Water Ways Consulting

Manuherekia minimum flow scenario assessments

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Cover photo: The Manuherekia River and Dunstan Creek

1 Introduction

1.1 Background

The Otago Regional Council is conducting an assessment of possible minimum flows for the Manuherekia River in Central Otago as part of the revision of its regional water plan. At present the Manuherekia River has a minimum flow of 0.82 m^3/s set at the Ophir flow monitoring site (see Otago Water Plan, Schedule 2A) and the Manuherekia irrigators, via the management of flow releases from Falls Dam and ratioing of water takes, maintain a voluntary 0. 9 m^3/s minimum flow in the lower Manuherekia at the campground flow recorder.

As part of the review process the Otago Regional Council (Council) has formed the Manuherekia Reference Group (MRG) that has representatives of environmental groups and water users from the Manuherekia catchment. The MRG has proposed seven minimum flow scenarios for the Council to assess the ecological outcomes for in the Manuherekia River.

To assess the minimum flows the Council has established three habitat models for the Manuherekia River, one each in the upper, mid and lower reaches of the river. These habitat models can be used to estimate the habitat provided for a range of fish, invertebrate and algal species present in the Manuherekia River and how the habitat the river provides changes with flow.

This report provides the initial assessment of habitat provided for the seven minimum flow scenarios.

1.1.1 Flow Scenarios

These scenarios are:

- *0.9* m^3/s *at the Campground flow recorder;*
- *1 2* m^3/s *at the Campground flow recorder;*
- *1.5* m^3/s *at the Campground flow recorder;*
- *1.7* m^3/s *at the Campground flow recorder;*
- *2.0* m^3/s *at the Campground flow recorder;*
- *2.5* m^3/s *at the Campground flow recorder; and*
- 3.0 m^3/s *at Campground flow recorder.*

The Campground flow recorder is located approximately 4 km upstream of the Manuherekia River's confluence with the Clutha River/Mata-au and it is downstream of all its tributary confluences. The river extends 68 km upstream from Campground to Falls Dam. Therefore, achieving the minimum flows at Campground requires an understanding of the contributing inflows and the water abstractions across the catchment downstream of Falls Dam.

It is important to note that these flow scenarios only set a minimum flow at Campground and without any further residual or minimum flows set at locations further upstream these minimum flow scenarios can be achieved via a broad range of combinations of water releases from Falls Dam and from flows in the tributaries. Some of the existing resource consents do have residual flow or minimum flow conditions, but minimum flow conditions are general set to the existing minimum flow site at Ophir. One important residual flow is the for the Pioneer Energy consent for hydro-electricity generation at Falls dam that requires a residual flow of 0.5 m^3/s year-round.

1.1.2 Habitat modelling

For the aquatic community, the river flow is an important habitat component controlling the habitat available to them. Instream habitat modelling can be used to consider the effects of changes in flow on instream values, such as habitat. The strength of instream habitat modelling lies in its ability to quantify the change in habitat available caused by changes in the flow, which helps to evaluate alternative flow scenarios. 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 in account a number of other factors, including the disturbance and mortality caused by flooding and droughts, biological interactions (such as predation), fish passage and riparian habitat conditions (that are important for aquatic insects and riverine birds) 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 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 determine the habitat available to aquatic flora and fauna but cannot predict the actual abundance of the organisms (Jowett, 2005).

For the purpose of assessing the flow scenarios above instream habitat modelling (using System for Environmental Flow Analysis, SEFA) has been used to assess the habitat available for a range of aquatic species for each flow scenario.

1.2 Key flow considerations for the Manuherekia flow scenarios

The key consideration for the flow scenarios is the water available in the catchment to provide the minimum flow and any infrastructure limitations that will influence the volume of water in the Manuherekia River. These factors include Falls Dam, the tributaries inflows, water abstraction from the mainstem of the Manuherekia River and its tributaries and water storage and releases elsewhere in the catchment.

1.2.1 Baseline flow for comparison

The Goldsim model for the Manuherekia catchment provides river flow data for 47 years and includes a model scenario where Falls Dam is full and spilling water at the same rate as the inflow and there is no irrigation occurring in the Manuherekia valley. This can be considered a baseline scenario and can be used for comparisons with the seven scenario flows.

1.2.2 Falls Dam outflow

The key control on the Manuherekia River flow during the summer low flow period is the water released from Falls Dam. Water stored in Falls Dam is conveyed to irrigation abstraction points using the Manuherekia River as the pathway. At present the Falls Dam water release valve can release up to 4 m^3/s to the Manuherekia River. Falls Dam can only release more than 4 m^3/s when the reservoir is full, and water flows through the spillway.

1.2.3 Tributary flows

Additional inflows to the Manuherekia mainstem are provided by the tributaries:

- Dunstan Creek;
- Lauder Creek;

- Thomson Creek;
- Chatto Creek;
- Ida/Pool Burn;
- Manor Burn; and
- minor tributaries

The tributary inflows during the summer low flow period are reduced due to water abstraction and as these flows vary, they can become very low during drought periods.

1.2.4 Irrigation abstraction from the Manuherekia River

There are four major irrigation abstraction from the Manuherekia River that are supplied, at least partially, by the Falls Dam water releases. These are:

- Blackstone Irrigation Scheme;
- Omakau Irrigation Scheme;
- Manuherekia Irrigation Scheme; and
- Galloway Irrigation Scheme.

The abstraction of water at the irrigation take locations gives rise to lower flows downstream of the abstraction points. This results in the flow in the Manuherekia River reducing in a downstream direction when irrigation is occurring unless tributary inflows are greater than the mainstem water abstractions (Figure 1) or the river is experiencing a high flow event.

1.2.5 Manuherekia River flow schematic

Combining the effects of water abstraction and tributary inflows the flow in the Manuherekia River can be very strongly influenced by the water released from Falls Dam and the downstream water abstraction. Under natural conditions the flow would increase in a downstream direction. However, under the present-day summer flows decrease in a downstream direction. For the flow scenarios being assessed this longitudinal change in flow should be considered in conjunction with the flow and habitat provided at Campground. The change in flow is best illustrated with a flow schematic (Figure 1).

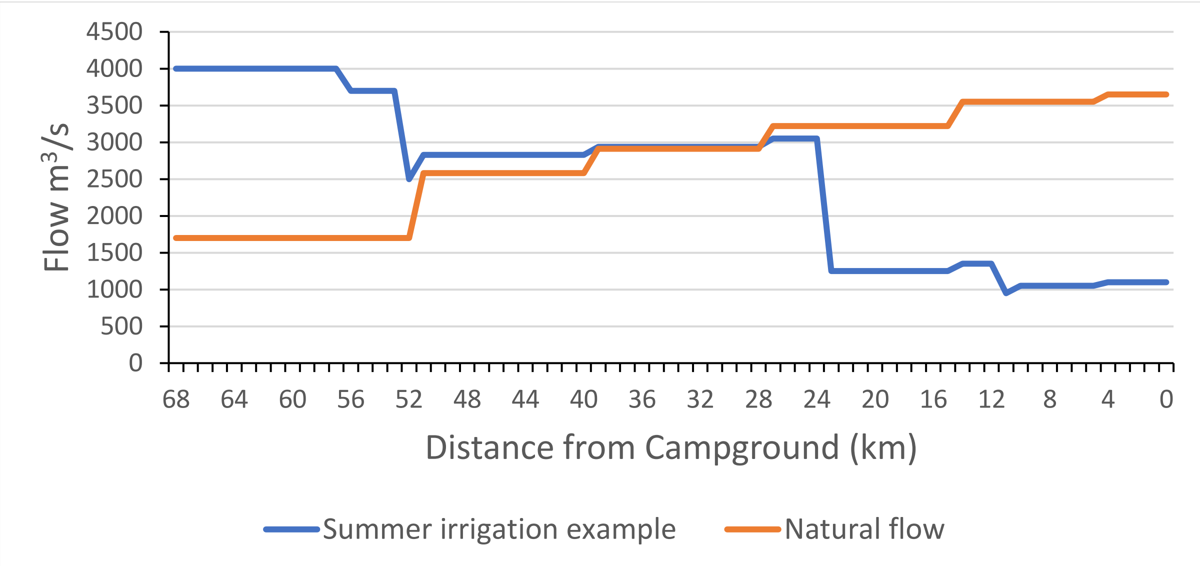

Figure 1: A longitudinal diagram of flow in the Manuherekia river under low flow conditions when Falls Dam is releasing water and the mainstem abstractions are operating.

Falls Dam has a second influence on the Manuherekia River. Between May and August each year the upper Manuherekia River below Falls Dam may flow at 0.5 m^3/s. This occurs while the dam is refilling and only the 0.5 m^3/s residual flow may be released from the dam until it is full.

1.2.6 Flow duration

The flow in the Manuherekia River is expected to vary throughout the irrigation season. This flow variability means that on any given year the period the river is drawn down to the minimum flow and possibly falls below the minimum flow (in drought events) will vary. A key aspect when considering the ecological effects of low flows is the duration. For the scenarios the assessment can determine the habitat available at the minimum flow (or other flows) but the duration of these minimum flow events will vary each year. Wet years may have limited periods of low flow whereas drought years will have extended low flow periods.

2 Habitat models

2.1 Introduction

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 weighted 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). (Olsen et al 2017)

2.2 Habitat preferences

To predict habitat available (RAWS) the habitat model requires the habitat preferences for the organisms that habitat availability is of interest. For each species and life history stage of interest their preferences for water depth, water velocity and riverbed substrates are determined, and habitat suitability curves (HSC) are developed that incorporate the variation in habitat preferences as the water depth, water velocity and substrate vary.

Habitat suitability curves are available for a range of organisms present in the Manuherekia catchment and the habitat for these species can be modelled (Table 1) to estimate the effect of flow regime changes in the Manuherekia catchment. For this report, the HSC used in the 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 1: Habitat suitability curves used in instream habitat modelling in the Manuherekia catchment.

Group	HSC name	HSC source	Manuherikia River		
			Blackstone	Ophir	Galloway
Periphyton	Cyanobacteria (*Phormidium*)	Ex Heath et al. (2013)	Y	Y	Y
	Diatoms	NIWA Unpublished data	Y	Y	Y
	Didymo (Waitaki)	Jowett unpublished data	Y	Y	Y
	Long filamentous	NIWA Unpublished data	Y	Y	Y
	Short filamentous	NIWA Unpublished data	Y	Y	Y
Macro-invertebrates	Mayfly nymph (*Deleatidium*)	Jowett et al. (1991)	Y	Y	Y
	Mayfly nymph (*Nesameletus*)	Jowett et al. (1991)	Y	Y	Y
	Net-spinning caddis fly (*Aoteapsyche*)	Jowett et al. (1991)	Y	Y	Y
	Free living caddis fly (Hydrobiosidae)	Jowett et al. (1991)	Y	Y	Y
	Cased caddis fly (*Olinga*)	Jowett et al. (1991)	Y	Y	Y
	Stony cased caddis fly (*Pycnocentrodes*)	Jowett et al. (1991)	Y	Y	Y
	Midge larvae (*Maoridiamesa*)	Jowett et al. (1991)	Y	Y	Y
Fish	Central Otago roundhead galaxias	Jowett & Richardson (2008)	Y	N	N
	Longfin eel > 300 mm	Jowett & Richardson (2008)	Y	Y	Y

	Longfin eel < 300 mm	Jowett & Richardson (2008)	Y	Y	Y
	Upland bully	Jowett & Richardson (2008)	Y	N	N
	Brown trout adult	Hayes & Jowett (1994)	Y	Y	Y
	Brown trout <100 mm	Jowett & Richardson (2008)	Y	Y	Y
	Brown trout spawning	Shirvell & Dungey (1983)	Y	Y	Y
	Adult brown and rainbow trout	Wilding et al (2014)	Y	Y	Y
	Juvenile brown and rainbow trout	Wilding et al (2014)	Y	Y	Y

2.2.1 Periphyton

The periphyton community forms the slimy coating on the surface of stones and other substrates in freshwaters and can include a range of different types and forms. Periphyton is an integral part of many stream food webs; it captures energy from the sun and converts it, via photosynthesis, to energy sources available to macroinvertebrates, which feed on it. These, in turn, are fed on by other invertebrates and fish. However, periphyton can form nuisance blooms that can detrimentally affect other instream values, such as aesthetics, biodiversity, recreation (swimming and angling), water takes (irrigation, stock/drinking water and industrial) and water quality.

The analyses presented in this report consider HSC for five classes of periphyton: cyanobacteria, diatoms, didymo (*Didymosphenia geminata*, an invasive non-native diatom), short filamentous algae and long filamentous algae (Figure 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 2) 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 elevated 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 (Olsen et al 2017).

2.2.2 Macroinvertebrates

Macroinvertebrates are an important part of stream food webs, linking primary producers (periphyton and terrestrial leaf litter) to higher trophic levels (fish and birds), and were included in these analyses to consider how changes in flow may affect food availability for fish and birds. Six macroinvertebrates common in the Manuherekia River; *Deleatidium*, *Aoteapysche* (Figure 3) and chronimid larvae (represented by *Maoridesma* in the habitat models) were the most abundant taxa in the Manuherekia River during drift sampling in summer 2019 (Shearer & Hayes 2020, Hayes et al 2021). These taxa are also present in the ORC State of the Environment monitoring sampling. Three other taxa, *Olinga, Pycnocentrodes, Nesameletus* that have HSC available and are common invertebrates and are also food for birds and fish were also modelled.

