natural hydrology of the Manuherikia catchment a complex task.

Naturalised low-flow statistics were estimated at the key locations within the Upper Manuherikia (Table 8.1). Recorded flows in Dunstan Creek at Gorge and in the upper Manuherikia River downstream of Fork were used as the key reference flow sites for estimating the naturalised low-flow statistics for other locations within the catchment.

Table 8.1 Summary of 7-d MALFs (low-flow season) at the key locations in this study.

Location	Flow data type	7-d MALF (m^3/s)
Manuherikia River downstream of Fork	Naturalised (gaps filled)	1.009
Manuherikia River at Falls Dam (downstream)	Naturalised	1.532
	Existing	1.737
Manuherikia River at Blackstone Bridge	Naturalised	1.779
	Estimated “existing”	1.513–1.947
Manuherikia River at Ophir	Modelled natural	3.200 (±600)
	Existing	2.197
Manuherikia River at Campground	Modelled natural	3.900 (±800)
	Existing	0.915
Dunstan Creek at Gorge	Natural (gaps filled)	0.692
Dunstan Creek at Loop Road Bridge	Naturalised	0.779
Dunstan Creek at Beattie Road	Naturalised	0.934
	Existing	0.350

The Manuherikia River supports a regionally significant brown trout fishery and has been in the top five most popular river fisheries in the Otago region in all national angler surveys conducted to date (Unwin, 2016). Dunstan Creek is categorised as backcountry fishery, which contains both brown and rainbow trout. Nine native fish are present in the Manuherikia catchment, including three threatened species of non-migratory galaxias: Central Otago roundhead galaxias and alpine galaxias (Manuherikia) are classified as "nationally endangered", while the Clutha flathead galaxias is classified as "nationally critical", the highest threat classification available (Goodman et al., 2014). Koaro and longfin eels are also present in the catchment and are listed as "at risk, declining" in the most recent threat classification (Goodman et al., 2014). In addition, koura (freshwater crayfish) are present and have a threat classification of "at risk, declining" (Granger et al., 2014).

The fish with the highest conservation values, the alpine galaxias and the Clutha flathead galaxias, are not found within the reach of the main stem affected by flow alteration and were not considered as part of this instream habitat assessment. Although Central Otago roundhead galaxias are not found within the main stem of the Manuherikia River, they are present within the main stem of the Dunstan Creek and so are considered in instream habitat analyses for Dunstan Creek.

Appropriate aquatic ecosystem management objectives for both the upper Manuherikia and Dunstan Creek modelling reaches are to maintain the regionally significant brown trout fishery, protect macroinvertebrate populations and limit the risk of proliferation of long filamentous algae. Instream habitat modelling suggests that 1.4 m^3/s in the upper Manuherikia would achieve these objectives (Table 7.19). The aquatic ecosystem flow recommendation for the upper Manuherikia equates to 2–3 m^3/s at Ophir. The current minimum flow at this site is 0.820 m^3/s. Instream habitat modelling in Dunstan Creek suggests that a flow of 0.4 m^3/s at the Loop Road modelling reach would achieve these objectives (Table 7.19). This equates to a flow of 0.480 m^3/s at Beattie Road (based on a ratio between naturalised MALFs for these two sites of 1.2).

Instream habitat modelling in the upper Manuherikia River suggests that the current minimum flow would significantly reduce available habitat for brown trout, macroinvertebrates and longfin eels, and significantly increase the risk of proliferation of long filamentous algae in the upper Manuherikia River compared with natural flows.

The results of instream habitat modelling for the lower Manuherikia vary markedly depending on the baseline flow used for calculation of habitat retention. For adult brown trout, 0.711 m^3/s would retain 80% of the habitat at the existing 7-d MALF. In contrast, analyses based on naturalised flows suggest that 2.7 m^3/s is required to achieve 80% habitat retention for adult brown trout.

The differences between the flow recommendations based on the two baselines highlight the difficulty associated with using the habitat retention approach in a river with such a modified hydrology. An alternative approach would be to choose a flow that would improve habitat relative to the existing baseline, but may be lower than that recommended based on the naturalised baseline.

Table 8.2 Summary of flows required to maintain instream values in the Manuherikia River at the Ophir and Campground flow sites and Dunstan Creek at Beattie Road, based on naturalised and existing flows.

		Units	Manuherikia at Ophir	Manuherikia at Campground	Dunstan Creek at Beattie Road
Naturalised 7-d MALF		m^3/s	3.200	3.900	0.934
Existing 7-d MALF		m^3/s	2.197	0.915	0.350
Aquatic ecosystem flow recommendation based on:	Naturalised flow baseline	m^3/s	2.500	2.500	0.750
	Existing flow baseline	m^3/s	1.750	0.750	-
Flow providing twice brown trout adult habitat available at existing MALF		m^3/s	-	1.513	-
Flow providing three times brown trout adult habitat available at existing MALF		m^3/s	-	2.059	-

9. Glossary

Catchment

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

Existing flows

The flows observed in a river under current water usage and with current water storage and transport.

Habitat suitability curves (HSC)

Representations of the suitability of different water depths, velocities and substrate types for a particular species or life stage of a species. Values vary from 0 (not suitable) to ideal (1). HSC are used in instream habitat modelling to predict the amount of suitable habitat for a species/life stage.

Instream habitat modelling

An instream habitat model 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.

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.

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

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 (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. NIWA modelled estimates of the natural MALF for the Manuherikia River at Ophir and Campground sites are based on the full hydrological year.

Taking

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

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Appendix A

Hydrological records

Dunstan Creek at Gorge

The Dunstan Creek at Gorge (hereafter, Gorge) flow monitoring site was established in 1973, with data collected at this point until 1989. Due to instability of the river bed at the original monitoring site, the recorder was subsequently moved downstream by 600 m and flow data was collected from this new site between 1989 and 1994, when the recorder was disestablished. The recorder was installed again in March 2007 and removed in 2010.

Downstream of Fork

The flow monitoring site in the upper Manuherikia River downstream of Fork was initially installed in May 1975 and operated until December 1993, with both the site and the data managed by NIWA. The site was later re-established and again managed by NIWA with funding from Pioneer Energy from 1998 to 2004. In September 2008 the site was re-established by the Otago Regional Council (ORC) and was operated for 2 years, ceasing in September 2010. The site has been recently reopened (June 2016) by the ORC.

Dunstan Creek at Beattie Road

The flow recorder in Dunstan Creek at Beattie Road has continuously monitored surface water flows since August 1996.

Lindis at Lindis Peak

This site in the neighbouring Lindis catchment was installed in September 1976 and has operated continuously since then. The recording equipment has always been the most accurate available at the time. Originally, the Ministry of Works operated the site, but it is now operated by NIWA Alexandra for Contact Energy Ltd. and the ORC. There are some gaps, mainly in the early part of the records, but the accuracy of the record at this site should be good (Aqualinc, 2012a).

Manuherikia River at Falls Dam

The Falls Dam flow recorder was located approximately 200 m downstream of the foot of the dam. It captured all the flows that passed through the turbines for hydro-generation and any water that may have naturally spilled over the crest of the spillway. The recorder was installed in February 1999 and ran for a period of 15 years, ceasing in June 2014. Synthetic flow information can be calculated to fill the data period from 2014 until the present, using the formula (provided by Pioneer Energy) based on lake level stage height and flows that passed through the turbines. However, there are issues surrounding the accuracy of these flow estimates. Given that the main interest of this study is the low flow hydrology of the Manuherikia when such spilling flows are unlikely to be occurring, in addition to concerns regarding the accuracy of the spill flow estimates, flow estimates based on the spill formula were not used as part of this analysis.

Hydrological analysis

Data preparation – gap filling

There were significant gaps in the flow records for the two natural reference flow sites (Dunstan Creek at Gorge and downstream of Fork). However, it is possible fill these gaps using relationships with nearby flow sites. The following section describes the three-step process used to fill these gaps in the flow records for the two reference flow sites.

Step I

As the flow recorder site at Gorge was moved in 1989, the recorded natural flows prior to 1989 need to be scaled to its shifted location (600 m downstream of the old location). The scaling factor used for this is 1.004, derived from the consideration of the extra annual rainfall over the extra catchment area between the two locations (Figure A.1). The scaled-up flow data for the old location can then be directly compared to the flows at the location of the flow recorder from 1989 onwards.

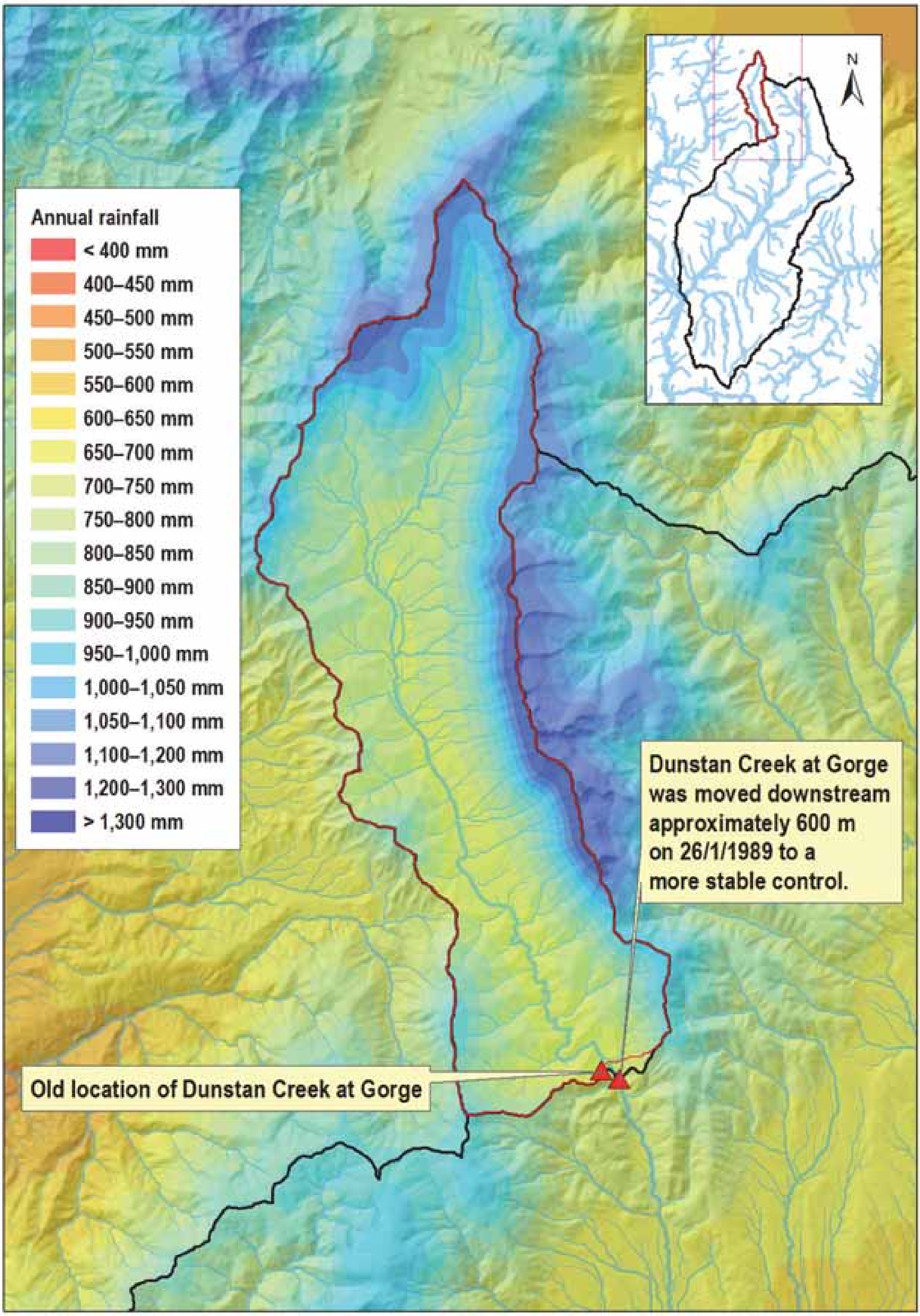

Figure A.1 **The old and shifted flow site locations at Gorge.**

Step II

Mean daily flow data (day starts at midnight) from Dunstan Creek at Gorge and the upper Manuherikia River downstream of Fork were correlated with one another, and the correlations used to fill data gaps. Due to a slightly higher R^2, an exponential relationship was used between the two sites (Figure A.2). After this step there were still gaps in the data for both sites where there were concurrent missing records.