Figure 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).

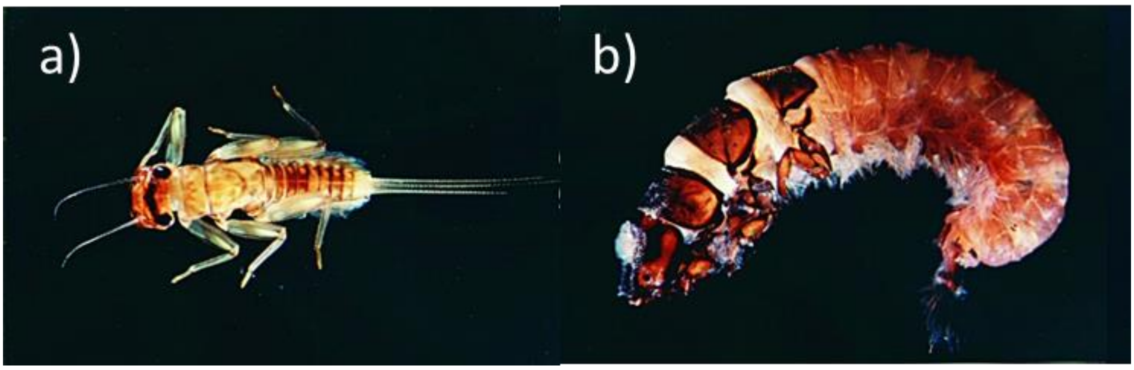

Figure 3: Common macroinvertebrate taxa in the Manuherikia catchment: a) common mayfly nymph (Deleatidium), b) net-spinning caddis fly (Aoteapsyche) larvae.

2.2.3 Native fish

HSC for native fish found in the main stem of the Manuherekia River 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 the Galloway reach as juveniles have been reported near the Chatto Creek confluence. 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 Manuherekia catchment is low due to the presence of Roxburgh Dam. Upland bullies are among the most widespread and abundant in the lower Manuherekia River fish species in the catchment and were modelled for the Galloway reach.

Figure 4: Galaxias anomalus, the Central Otago roundhead galaxias

Figure 5: Gobiomorphus breviceps, upland bully.

2.2.4 Sports fish

Brown and rainbow trout are found throughout the Manuherekia catchment. Two HSC for different life stages of brown trout and two combined brown and rainbow trout HSC were included in these analyses to consider how changes in flow in the modelled reaches will affect habitat availability for sports fish.

Spawning habitat was included in the analysis as spawning occurs in the low flow period that can occur when Falls Dam is filling. Brook char have also not been included as while present in the Manuherekia River the known populations are in the headwaters of the Manuherekia River (upstream of Falls Dam) Dunstan Creek and Ida Burn.

Figure 6 Juvenile sports fish Salmo trutta, brown trout (top); Salvelinus fontinalis, brook char (middle); and Oncorhynchus mykiss. rainbow trout (bottom).

2.3 Instream habitat modelling

To assess the changes in habitat available as flow changes three model reaches have been developed for the Manuherekia River at:

- Galloway (Figure 7, Figure 8);
- Omakau (Figure 9, Figure 10); and
- Blackstone (Figure 11, Figure 12).

The river has also been walked to assess the length of the areas of the river each habitat model applies to. In total the combined models apply to 38 km of the 68 km reach from Falls Dam to the Clutha River confluence.

The Galloway model reach extends from Shaky Bridge upstream to the Chatto Creek confluence. The Omakau reach extends from the upstream end of the Ophir Gorge to Lauder Creek excluding the Lauder Gorge. The Blackstone reach extends downstream from the Blackstone irrigation take to the gorge section of river upstream of the Lauder confluence. All the reaches are dominated by run and riffles habitats and pool habitat is rare.

The field surveys for the Galloway and Ophir reach models were undertaken in March 2019 by Otago Regional Council staff with models developed by Water Ways Consulting using SEFA for both reaches. The Blackstone reach by surveyed by NIWA (Duncan & Bind, 2016) who also constructed the habitat model using the hydraulic and instream habitat model RHYHABSIM (Jowett, 1989). The RHYHABSIM model has subsequently been updated to the SEFA modelling software. Calibration measurements for all three models were undertaken on two different occasions in addition to the initial survey (Table 2).

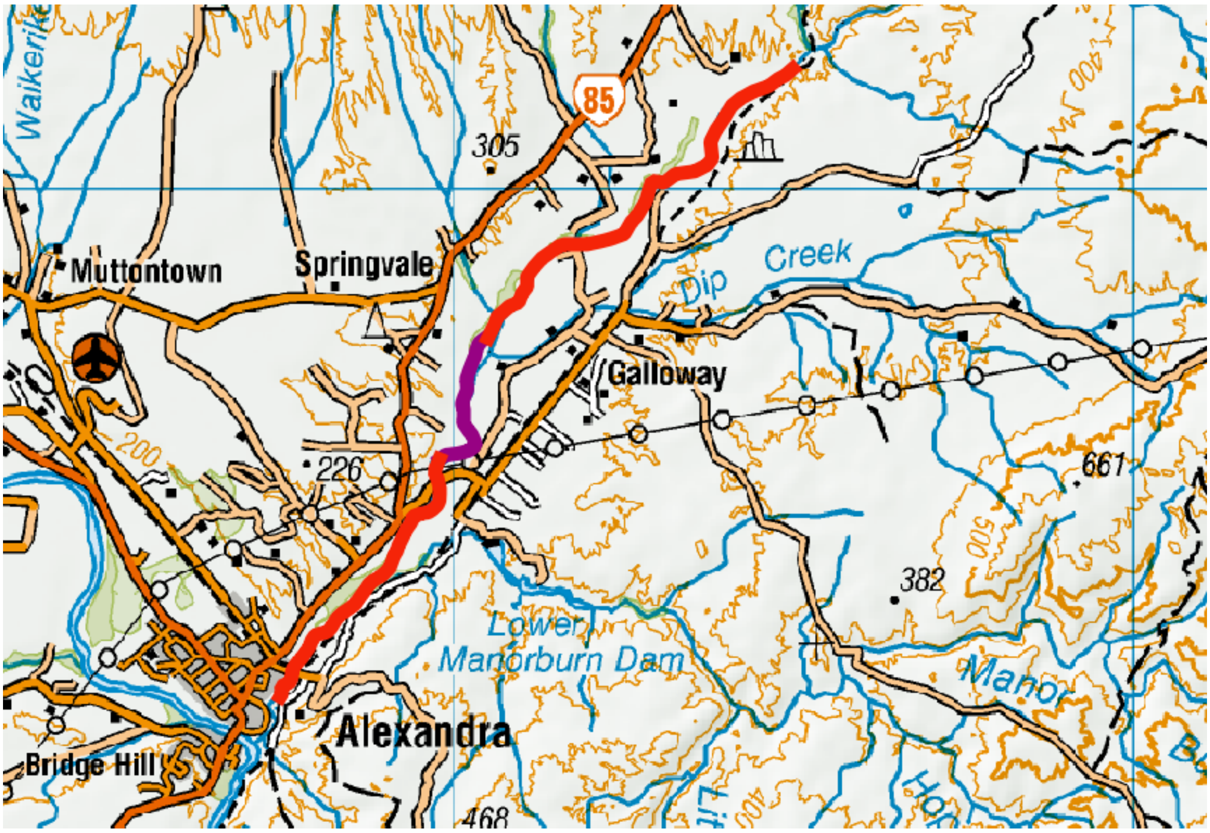

Figure 7: The Galloway habitat model reach (purple line) and reach of the Manuherekia River the model applies to (red line).


Figure 8: The Manuherekia River at the Galloway Irrigation Company intake.

Figure 9: The Omakau habitat model reach (purple line) and reach of the Manuherekia River the model applies to (red lines).

Figure 10: The Manuherekia River at Omakau.

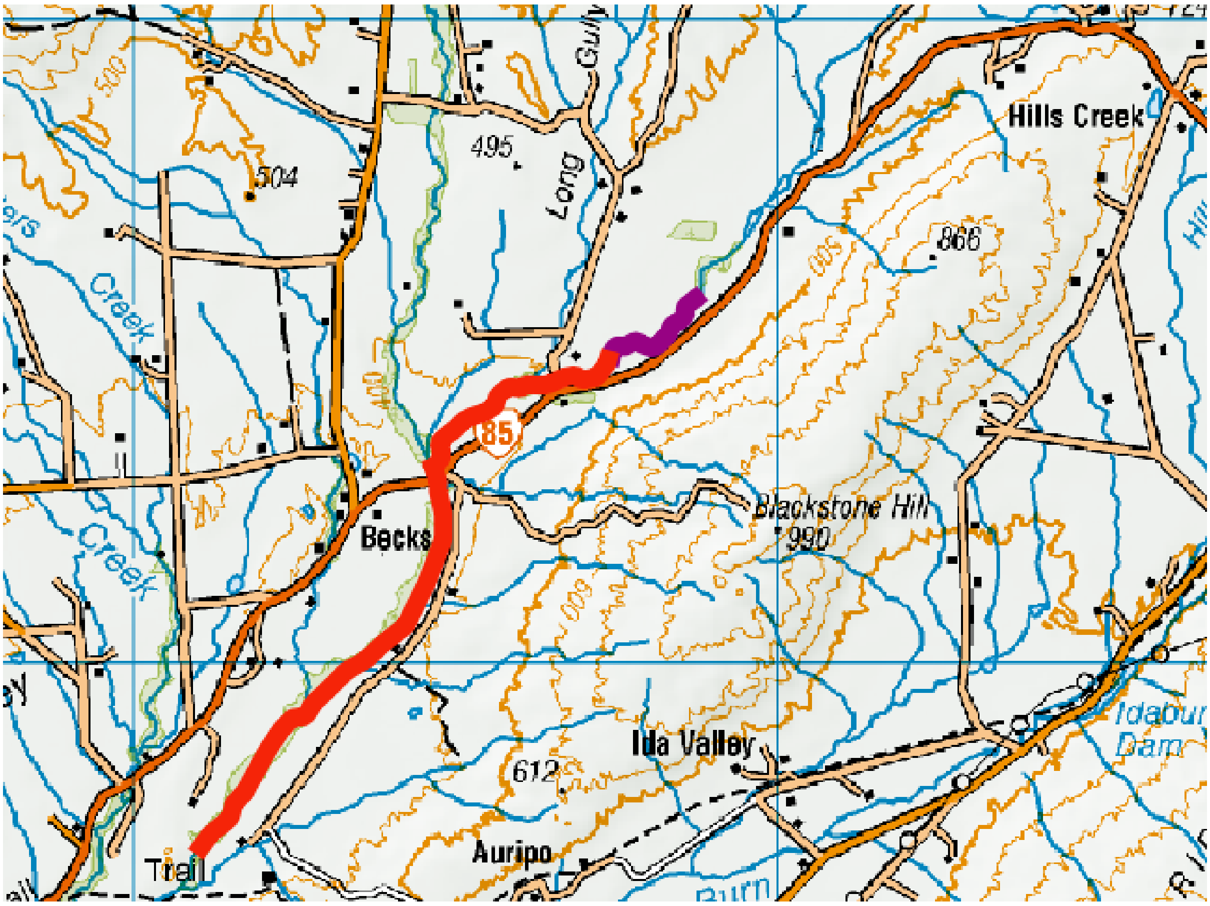

Figure 11: The Blackstone habitat model reach (purple line) and reach of the Manuherekia River the model applies to (red line).


Figure 12: The Manuherekia River at the Blackstone Irrigation Company intake.

Table 2: Survey flow and calibration flows for the three model reaches.

Survey reach	Survey flow (m^3/s)	Calibration flow 1 (m^3/s)	Calibration flow 2 (m^3/s)	Estimated naturalised 7-d MALF (m^3/s)*
Galloway	5/3/2019	13/3/2019	19/3/2019	
	0.760	1.443	3.276	4.038
Ophir	6/3/2019	13/3/2019	19/3/2019	
	2.160	2.777	4.404	3,400
Blackstone	3/2/2016	14/4/2016	2/5/2016	
	2.200	2.049	1.390	1.779

*Goldsim 7dMALF estimates

Modelling has not been conducted for the reach from Falls Dam to the Blackstone Irrigation Company water take. This is because this 11 km reach of the river has augmented flows with the release of water from Falls Dam as is upstream of all the major water abstractions. Therefore, this reach of the river will not be subject to low flows unless naturally occurring drought have led to run of the river conditions and there is not stored water left in Falls Dam.

2.3.1 Predicted habitat at Galloway

The physical habitat parameters, water depth and river width increase rapidly from 0 m^3/s to 0.15 m^3/s (Figure 13). After the initial rise water depth increases only slowly as flow increases to 6 m^3/s and average river depth from a flow of 2 m^3/s to 6 m^3/s only increases from 30 cm to less than 40 cm over this flow increase. However, river width and water velocity increase more rapidly as flow increases and this leads to the riverine habitat subject to higher water velocities and organisms that prefer low water velocities will find the reach becomes less suitable. The rarity of pool habitat and the small increase in water depth also limits organisms that prefer deep water throughout the flow range.

For the algal taxa there are differing responses for their habitat with the increase in flow (Figure 14). Long filamentous algae that is most suited to long water velocities has its maximum habitat at 0.15 m^3/s and then habitat decreases until the flow reaches 2 m^3/s and them it remains constant. Habitat for short filamentous algae increases with flow to 2 m^3/s and then plateaus. Both the didymo and *Phormidium* habitat increases rapidly until 0.5 m^3/s is reached and then while the habitat continues to increase, with increasing flow the rate of increase is much lower. Diatoms, an important food item for macroinvertebrates, do not have any habitat until flow exceeds 0.25 m^3/s and then it steadily increases until the flow reaches 5 m^3/s before slowing. The habitat suitability (CSI, Figure 15) shows the same trends to the habitat available for all five taxa and importantly for diatoms habitat suitability increases with flow until flow reaches 6 m^3/s.

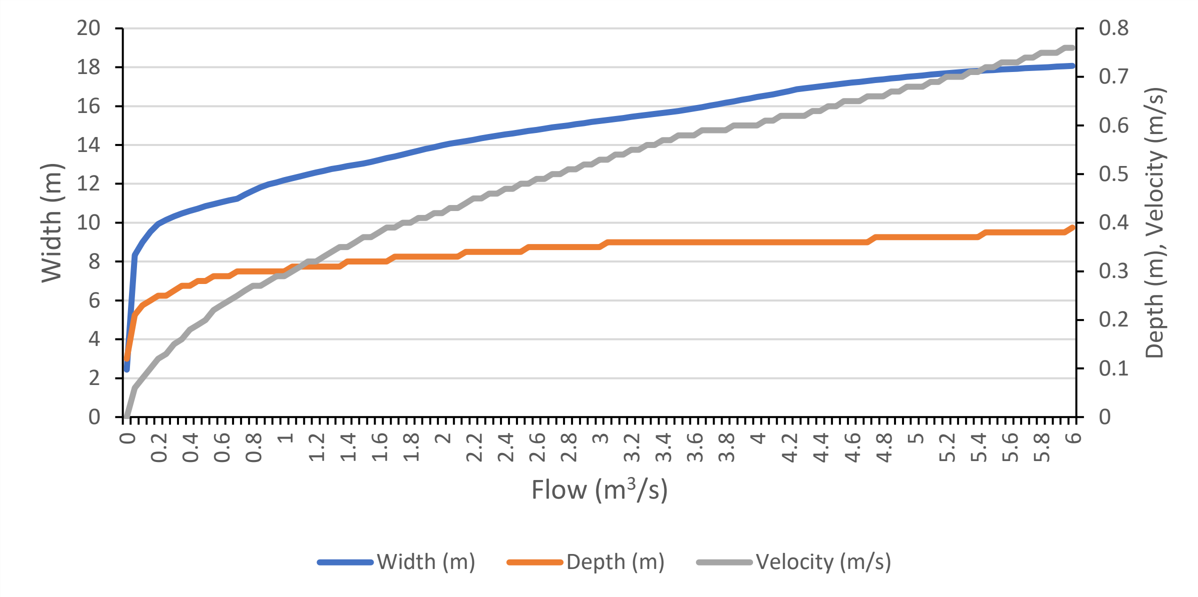

Figure 13: Changes in width, depth and water velocity with flow at Galloway.

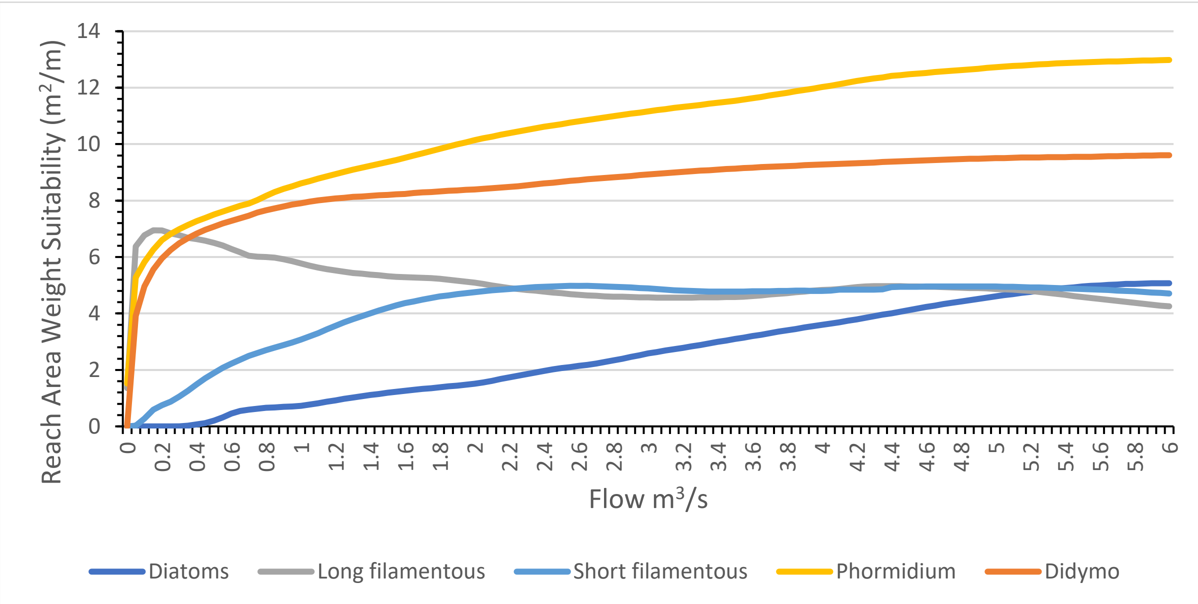

Figure 14: Changes in modelled habitat with flow for algal taxa at Galloway.

Macroinvertebrates show two trends at the Galloway reach (Figure 16). Habitat for *Aoteapsyche* and *Maoridiamesa* increase as flow increases throughout the flow range modelled. The other five taxa have rapid increases in habitat from 0 m^3/s to 1 m^3/s and then the rate at which habitat increases slows and for *Nesameletus* it declines slowly once the flow exceeds 1.75 m^3/s.

The native fish all have rapid increases in habitat available as flow increases from 0 m^3/s to 1 m^3/s (Figure 17). For Central Otago roundhead galaxias and upland bully the peak habitat occurs at or under 0.5 m^3/s and then its declines between 0.5 m^3/s and 2 m^3/s before stabilising. For the two longfin eel size classes peak habitat is 1 m^3/s to 1.5 m^3/s. The large longfin eel habitat does decline after it reaches its peak at 1.5 m^3/s, whereas for small eels habitat remains relatively constant once it peaks.

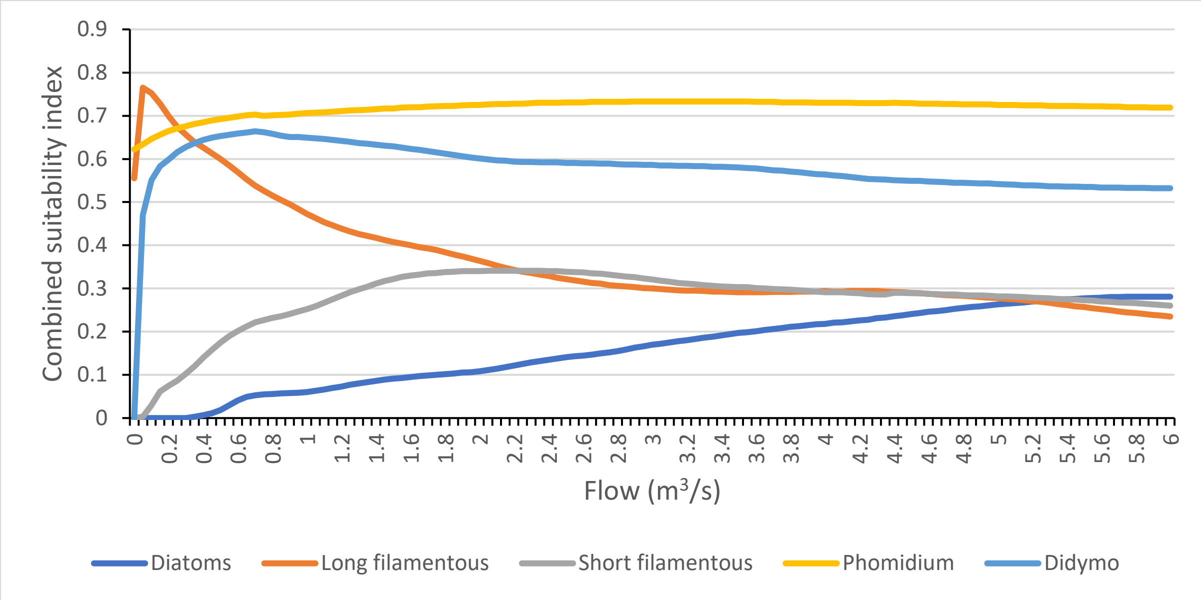

Figure 15: Changes in modelled habitat suitability with flow for algal taxa at Galloway.

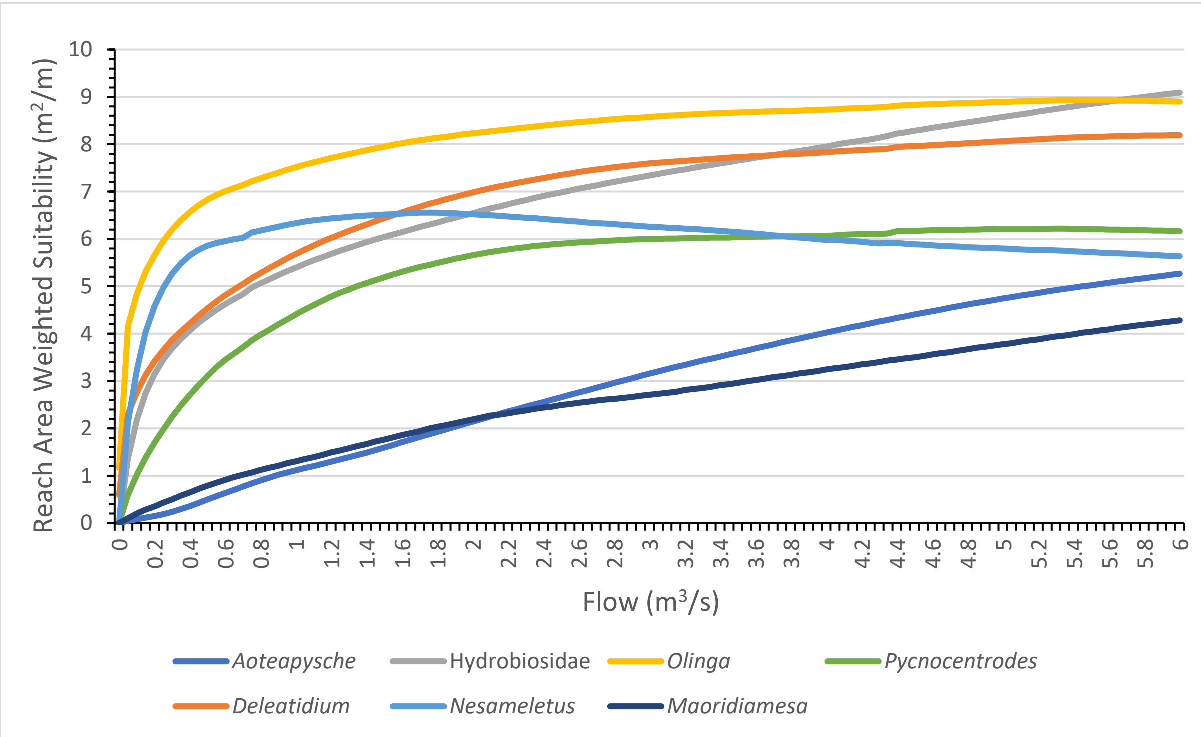

Figure 16: Changes in modelled habitat with flow for macroinvertebrate taxa at Galloway.

For brown and rainbow trout the adult and juvenile habitat rises as flow increases and then aside from adult brown trout the habitat tends to stabilise (Figure 18). Adult brown trout habitat peaks at 2 m^3/s and then declines by 50 % as the flow rises to 6 m^3/s.