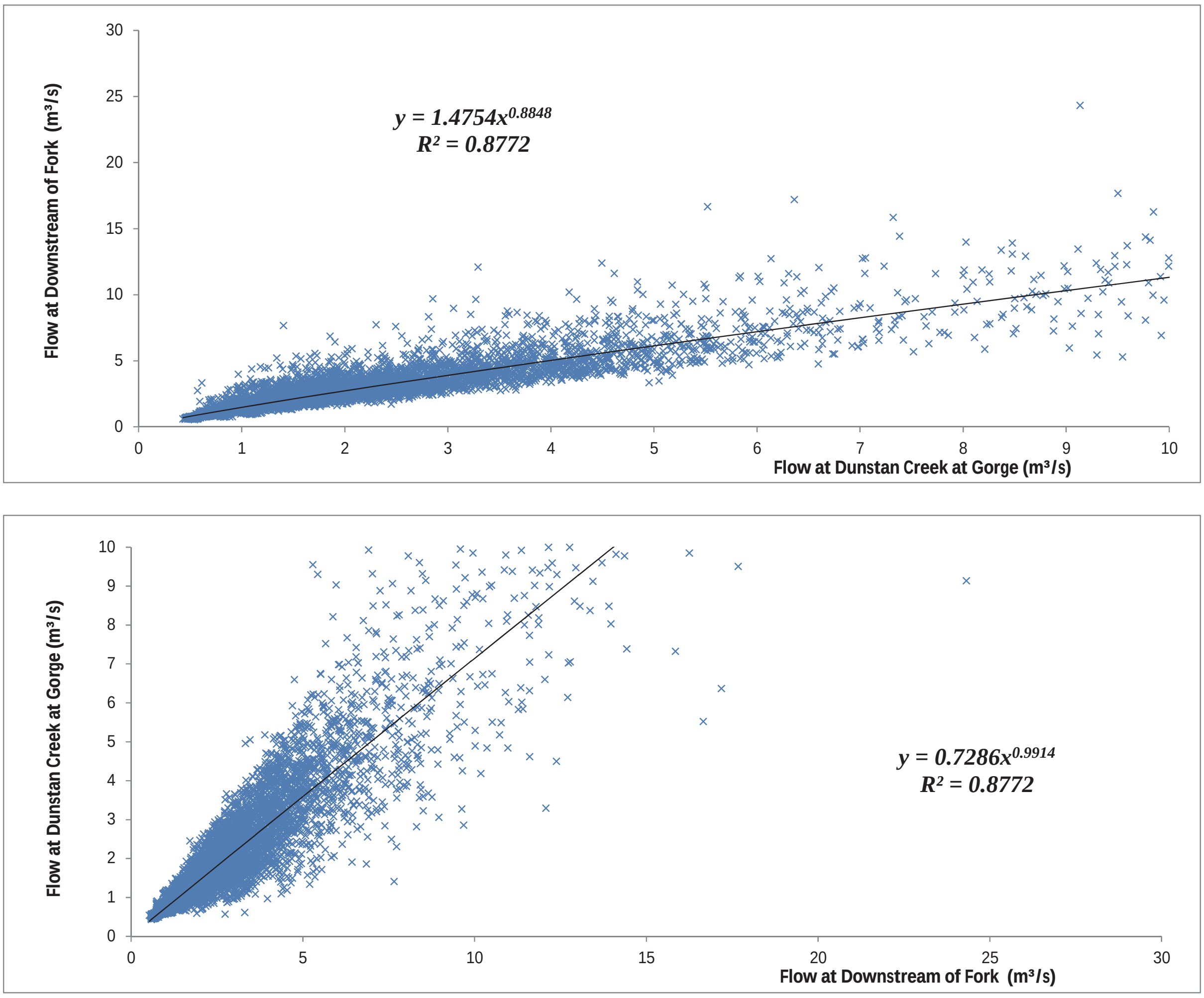

Figure A.2 **The exponential correlations between the actual records from the reference sites at Dunstan Creek at Gorge and Manuherikia River downstream of Fork.**

Step III

Remaining gaps in the Gorge data set were filled using a correlation between the daily flow records at Gorge and records for Lindis at Lindis Peak, using data from the irrigation season (October–April, inclusive) and remaining months. Again, exponential relationships were used as they had higher R^2 values than fitted linear relationships. Figure A.3 shows the relationship between the records from Gorge and Lindis at Lindis Peak.