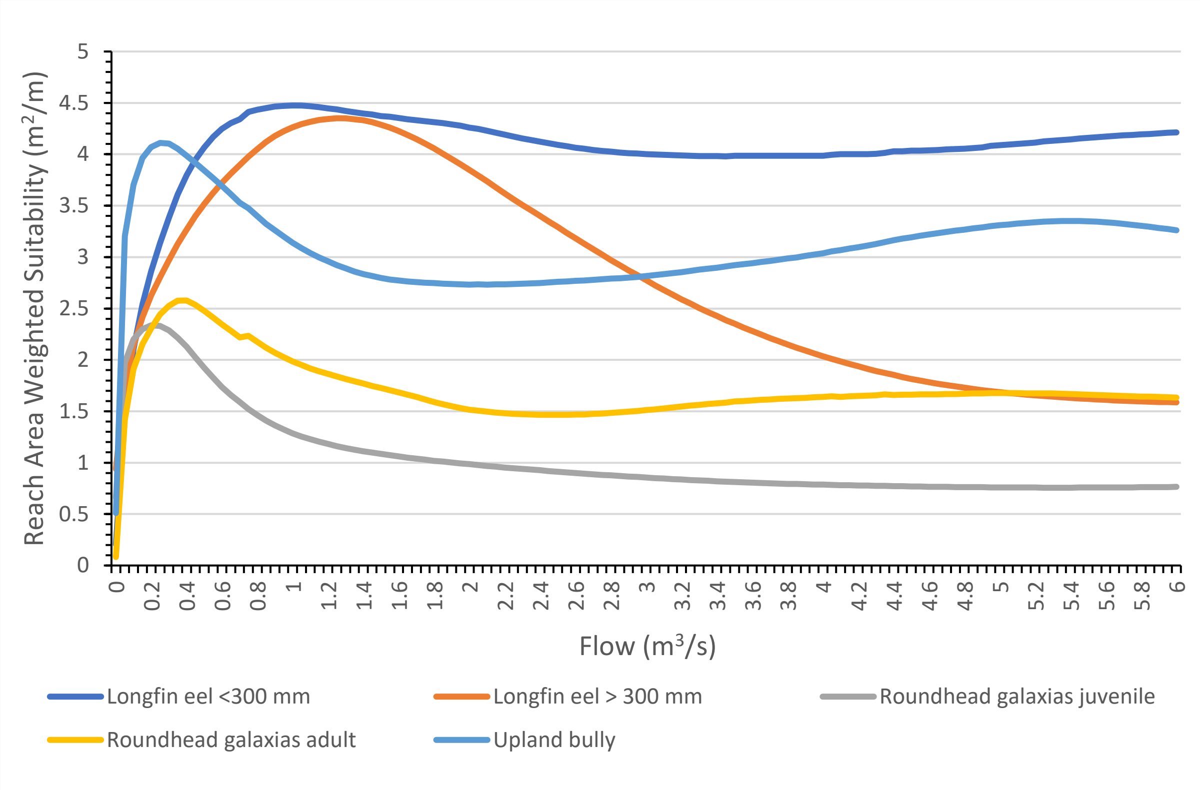

Figure 17: Changes in modelled habitat with flow for native fish at Galloway.

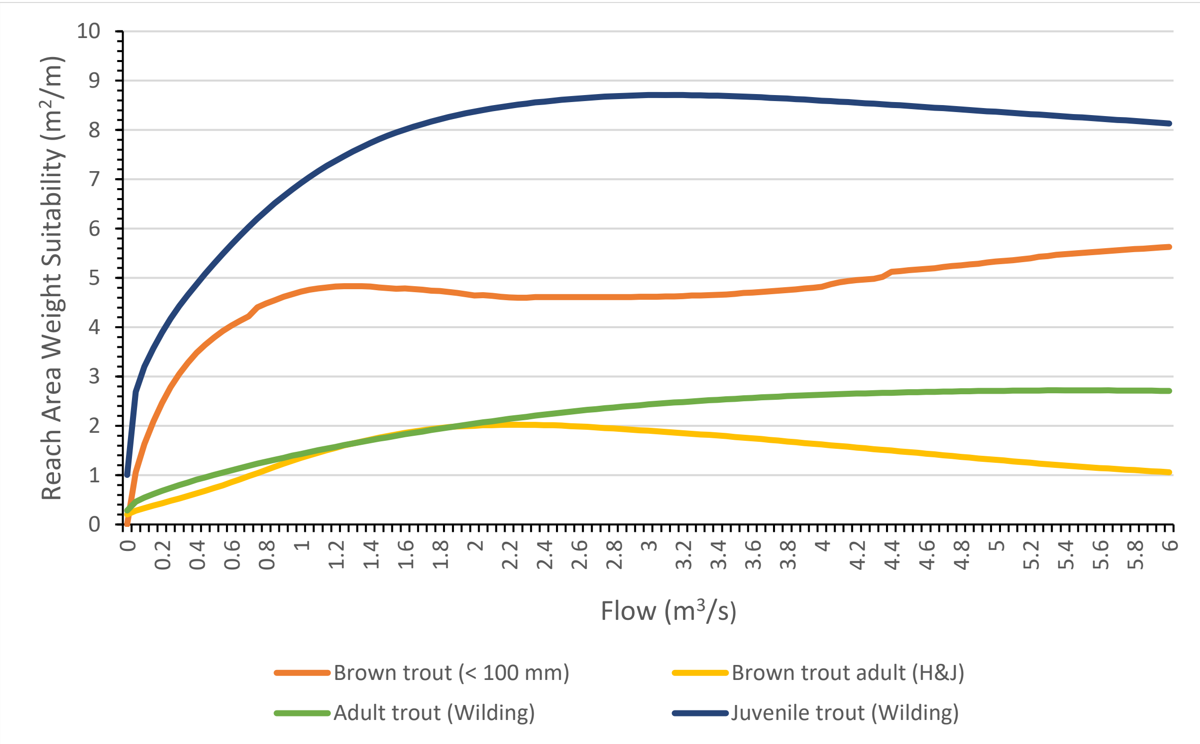

Figure 18: Changes in modelled habitat with flow for trout at Galloway.

2.3.2 Predicted habitat at Omakau

Average river width and water depth increase very rapidly from 0 m³/s to 0.5 m³/s at the Omakau reach (Figure 19). Once the flow exceeds 0.5 m³/s the rate of river width and water depth increase slows. Average water velocity has a steady rate of increase throughout the 0 m³/s to 6 m³/s indicating the increase in flow is being accommodated by the increase in water velocity rather than an increase in stream width or depth.

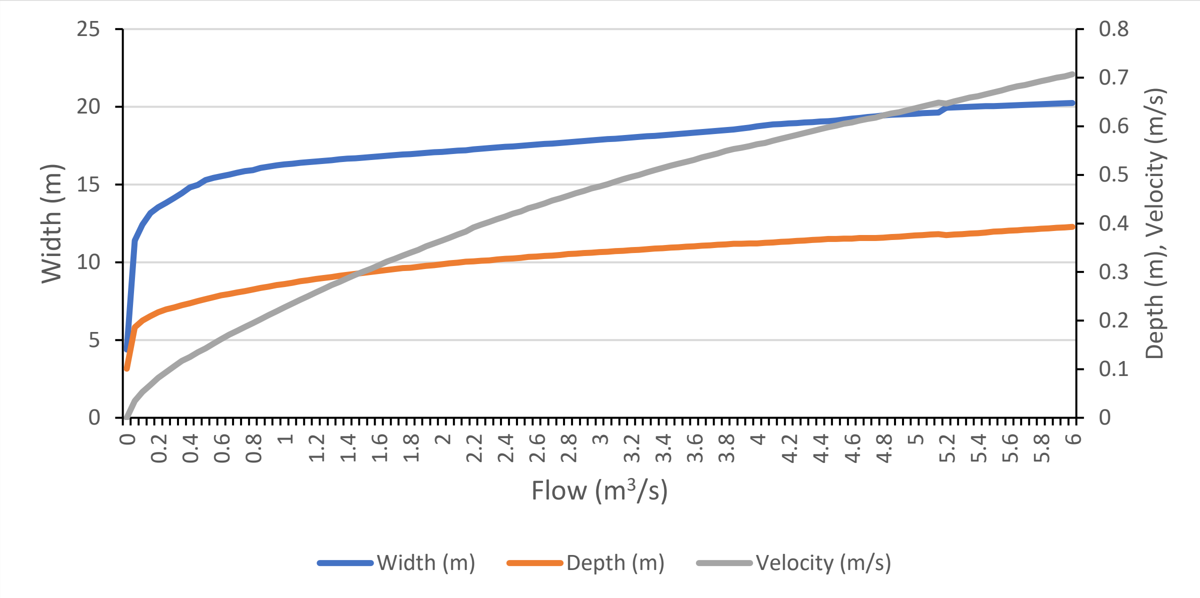

Figure 19: Changes in width, depth and water velocity with flow at Omakau.

The algal taxa have differing responses for their habitat with the increase in flow (Figure 20). Long filamentous algae has its maximum habitat at 0.5 m³/s and then habitat decreases until the flow reaches 4 m³/s before stabilising. Habitat for short filamentous algae increases with flow to 2.8 m³/s and then plateaus. Both the didymo and *Phormidium* habitat increases rapidly until 0.5 m³/s is reached and then while the habitat continues to increase, the rate of increase is much lower. Diatoms do not have any habitat until flow exceeds 0.5 m³/s and then it steadily increases until the flow reaches through the flow range modelled. The habitat suitability (CSI, Figure 21) shows the same trends to the habitat available for all five taxa and importantly for diatoms habitat suitability increases with flow until flow reaches 6 m³/s.

Macroinvertebrates show two trends at the Omakau reach (Figure 22). Habitat for *Aoteapsyche* and *Maoridiamesa* increase as flow increases throughout the flow range modelled. The other five taxa have rapid increases in habitat from 0 m³/s to 1 m³/s and then the rate at which habitat increases slows and for *Nesameletus* it declines slowly once the flow exceeds 1.5 m³/s.

The habitat for the two longfin eel size classes peaks at 1.35 m³/s to 1.8 m³/s in the Omakau reach (Figure 23). For both size classes the habitat then declines for the high flows up t at least 6 m³/s.

The habitat for brown and rainbow trout the adult and juvenile habitat rises as flow increases and then tends to stabilise or decline slowly (Figure 24). Adult brown trout habitat peaks at 2.85 m³/s and the combined adult rainbow trout and brown trout habitat does not peak but the increase in habitat is slow once the river is flowing above 3 m³/s.

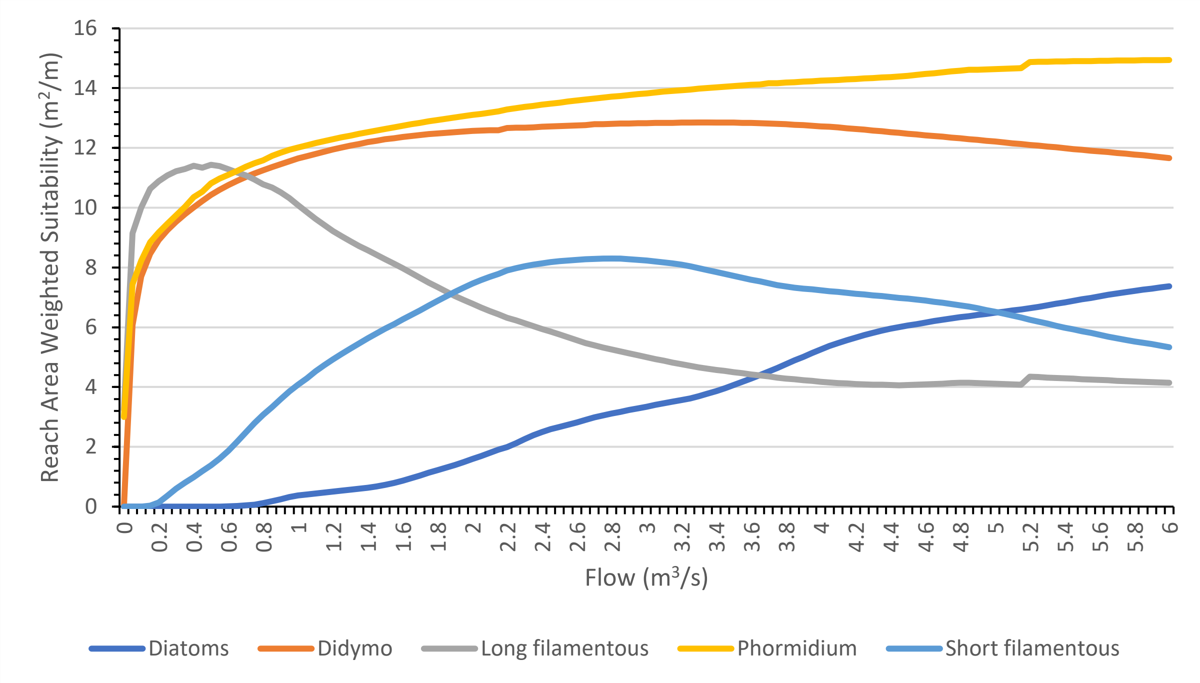

Figure 20: Changes in modelled habitat with flow for algal taxa at Omakau.

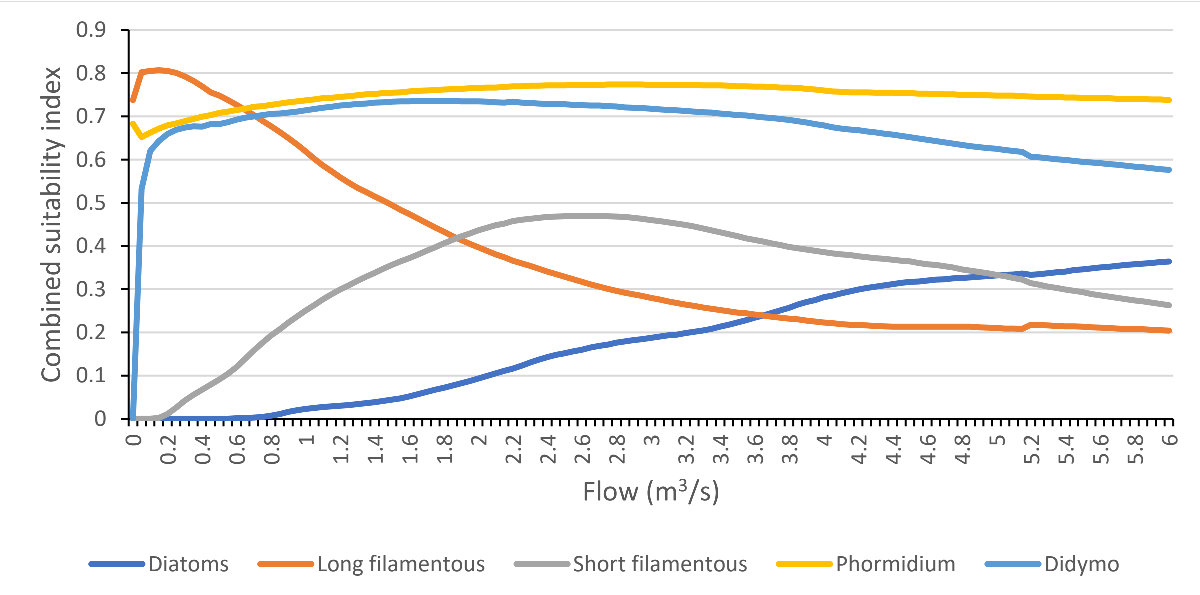

Figure 21 Changes in modelled habitat suitability with flow for algal taxa at Omakau.

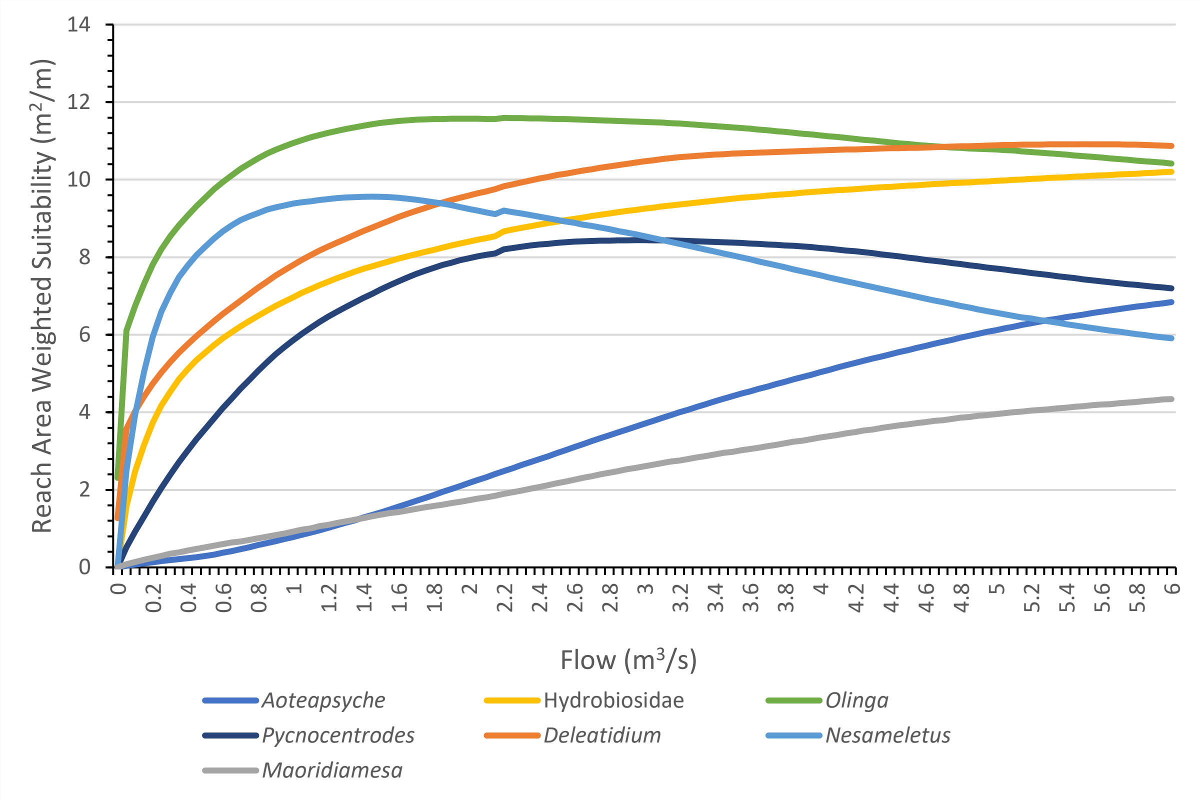

Figure 22: Changes in modelled habitat with flow for macroinvertebrate taxa at Omakau.

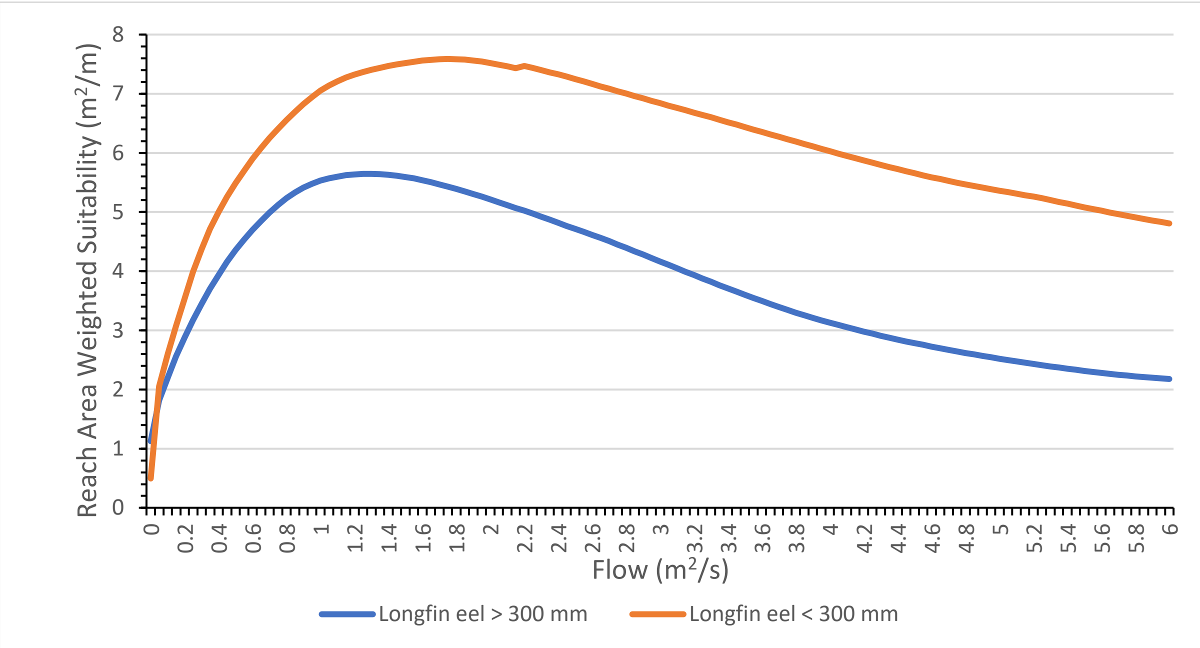

Figure 23: Changes in modelled habitat with flow for longfin eel at Omakau.

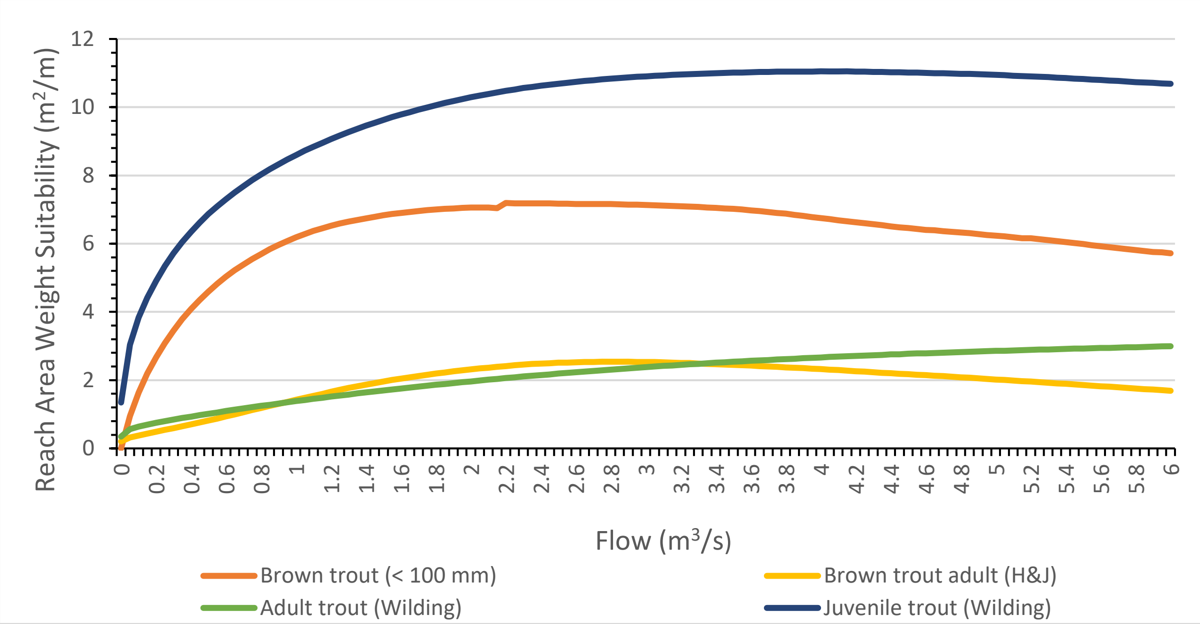

Figure 24: Changes in modelled habitat with flow for trout at Omakau.

2.3.3 Predicted habitat at Blackstone

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 25). 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, depth and velocity drop rapidly.

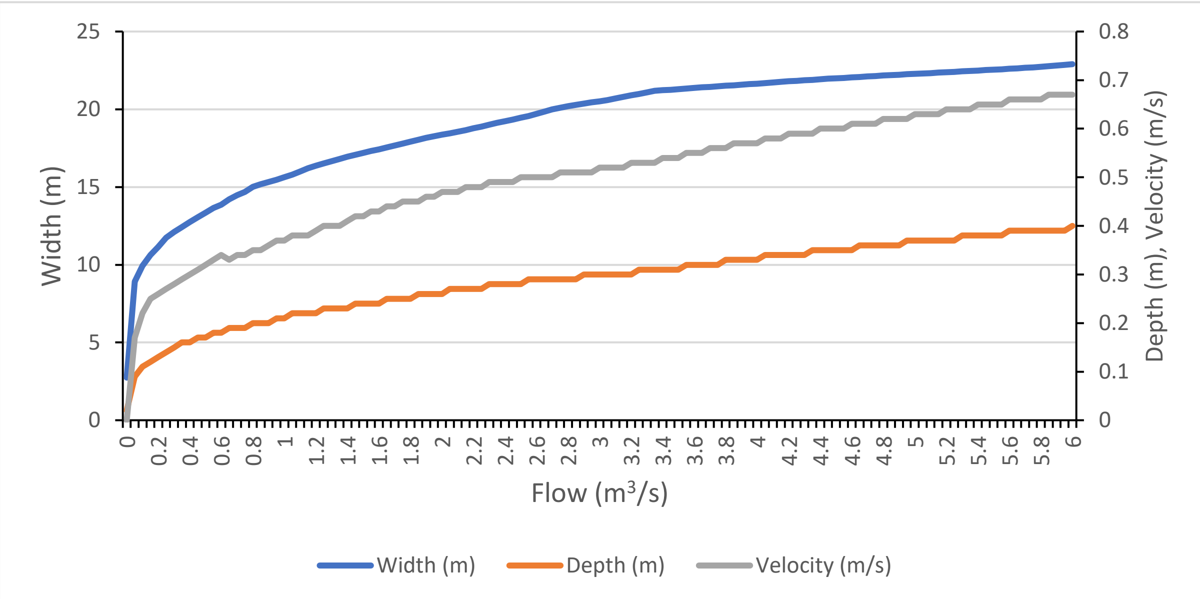

Figure 25: Changes in width, depth and water velocity with flow at Blackstone.

The habitat for diatoms increases as flow increases with the rate of habitat increase increasing between 2 m^3/s and 6 m^3/s (Figure 26). Habitat for *Phormidium* and didymo increases rapidly from 0 m^3/s to 0.5 m^3/s and then the rate of increases slows and nearly plateaus at and above 2 m^3/s. Long filamentous algae habitat peaks at very low flows (0.1 m^3/s) and declines as flow increases above this low flow. Habitat for short filamentous algae rises slowly and peaks at 2.8 m^3/s before gradually declining as flow increases further.