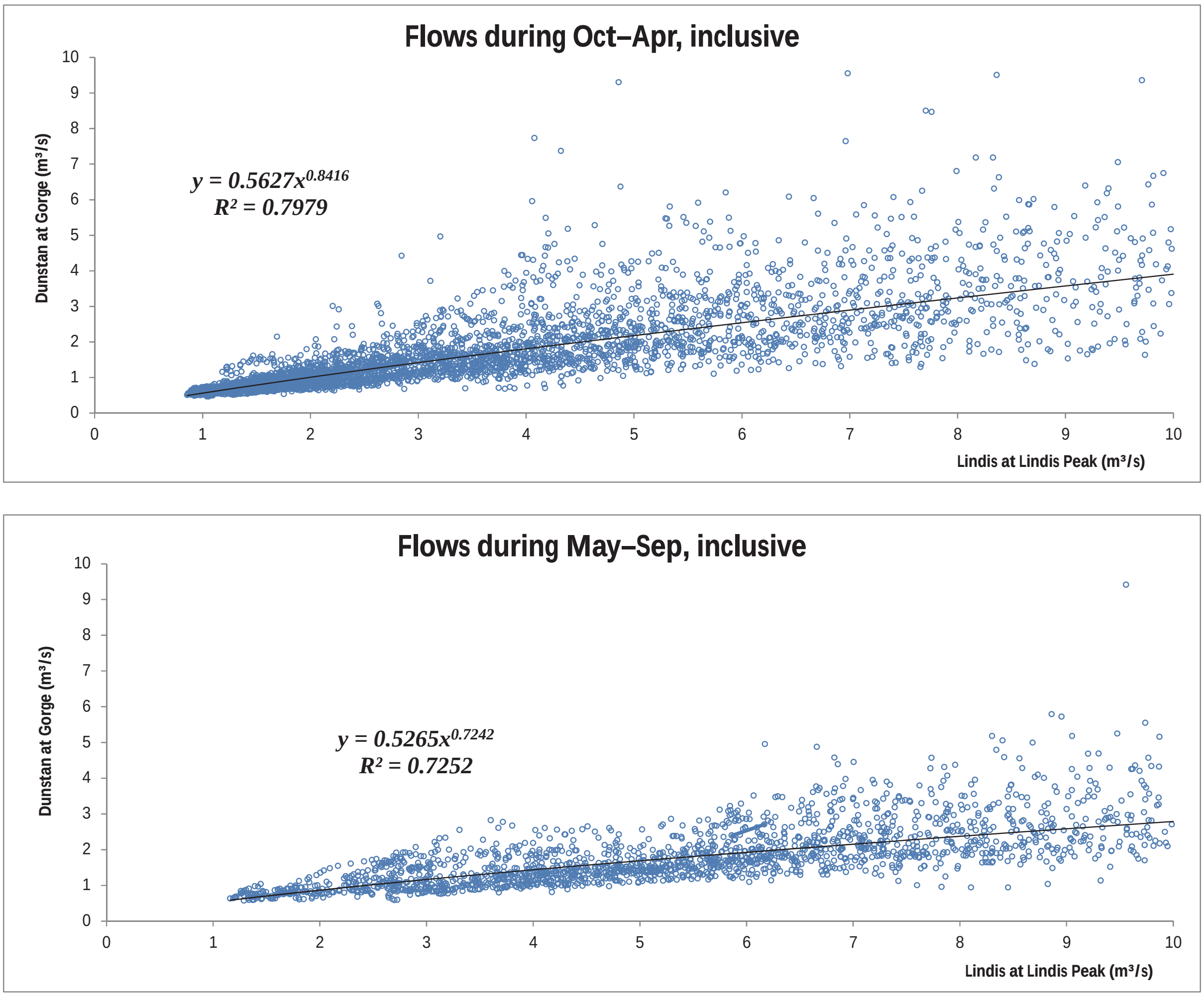

Figure A.3 The exponential correlations between the records from Dunstan Creek at Gorge and Lindis at Lindis Peak.

These three steps are illustrated in the flow chart shown in Figure A.4. Following this process, the two final naturalised flow datasets were ready for calculating the seven-day mean low flow (7-d MALF) for the irrigation season (October–April, inclusive). Figure 4.2 shows the gap-filled hydrographs produced by these analyses.

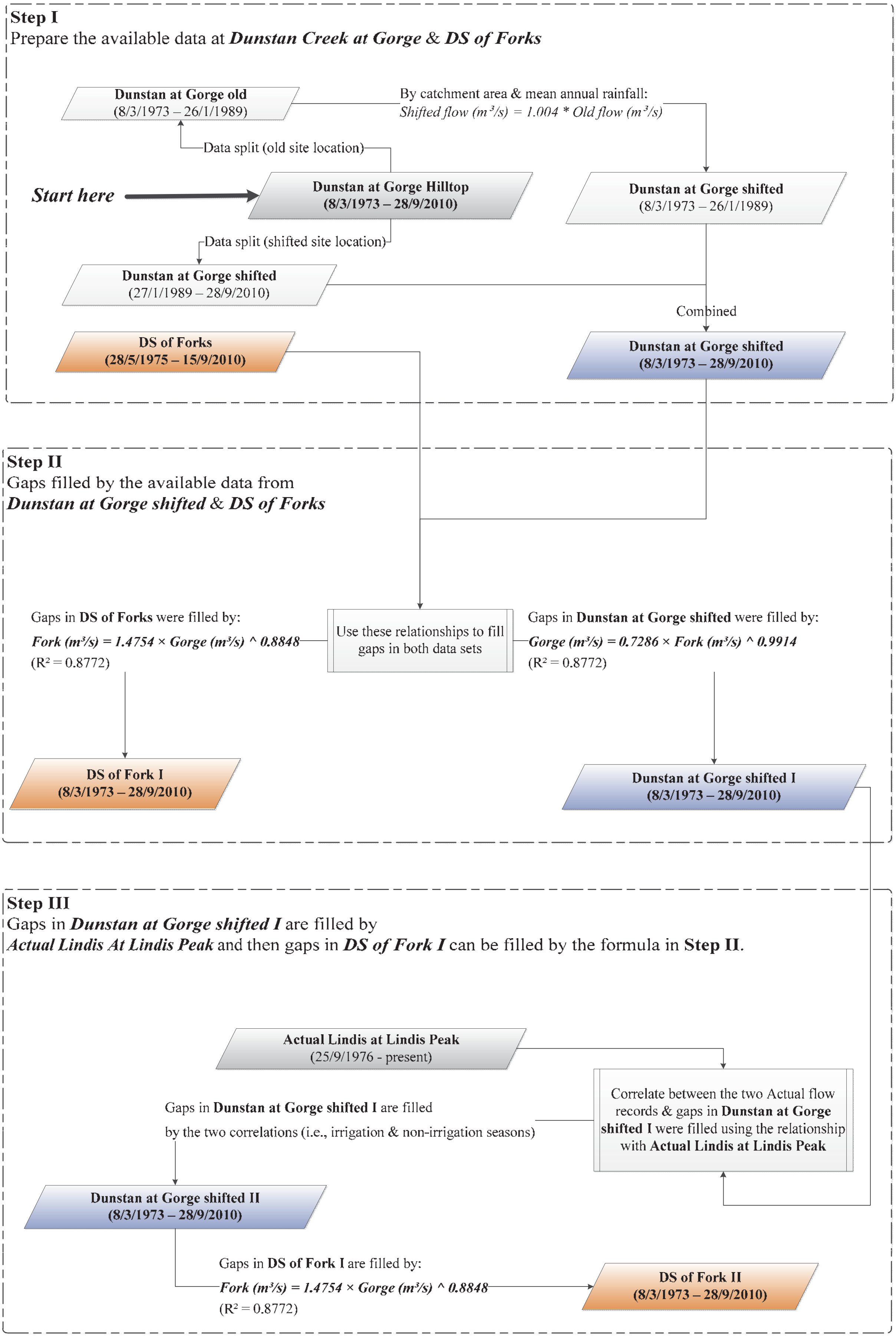

Figure A.4 **Diagram of gap-filling for the two reference flow sites.**

Estimating the naturalised 7-d MALF for sites with modified hydrology

The naturalised 7-d MALF was estimated using an improved combined ratio method for the following sites:

- Manuherikia River at Falls Dam (downstream)
- Manuherikia River upstream of Blackstone Bridge (upstream of water take 2001.702)
- Dunstan Creek at Loop Road Bridge.

Two assumptions are made when the combined ratio method is used:

- Catchments in comparison are reasonably climatically similar, i.e., the difference between the annual mean aerial precipitation (MAP) and actual evapotranspiration (AET) is similar. The reasoning behind this is that surface runoff at times of low flow is usually driven by this difference:

$$\boldsymbol{Runoff = MAP - AET} \qquad \textbf{(Equation 1)}$$

- The annual runoff (in volume) is proportional to its naturalised river flows at the catchment outlet:

$$\frac{\boldsymbol{Runoff\ above\ the\ reference\ site}}{\boldsymbol{Runoff\ above\ the\ location\ of\ interest}} = \frac{\boldsymbol{Naturalised\ flows@reference\ site}}{\boldsymbol{Naturalised\ flows@location\ of\ interest}}$$

(Equation 2)

The relevant spatial layers to undertake these analyses were obtained from NIWA. These spatial layers are in ASCII format with a resolution of 500 m × 500 m. Specifically, they are as follows:

- Rainfall is average annual rainfall for 1960 to 2006, interpolated from rainfall gauge data
- Potential evaporation is average annual Penman Potential Evapotranspiration for 1960 to 2006
- Actual evaporation is an estimated average annual value for 1960 to 2006.

The annual runoff for each cell over the Manuherikia catchment was obtained by the 'Raster calculator' tool from the ArcGIS Toolbox using Equation 1. This calculation is illustrated in Figure A.5.

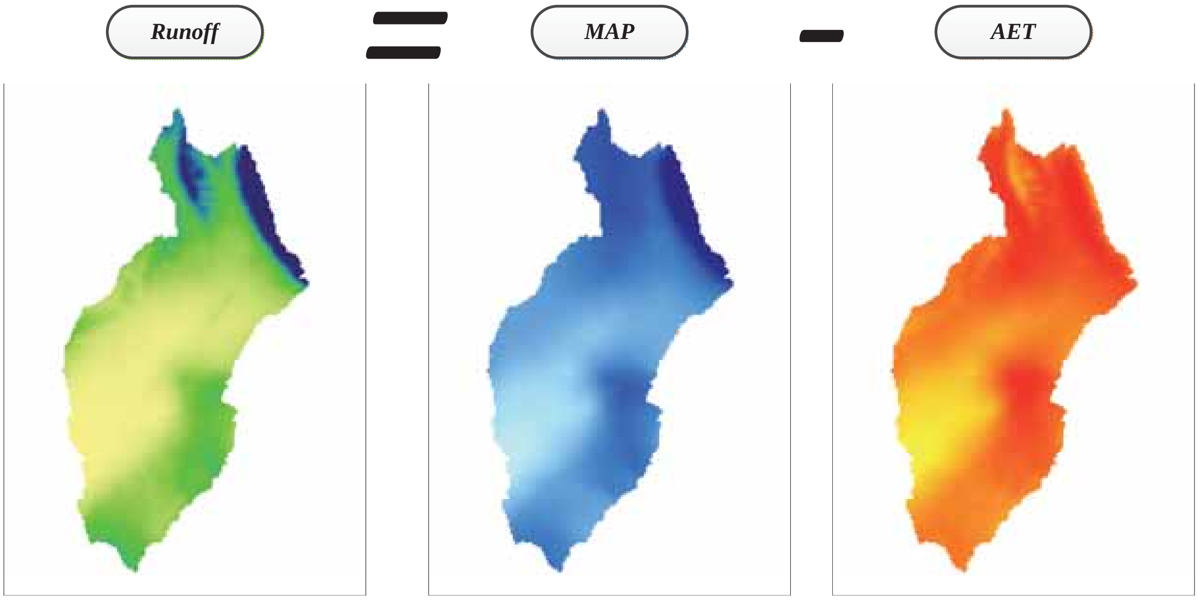

Figure A.5 **Illustrating the application of Map Algebra to calculate low flow runoff using Equation 1.**

The drainage area for the Mt Ida Water Race is shown in Figure A.6 as the areas labelled A and B. To estimate the total annual runoff above Falls Dam and the Manuherikia at the confluence with Dunstan Creek, areas A and B were excluded as this water race transports any water captured out of the study catchment.