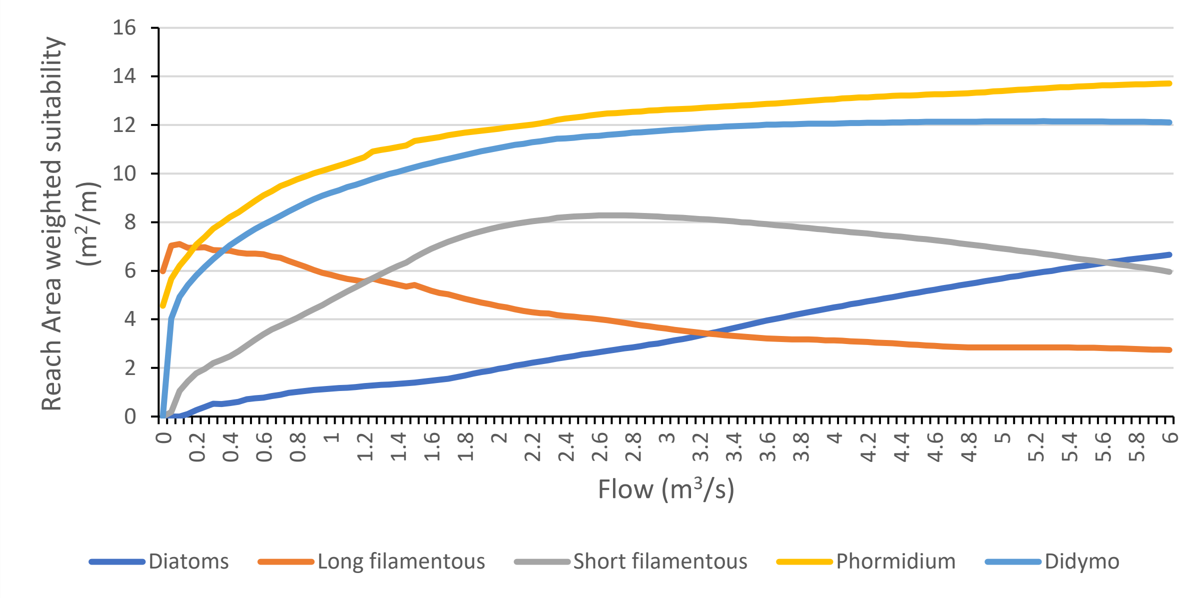

Figure 26: Changes in modelled habitat with flow for algal taxa at Blackstone.

The CSI for the algal taxa shows the same patterns as the habitat available predictions (Figure 27).

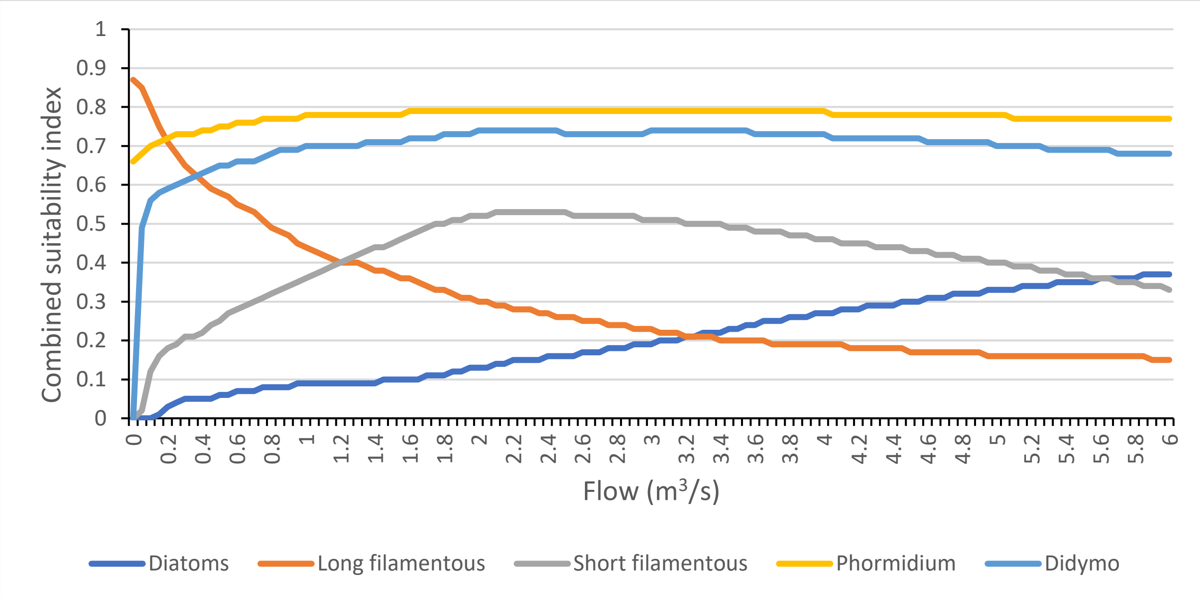

Figure 27: Changes in modelled habitat suitability with flow for algal taxa at Blackstone.

Macroinvertebrates show two trends at the Blackstone reach (Figure 28). Habitat for *Aoteapsyche* and *Maoridiamesa* increase as flow increases throughout the flow range modelled. The other five taxa have rapid increases in habitat from 0 m^3/s to 0.5 m^3/s and then the rate at which habitat increases slows and for *Nesameletus* it declines slowly once the flow exceeds 2 m^3/s.

The habitat for small longfin eel peaks when flow reaches 1.9 m^3/s in the Blackstone reach (Figure 29). The habitat then declines, and the rate of decline reduces as flow increases. At 6 m^3/s the decline in habitat has near stopped. For large longfin eel habitat rises from 0 m^3/s to 1.9 m^3/s. As flow increase over 2 m^3/s the large longfin eel habitat is stable.

The habitat for adult brown and rainbow trout increases with increasing flow throughout the 0 m^3/s to 6 m^3/s flow range modelled (Figure 30). Juvenile brown trout habitat peaks at 1.75 m^3/s and then declines steeply with increasing flow. The combined juvenile rainbow trout and brown trout habitat increases with flow up to 4.2 m^3/s and is stable at flows above this.

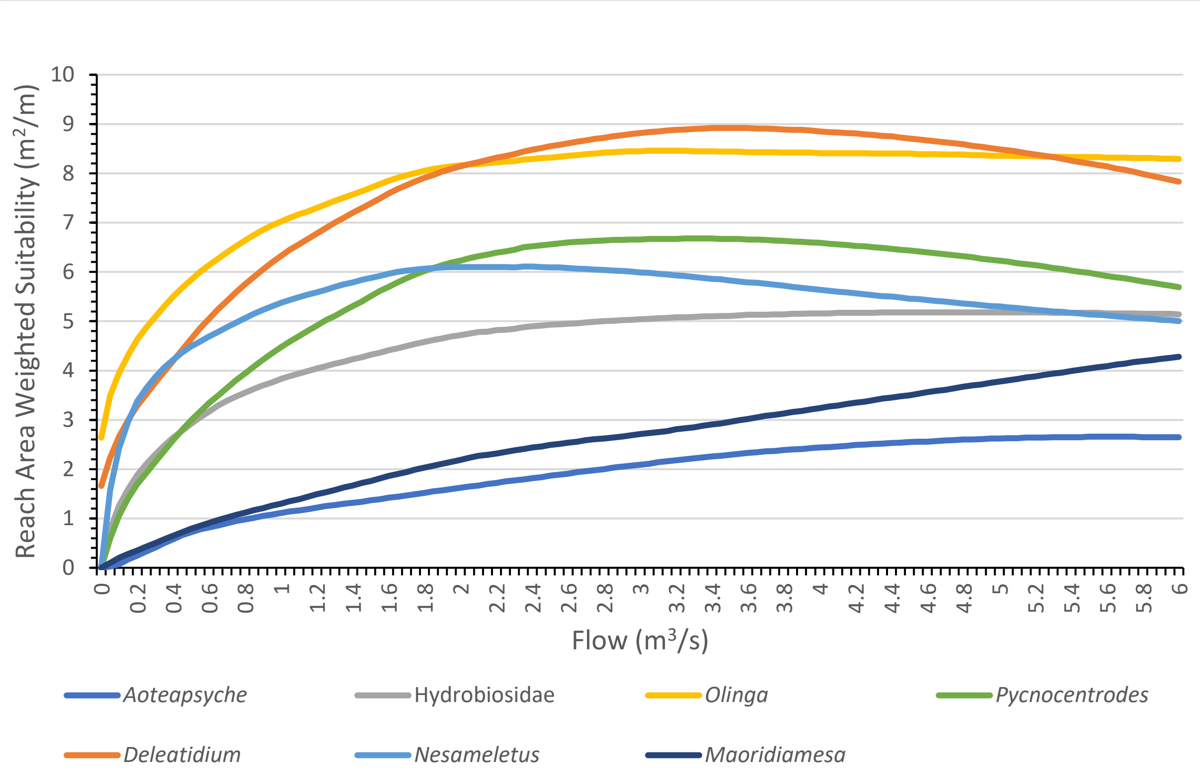

Figure 28: Changes in modelled habitat with flow for macroinvertebrate taxa at Blackstone.

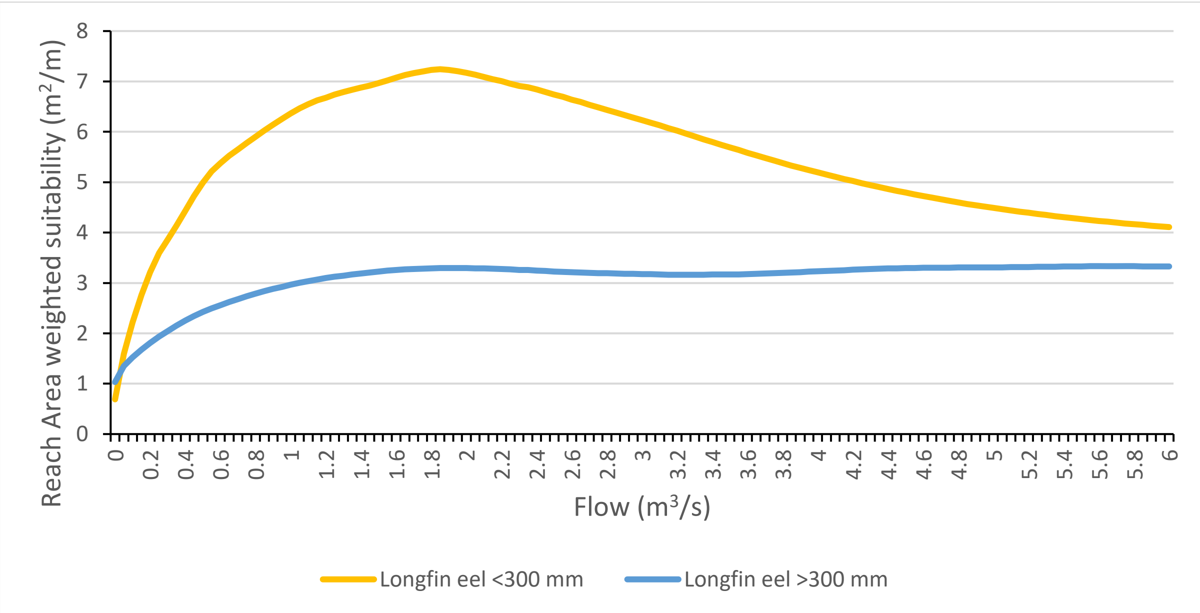

Figure 29: Changes in modelled habitat with flow for longfin eel at Blackstone.

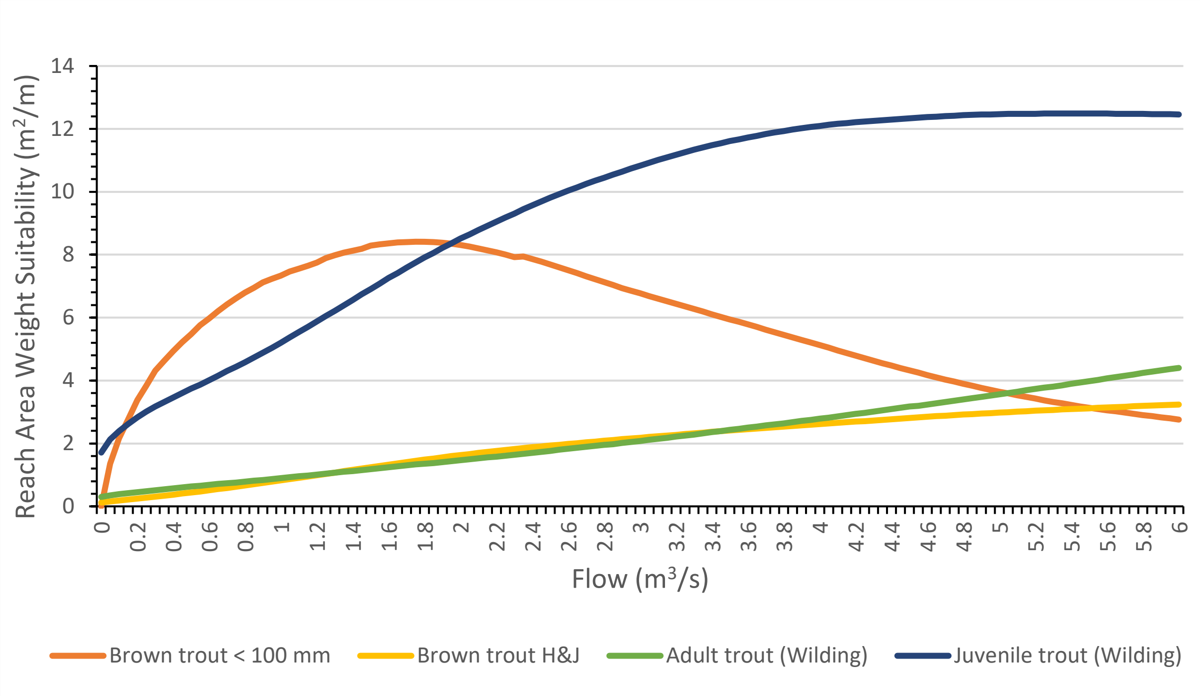

Figure 30: Changes in modelled habitat with flow for trout at Blackstone.

3 Flow Scenarios

For each flow scenarios the habitat model predictions for each of the taxa is presented and compared to the estimated 7dMALF of 4.040 m^3/s (estimated from the Goldsim model) at Campground.

It should be noted that this flow scenario analysis is useful for predicting aquatic habitat downstream of the Galloway Irrigation Company bywash point. Upstream of this location the combination of tributary inflows and water abstractions mean the river flow and the scenario minimum flows can be achieved by adjusting water takes in both the tributaries and along the mainstem and by adjusting flow releases from Falls Dam between 0 m^3/s and 4 m^3/s. This means the river flow, and habitat at points upstream of the Galloway can vary while still complying with the scenario minimum flow.

The 0.9 m^3/s scenario is the equivalent to the present-day status quo as the Manuherekia water users voluntarily maintain a 0.9 m^3/s minimum flow at campground. The six higher minimum flows represent incremental increases in the minimum flow. All of scenarios are less than the estimated natural 7dMALF so would supply some water for abstraction when the Manuherekia River is flowing at the 7dMALF. However, for the scenarios with the higher minimum flows water available for out of river use will be substantially less than with the status quo minimum flow of 0.9 m^3/s.

3.1 Flow scenario comparison methods

The comparison provides the predicted habitat available at each flow scenario for the Galloway to Campground reach of the Manuherekia River (Table 3) that presents the predicted habitat available for each taxa at the seven flow scenarios and at the estimated natural 7dMALF. Table 4 presents the habitat available as a percentage of the habitat available at the estimated naturalised 7dMALF.

To visualise the effect of changing flow on habitat the predicted habitat available has been plotted in 10% increments of the habitat available at the estimated naturalised 7dMALF (Figure 31). For eleven key taxa the 10% habitat increments have been plotted against river flow to indicate the flow range each 10% habitat band occupies (Figure 31).

Table 3: Predicted habitat available in the Galloway to campground reach for taxa at the estimated naturalist 7dMALF and for seven minimum flow scenarios at Campground.

Taxa	Habitat at 4.040 m³/s	Habitat at 0.9 m³/s	Habitat at 1.2 m³/s	Habitat at 1.5 m³/s	Habitat at 1.7 m³/s	Habitat at 2 m³/	Habitat at 2.5 m³/s	Habitat at 3 m³/s
Phormidium	12.38	8.44	9.02	9.49	9.86	10.37	10.97	11.4
Diatoms	3.60	0.69	0.92	1.19	1.32	1.57	2.06	2.58
Didymo	9.7	7.85	8.21	8.45	8.60	8.84	9.22	9.53
Long filamentous algae	4.84	5.96	5.47	5.15	5.12	5.05	4.84	4.72
Short filamentous algae	4.18	2.80	3.19	3.58	3.77	3.97	4.17	4.19
Deleatidium	7.47	5.52	6.05	6.45	6.68	6.92	7.12	7.29
Nesameletus	6.75	6.33	6.57	6.74	6.85	6.94	6.93	6.87
Aoteapsyche	3.90	1.02	1.29	1.59	1.81	2.13	2.40	3.1
Hydrobiosidae	8.07	5.28	5.74	6.13	6.37	6.72	7.17	7.51
Olinga	9.38	7.47	7.85	8.18	8.39	8.66	8.96	9.19
Pycnocentrodes	5.63	4.18	4.72	5.08	5.26	5.46	5.64	5.68
Maoridiamesa	2.46	1.01	1.28	1.45	1.53	1.69	1.89	2.08
Central Otago roundhead galaxias adult	1.69	2.07	1.82	1.77	1.75	1.74	1.74	1.73
Central Otago roundhead galaxias juvenile	1.17	1.38	1.24	1.16	1.12	1.09	1.09	1.11
Upland bully	3.65	3.96	3.65	3.52	3.49	3.51	3.53	3.57
Longfin eel > 300 mm	3.75	4.29	4.70	4.77	4.67	4.45	4.12	3.95
Longfin eel < 300 mm	4.11	4.41	4.28	4.22	4.23	4.28	4.23	4.25
Brown trout adult	2.23	1.25	1.61	1.92	2.10	2.31	2.46	2.40
Brown trout <100 mm	4.38	4.54	4.62	4.51	4.45	4.30	4.22	4.18
Adult brown and rainbow trout	3.58	1.36	1.62	1.87	2.03	2.27	2.66	3.02
Juvenile brown and rainbow trout	9.08	6.75	7.54	8.06	8.31	8.62	8.96	9.13

Table 4: Predicted habitat available in the Galloway to Campground reach as a percentage of the habitat available at estimated naturalised 7dMALF for taxa at the seven minimum flow scenarios at Campground. Green shading indicates 80% or more habitat retention, orange shading indicates 50 to 80 % habitat retention and red shading 50% or less habitat retention when compared to the estimated naturalised 7dMALF.

Taxa	% habitat at 0.9 m^3/s	% habitat at 1.2 m^3/s	% habitat at 1.5 m^3/s	% habitat at 1.7 m^3/s	% habitat at 2 $m^3/$	% habitat at 2.5 m^3/s	% habitat at 3 m^3/s
*Phormidium**	68%	73%	77%	80%	84%	89%	92%
Diatoms	19%	26%	33%	37%	44%	57%	72%
Didymo*	81%	85%	87%	89%	91%	95%	98%
Long filamentous algae*	123%	113%	106%	106%	104%	100%	98%
Short filamentous algae*	67%	76%	86%	90%	95%	100%	100%
Deleatidium	74%	81%	86%	89%	93%	95%	98%
Nesameletus	94%	97%	100%	101%	103%	103%	102%
Aoteapsyche	26%	33%	41%	46%	55%	62%	79%
Hydrobiosidae	65%	71%	76%	79%	83%	89%	93%
Olinga	80%	84%	87%	89%	92%	96%	98%
Pycnocentrodes	74%	84%	90%	93%	97%	100%	101%
Maoridiamesa	41%	52%	59%	62%	69%	77%	85%
Central Otago roundhead galaxias adult	122%	108%	105%	104%	103%	103%	102%
Central Otago roundhead galaxias juvenile	118%	106%	99%	96%	93%	93%	95%
Upland bully	108%	100%	96%	96%	96%	97%	98%
Longfin eel > 300 mm	114%	125%	127%	125%	119%	110%	105%
Longfin eel < 300 mm	107%	104%	103%	103%	104%	103%	103%
Brown trout adult	56%	72%	86%	94%	104%	110%	108%
Brown trout <100 mm	104%	105%	103%	102%	98%	96%	95%
Adult brown and rainbow trout	38%	45%	52%	57%	63%	74%	84%
Juvenile brown and rainbow trout	74%	83%	89%	92%	95%	99%	101%

*Nuisance algal taxa are shaded gray.

Table 5: Predicted habitat in increments of 10% of the predicted habitat available at the estimated naturalist 7dMALF for the Galloway to Campground reach

Taxa	Percentages of predicted habitat available at estimated naturalised 7dMALF (m^2/m)										
	50%	**60%**	**70%**	**80%**	**90%**	**7dMALF 100%**	**110%**	**120%**	**130%**	**140%**	**150%**
*Phormidium**	6.19	7.428	8.666	9.904	11.142	12.38	13.618	14.856	16.094	17.332	18.57
Diatoms	1.8	2.16	2.52	2.88	3.24	3.6	3.96	4.32	4.68	5.04	5.4
Didymo*	4.85	5.82	6.79	7.76	8.73	9.7	10.67	11.64	12.61	13.58	14.55
Long filamentous*	2.42	2.904	3.388	3.872	4.356	4.84	5.324	5.808	6.292	6.776	7.26
Short filamentous*	2.09	2.508	2.926	3.344	3.762	4.18	4.598	5.016	5.434	5.852	6.27
Deleatidium	3.735	4.482	5.229	5.976	6.723	7.47	8.217	8.964	9.711	10.458	11.205
Nesameletus	3.375	4.05	4.725	5.4	6.075	6.75	7.425	8.1	8.775	9.45	10.125
Aoteapsyche	1.95	2.34	2.73	3.12	3.51	3.9	4.29	4.68	5.07	5.46	5.85
Hydrobiosidae	4.035	4.842	5.649	6.456	7.263	8.07	8.877	9.684	10.491	11.298	12.105
Olinga	4.69	5.628	6.566	7.504	8.442	9.38	10.318	11.256	12.194	13.132	14.07
Pycnocentrodes	2.815	3.378	3.941	4.504	5.067	5.63	6.193	6.756	7.319	7.882	8.445
Maoridiamesa	1.23	1.476	1.722	1.968	2.214	2.46	2.706	2.952	3.198	3.444	3.69
Central Otago roundhead galaxias adult	0.845	1.014	1.183	1.352	1.521	1.69	1.859	2.028	2.197	2.366	2.535
Central Otago roundhead galaxias adult	0.585	0.702	0.819	0.936	1.053	1.17	1.287	1.404	1.521	1.638	1.755
Upland bully	1.825	2.19	2.555	2.92	3.285	3.65	4.015	4.38	4.745	5.11	5.475
Longfin eel > 300 mm	1.875	2.25	2.625	3	3.375	3.75	4.125	4.5	4.875	5.25	5.625
Longfin eel < 300 mm	2.055	2.466	2.877	3.288	3.699	4.11	4.521	4.932	5.343	5.754	6.165
Brown trout adult	1.115	1.338	1.561	1.784	2.007	2.23	2.453	2.676	2.899	3.122	3.345
Brown trout <100 mm	2.19	2.628	3.066	3.504	3.942	4.38	4.818	5.256	5.694	6.132	6.57
Adult brown and rainbow trout	1.79	2.148	2.506	2.864	3.222	3.58	3.938	4.296	4.654	5.012	5.37
Juvenile brown and rainbow trout	4.54	5.448	6.356	7.264	8.172	9.08	9.988	10.896	11.804	12.712	13.62
Upland bully	1.825	2.19	2.555	2.92	3.285	3.65	4.015	4.38	4.745	5.11	5.475