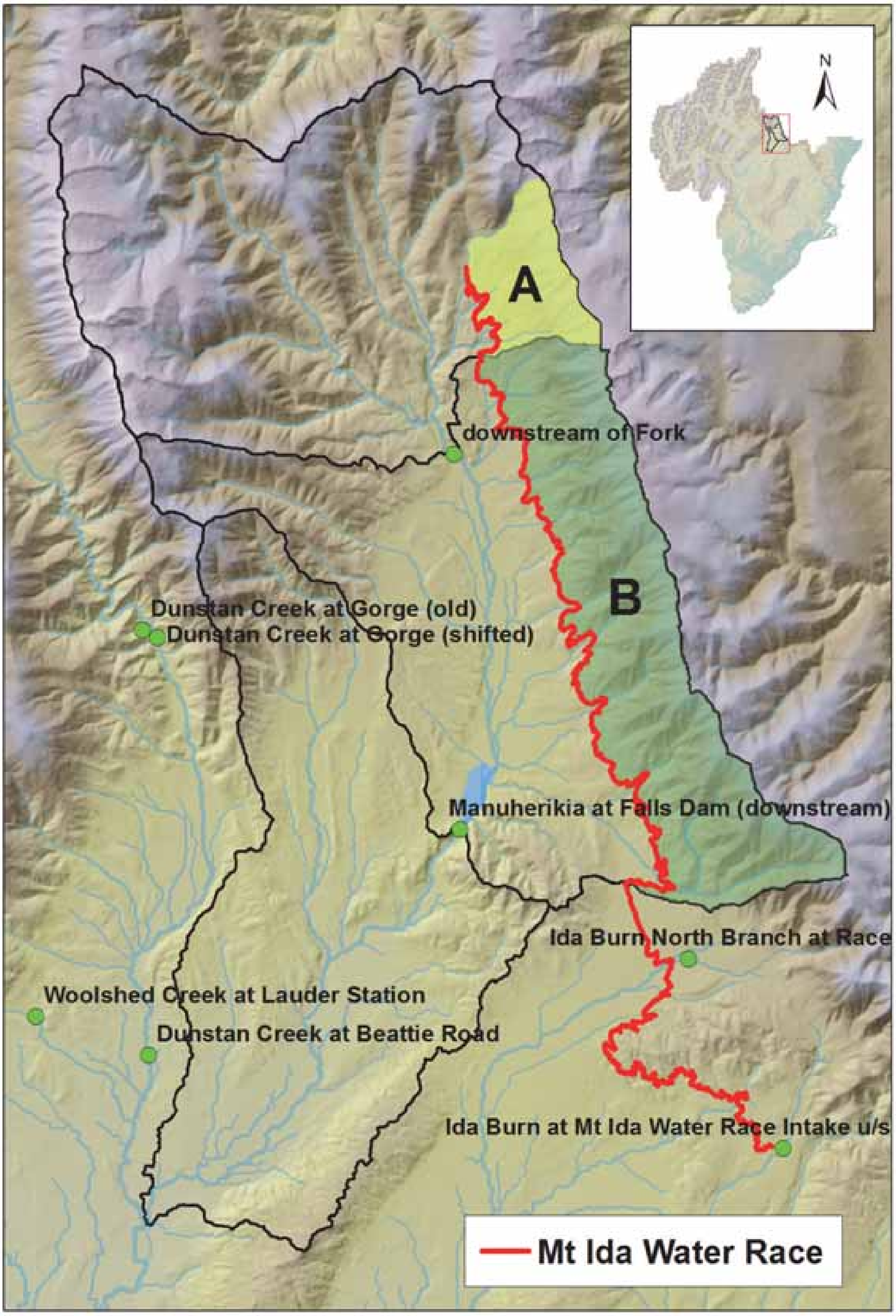

Figure A.6 **Drainage areas above the Mt Ida Water Race.**

Appendix B

NIWA
Taihoro Nukurangi

19 August 2016

Dr D Olsen
Otago Regional Council
Private Bag 1954
DUNEDIN

Dear Dean

ESTIMATION OF NATURAL 7-DAY MEAN ANNUAL LOW FLOW AT TWO SITES ON THE MANUHERIKIA RIVER

Thank you for engaging us to provide this assessment of low flows on the Manuherikia River.
We understand that you require estimates of natural mean annual 7-day low flow (7-day MALF) at two locations on the Manuherikia River. These are the flow recorder sites at Ophir and Campground. The need for an estimated natural 7-day MALF arises because the flow data at both locations are affected by many upstream abstractions, most of which are not monitored and make estimation of natural flow behavior problematic.

Methods for MALF estimation

To make estimates of natural mean annual low flow at these locations we have used two national maps of 7-day MALF as described in Booker and Woods (2013)[1]. The two national map estimates of MALF are based on two different premises. The first (HUC, or the hydrology of ungauged catchments model) is a "data-driven empirical approach informed by hydrological theory", and the second (RF, or random forests) is a "purely empirically-based machine learning regression model".

We extracted the results from the two national maps at the two locations and at other flow recorders in the Manuherikia and other nearby catchments where we considered the flow data were reasonably natural and would provide checks on the map output.

The flow recorder locations used are detailed in Table 1. The catchment area of Manuherikia at D/S Forks has been adjusted by the command area of the Mt Ida Water Race, as per Maurice Duncan's work for you earlier this month.

[1] Booker, D.J., Woods, R.A. (2013) Comparing and combining physically-based and empirically-based approaches for estimating the hydrology of ungauged catchments. *Journal of Hydrology*, 508: 227-239.

Table 1: Flow recorder sites where MALF estimates were extracted from maps, models and data.

Site No.	Site Name	Start date	End date	Catchment Area (km²)	NZ Reach no.
74318	Taieri at Canadian Flat	27-Nov-82		158	14050626
74353	Gimmerburn at Rough Ridge	18-Aug-71	12-Jan-94	23.7	14032461
75219	Lindis at Lindis Peak	24-Sep-76		542	14014785
75251	Manuherikia at D/S Forks	28-May-75	14-Apr-04	174 – 15	14015200
75253	Manuherikia at Ophir	1-Feb-71		2036	14031628
75257	Dunstan Ck at Gorge	7-Mar-73	28-Apr-94	157	14017269
75259	Fraser at Old Man Range	27-May-69	21-Jan-94	122	14037789
75265	Nevis at Wentworth Station	7-Apr-77		689	14030193
1075252	Manuherikia at Campground	22-Oct-08		3010	14039047

Model estimates

Estimated 7-day MALF values and those derived from data are presented in Table 2.

Table 2: Estimated 7-day MALF values (L/s) from data and two national models.

Site No.	Site Name	Data 7-day MALF	HUC 7-day MALF	RF 7-day MALF
74318	Taieri at Canadian Flat	934	578	859
74353	Gimmerburn at Rough Ridge	3.8	3	21
75219	Lindis at Lindis Peak	1516	643	1724
75251	Manuherikia at D/S Forks	1006	442	779
75253	Manuherikia at Ophir		1621	2875
75257	Dunstan Ck at Gorge	689	278	629
75259	Fraser at Old Man Range	495	201	653
75265	Nevis at Wentworth Station	5241	1458	4817
1075252	Manuherikia at Campground	934	1967	3511
All sites	Bias (average relative error)		-51%	66%
	RMSE error		54%	176%
Best sites	Bias		-54%	1%
	RMSE		58%	18%

For the two models, the results are overly affected by one or two catchments with large errors. The Nevis and Gimmerburn are not well estimated, perhaps as they have high elevations and significant snow. Also the Gimmerburn is a small catchment where the models may perform less well. By omitting these two sites the RF results are much improved, whereas the HUC results still display a large negative bias and a higher RMSE (root mean squared error).

Model scaling

To provide an estimate of 7-day MALF from each model, we scale the model results by the bias calculated over the remaining five flow records, on the assumption that this adjustment over the area of interest will provide the best estimate from that model. The results from each model for each site are then averaged to give the final estimate. Results of these steps are shown in Table 3.

Table 3: Scaled estimates for 7-day MALF and the final averaged estimates. All in L/s.

Site No.	Site Name	HUC MALF scaled	RF MALF scaled	Averaged 7-day MALF
74318	Taieri at Canadian Flat	1285	832	1058
74353	Gimmerburn at Rough Ridge	8	21	14
75219	Lindis at Lindis Peak	1430	1669	1550
75251	Manuherikia at D/S Forks	983	754	868
75253	Manuherikia at Ophir	3606	2783	3194
75257	Dunstan Ck at Gorge	619	609	614
75259	Fraser at Old Man Range	447	632	539
75265	Nevis at Wentworth Station	3245	4663	3954
1075252	Manuherikia at Campground	4376	3399	3887
Best sites	Bias (average relative error)	2%	-2%	0%
	RMSE error	18%	19%	20%

This procedure leads to 7-day MALF estimates for Ophir of 3,200 L/s, and Campground of 3,900 L/s. Uncertainty of these estimates is ±20%, derived from the RMSE of the scaled estimates. Thus the 7-day MALF at Ophir lies between 2,600 and 3,800 L/s, and that for Campground lies between 3,100 L/s and 4,700 L/s.

We hope this information meets your needs and would be happy to provide any further clarification that may be required.

Yours sincerely

Roddy Henderson
Group Manager, Applied Hydrology
ORC17501

Quality Assurance Statement		
	Reviewed by:	Maurice Duncan
	Approved for release by:	Helen Rouse

Appendix C

Verification of water temperature logger data

Manuherikia at Ophir

Manual temperature readings from the Manuherikia at Ophir were available. On 38 occasions these readings matched the data from the water temperature logger installed at this site. The agreement between the manual readings and the logger values was very strong, with a slope very close to the 1:1 line (Figure C.1, R^2=0.982, p<0.0001, slope = 1.0005).

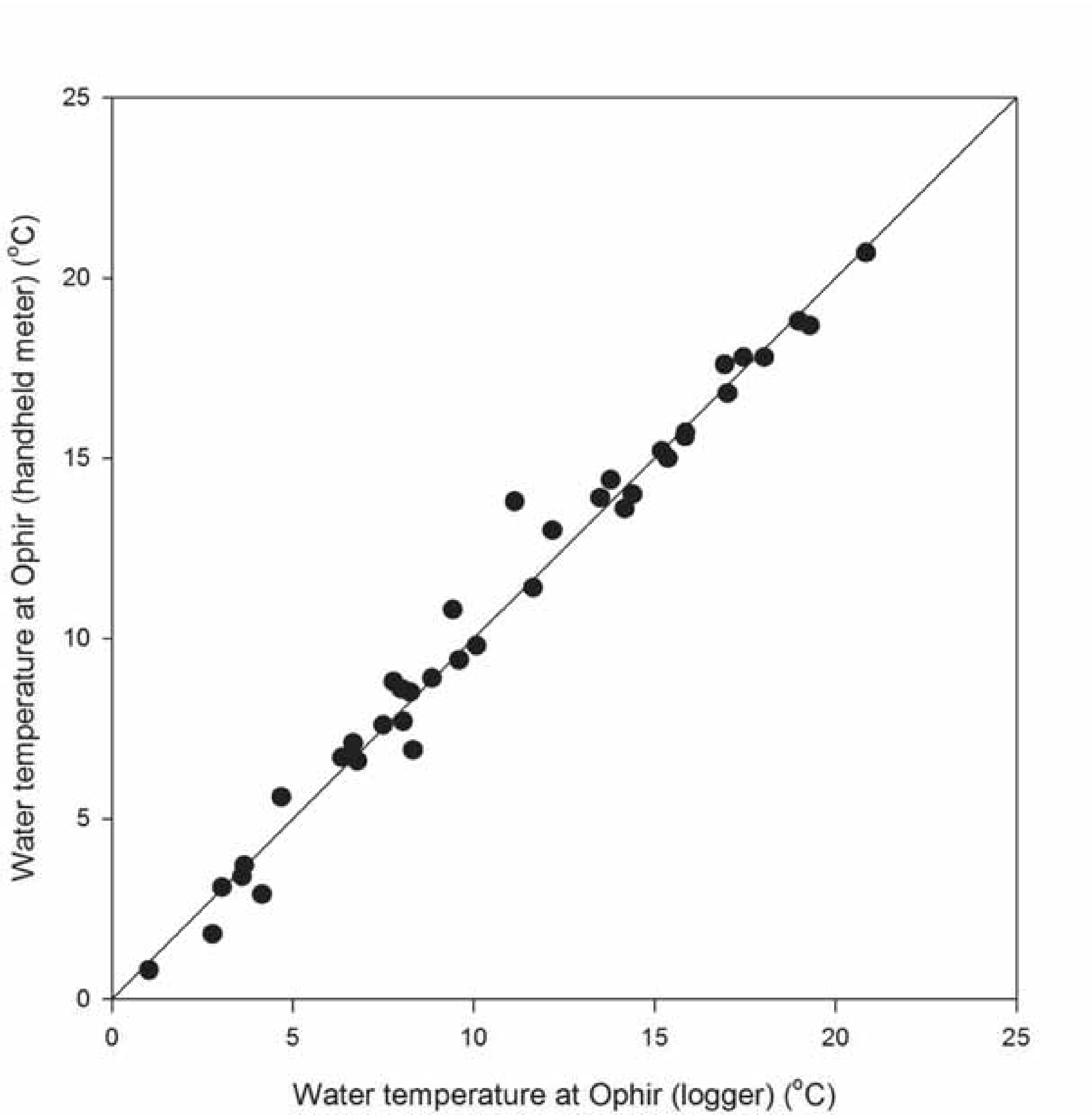

Figure C.1 **Relationship between water temperature logger readings and readings taken using a handheld meter in the Manuherikia River at Ophir.**

Manuherikia at Campground

Unfortunately, manual temperature readings were not available for the Manuherikia River at Campground. However, manual temperature readings were available from the Manuherikia at Galloway, some 3 km upstream of the Campground site. Matching data was available for 37 occasions. The agreement between these manual readings and the logger values was very strong, with a slope very close to the 1:1 line (Figure C.2, R^2=0.983, p<0.0001, slope = 0.955).

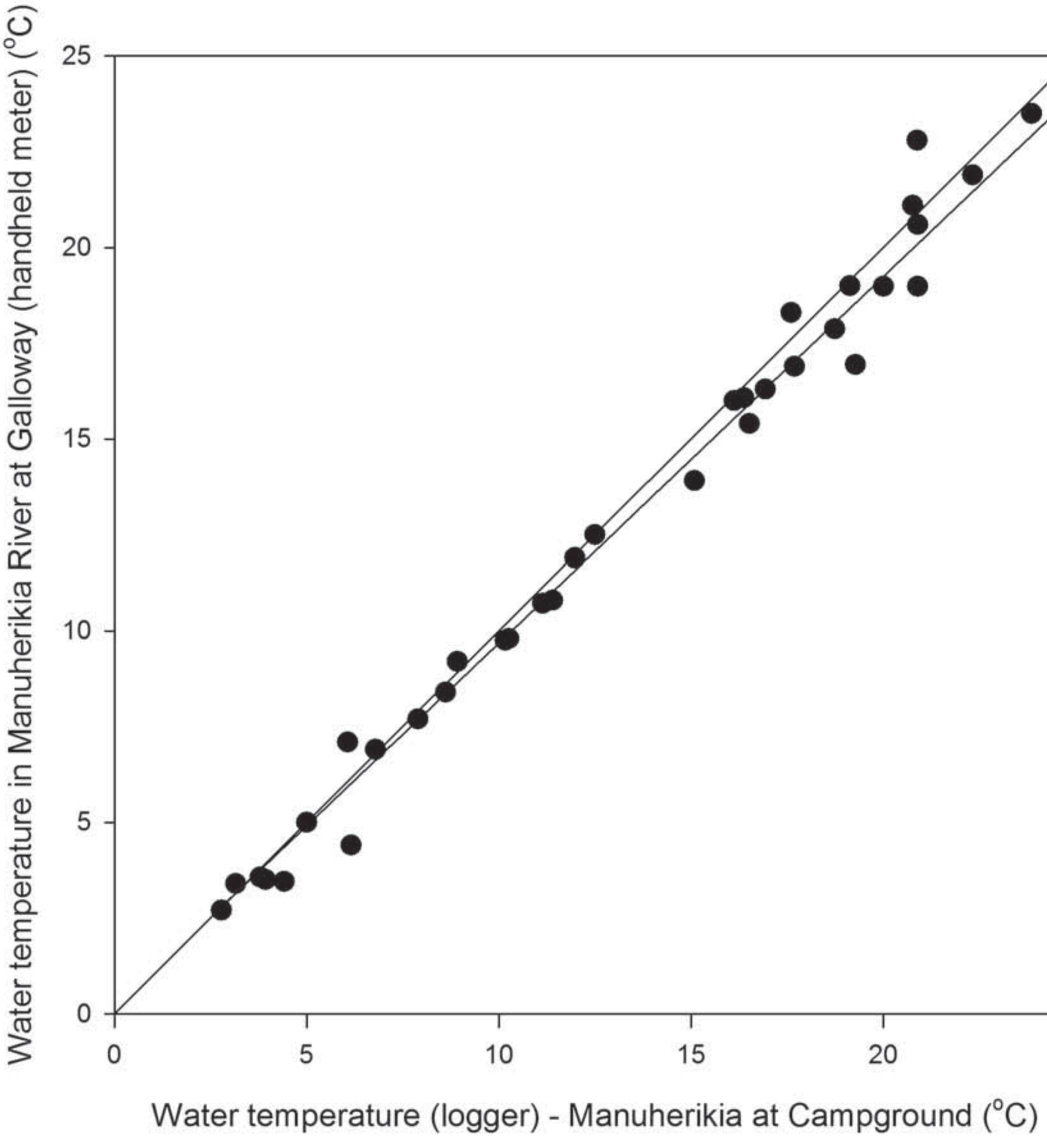

Figure C.2 **Relationship between water temperature logger readings from the Manuherikia River at Campground and readings taken using a handheld meter in the Manuherikia River at Galloway.**