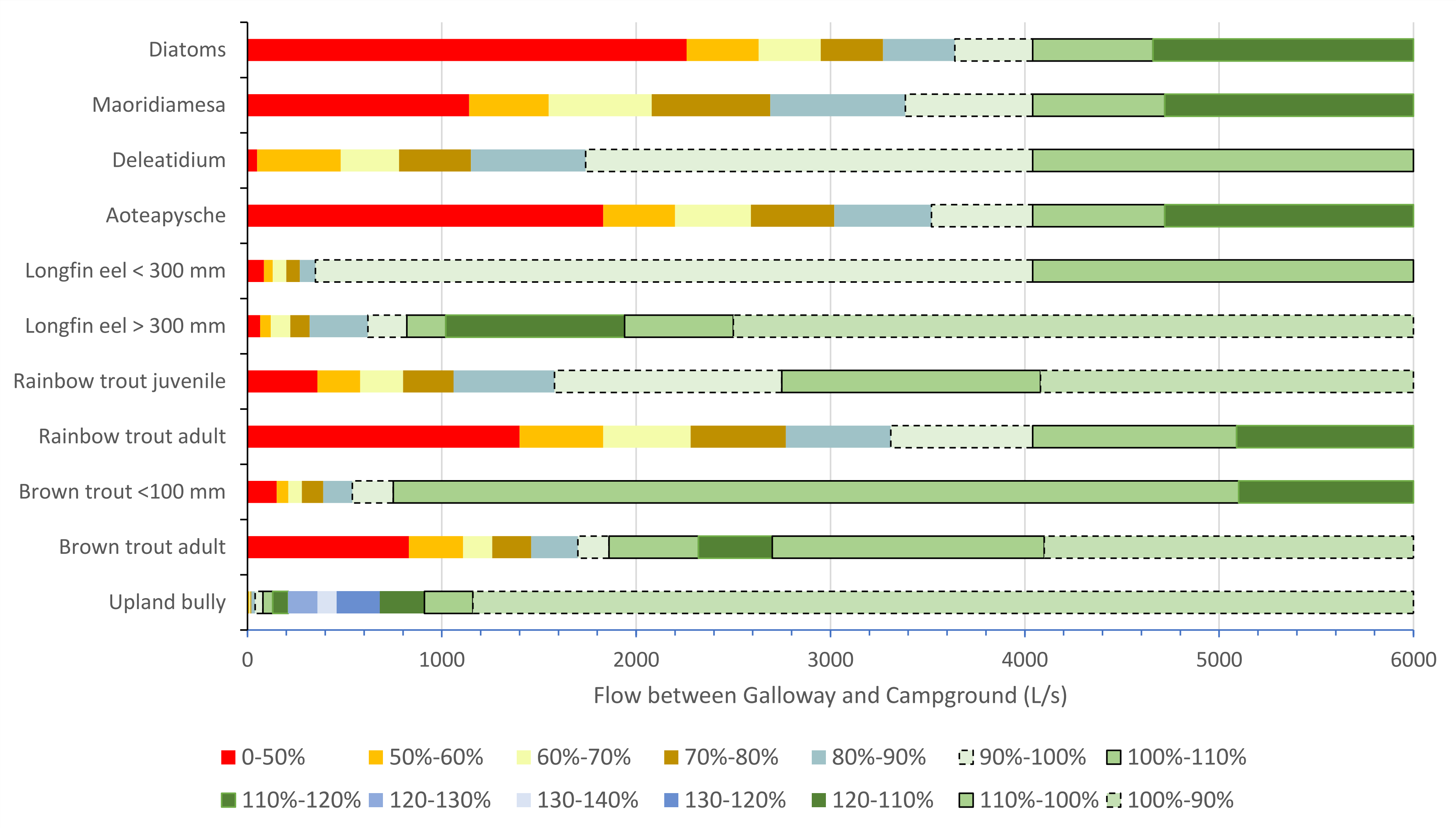

Figure 31: The predicted available habitat for key food web and fish species presented in the Galloway to Campground reach with habitat presented in 10% increments of the predicted habitat available at the estimated naturalist 7dMALF.

3.2 Scenario Assessment

The percentage habitat retained when compared with the naturalised 7dMALF shows that all the fish species retain a high percentage of their habitat regardless of the flow scenario with the exception of the combined adult brown trout rainbow trout habitat. With the macroinvertebrates the taxa are varied in their percentage of habitat retention but key fish food species, *Deleatidium*, *Aoteapsyche,* and *Maoridiamesa* all benefit from higher flows as do other invertebrate species the hydrobiosids *and Pycnocentrodes*. This will have benefits for fish as these provide food and an increase in food supply has the potential to improve fish populations and/or fish condition and fish growth rates. The habitat for the key algal taxa, diatoms, is significantly reduced in the lower flow scenarios and even at the 3 m^3/s flow diatom habitat does not reach 80% habitat retention when compared with the estimated naturalist 7dMALF of 4.038 m^3/s. As a key food source for macroinvertebrates this may represent a food web limitation for the lower Manuherekia River.

The seven flow scenarios create little change in the habitat available for the nuisance algal taxa. Therefore, if stable low flow conditions are present in the river algal accrual will occur and none of the minimum flow scenarios are likely to prevent algal blooms.

4 Discussion

4.1 Fish habitat

For the Galloway to Campground reach of the Manuherekia River the habitat for longfin eel, upland bully, juvenile rainbow trout and brown trout is over 80% of the habitat available at the estimated naturalised 7dMALF when the river flow is at or over 1.5 m^3/s. For rainbow trout adults a higher flow of 2.5 m^3/s is required to provide at least 80 % of the habitat at the naturalised 7dMALF. The habitat predictions also indicate that maximum habitat for adult brown trout and large longfin eels is reached at a river flow of 2.0 m^3/s. Increases in flow above 2.0 m^3/s is not predicted to increase habitat for the eels and brown trout.

For the smaller native fish, upland bully and Central Otago roundhead galaxias, peak habitat is at much lower flows less than 0.500 m^3/s. When considering the galaxiid and bully habitat it is worth noting that the naturalised 7dMALF is over 4.0 m^3/s and this would not have provided abundant galaxiid and bully habitat. Therefore, adopting flows far below the naturalised 7dMALF to provide for these species would be creating a low flow river far below the natural low flow range and a highly significant departure from the natural flow regime. As such the low flow preference of these species and the habitat model predictions are good indicators that the Manuherekia River, in its natural state, was unlikely to provide significant habitat for the galaxiids, unless the habitat structure in the Manuherekia River differed substantially from the habitat present today.

For the seven flow scenarios the scenarios the 1.5 m^3/s scenario provides reasonable habitat, and the 1.7 m^3/s provides 90% or more of the naturalised 7dMALF habitat for all fish species aside from adult rainbow trout.

4.2 Invertebrate habitat

The invertebrate species show two trends, either habitat peaks and then stabilises or even declines as flow increases or habitat for the species increases continuously as flow increases. For the species, such as *Pycnocentrodes* and *Nesameletus* there is a flow that provides maximum habitat. For *Deleatidium, Aoteapysche* and *Maoridiamesa* habitat increases with flow throughout the 0 m^3/s to 6 m^3/s flow range modelled.

The key consideration when assessing the invertebrate flow requirements is providing enough habitat to meet the NPS-FW requirement for river ecosystem health. Ecosystem health does not just require habitat is provided but that the ecosystem functions close to the natural state. For this it is important to consider that role the invertebrates have as prey for the fish species, in their aquatic life stages and birds in their winged adult life history stages. Hayes et al (2021) found that *Deleatidium*, *Aoteapysche* and chironomids (a group that includes *Maoridiamesa*) are the most abundant invertebrates being entrained in the water column and available as fish prey items. This makes these species important for trout, galaxiid, bully and eel diets. Providing more habitat for these invertebrate taxa will provide more food for fish in the Manuherekia River. In addition, as the insect emerge as winged adults, they provide food for birds that forage along the river channel. Therefore, when considering the seven flow scenarios a flow of at least 2 m^3/s is required to provide 50% or more the habitat at the naturalised 7dMALF.

4.3 Algal habitat

Diatoms are one of the important food resources used by invertebrates such as the grazing mayfly *Deleatidium*. Habitat for diatoms is predicted to increase with flow from 0 m^3/s to 6 m^3/s and at least 2.5 m^3/s is required to achieve more that 50% of habitat for diatoms available at the estimated naturalised 7dMALF.

4.4 Ecosystem considerations

The habitat modelling makes predictions for the habitat available for species and life history stages. It does not indicate how individuals will be using the habitat or the health of the individuals. Other factors aside from habitat may limit the number and health of individuals. Other limitations include recruitment, food supply and predation.

For longfin eel recruitment and present or recent harvest effects are key non-habitat related effects that are believed to be limiting the longfin eel population in the Manuherekia River. Therefore, providing longfin eel habitat is only one step for recovering the Manuherekia longfin eel population.

For the trout and bullies recruitment is not expected to be limiting and rather habitat or food or both are limiting factors. When considering the seven flow scenarios maximum habitat for these species can be provided by flows up to 2 m^3/s. The 2 m^3/s flow can be considered a flow at which any habitat limitations match the natural state. However, increasing the flow above 2 m^3/s increases invertebrate and diatom habitat and this increases the potential food supply to the bullies and trout. Under natural flow conditions in the Manuherikia River the habitat modelling indicates there is significantly more invertebrate habitat than that provided in all the flow scenarios. Therefore, while habitat may not be a limiting factor the invertebrate food supply through the river food web has the potential to limit fish (and bird) abundance, growth rates, and condition. Higher flows in the scenarios 2 m^3/s to 3 m^3/s range have the potential to provide a healthier ecosystem more similar to the natural state than the lower range scenarios below 2 m^3/s. Support for this is provided by the studies of Allen (1951) in Horokiri Stream and Huryn (1996) in Sutton Stream where both studies found brown trout consumed all the invertebrate production in both stream and as such food supply was the limiting factor on trout growth and abundance. Jowett (1992) also found that the invertebrate biomass at median flow was a strong predictor of brown trout (>200 mm) again indicating that food supply has a strong relationship to trout abundance.

4.5 Minimum flow effects in the mid and upper reaches of the Manuherekia River

The scenario assessment has investigated the effect of seven minimum flow scenarios on the habitat in lower reaches of the Manuherekia River but has not assessed the effects of the varying scenarios at other reaches in the river. This is due to flows in the mid and upper reaches varying significantly when the minimum flow at Campground is being maintained. This is due to the variations in the tributary inflows, water releases from Falls Dam and water abstractions giving rise to a multitude of ways to meet the Campground minimum flow requirement. Using the Goldsim model flow data this can be illustrated (Figure 32) with the variable flows in the mid and upper reaches on the same days that the river at the campground flow recorder is between 0.900 m^3/s and 0.910 m^3/s. This variation in flow in the mid and upper reaches means that while habitat models are available the actual flow in these reaches is unpredictable when the scenario flows are being achieved at Campground.

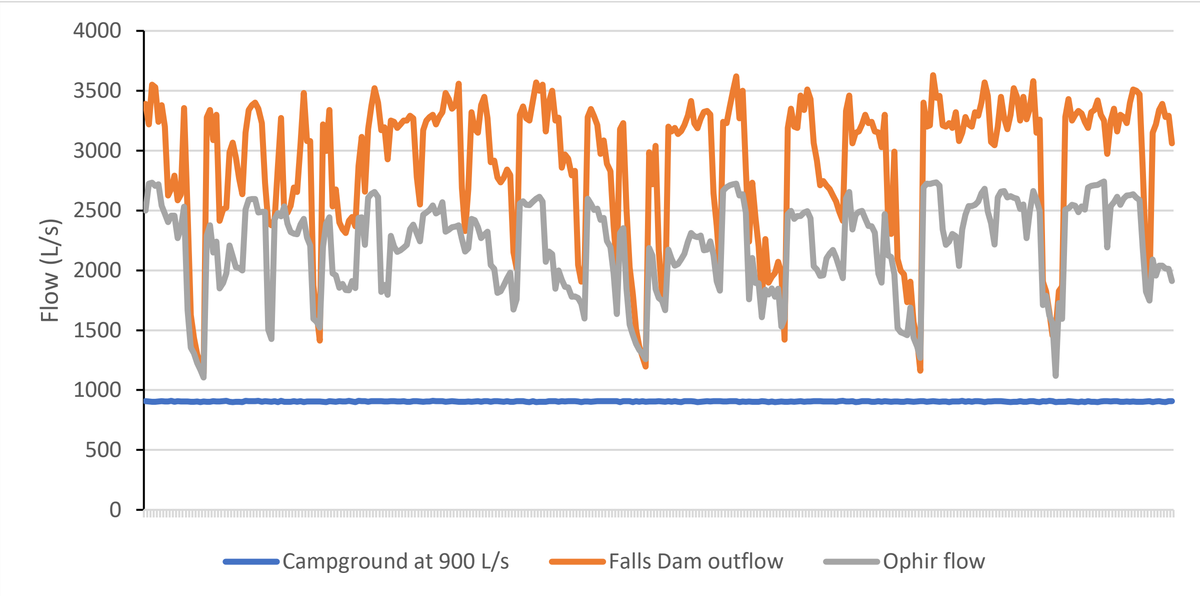

Figure 32: The Manuherekia River flow at Ophir and below Falls Dam when the campground flow is between 0.9 m^3/s and 0.91 m^3/s (data from Goldsim).

Therefore, this assessment of habitat available at the seven minimum flow scenarios does not address habitat available in the mid and upper reaches of the Manuherekia River.

5 Summary

The Otago Regional Council has developed three habitat models for the Manuherekia River, at Blackstone, Ophir and Galloway that can be used to predict habitat for a range of algal taxa, aquatic invertebrates and fish that are present in the Manuherekia River. The reaches of the river these habitat models can be applied to has been determined and over 50 % of the river length below Falls Dam can be included in the habitat models.

The habitat models have been used to predict habitat with flow from 0 m^3/s to 6 m^3/s at the three model sites. The various taxa show varying responses to change in river flow and can be broadly described in two ways. For diatoms, an important food source for invertebrates, habitat increases with increasing flow. For three key invertebrates that are common in the river and in fish diets, *Deleatidium, Aoteapysche* and chironomids (represented by *Maoridiamesa*) habitat also increases as flow increases. This relationship occurs at all three reaches in the river. For fish habitat key species, longfin eel and brown trout the habitat increases from very low levels at low flows to reach habitat plateaus or peaks and then the habitat either remains essentially stable or increases or decreases slowly with increasing flow.

The seven minimum flow scenarios, 0.9 m^3/s, 1.2 m^3/s, 1.5 m^3/s, 1.7 m^3/s, 2.0 m^3/s, 2.5 m^3/s and 3.0 m^3/s; provided different levels of habitat retention. The habitat provided was compared to the habitat predicted to be available at the estimated naturalist 7dMALF of 4.038 m^3/s. For taxa for which habitat continuously increased with flow the higher minimum flow scenarios were those that provided habitat close to the habitat predicted to be available at the naturalised 7dMALF. For the various fish species modelled, habitat for all aside from small brown trout peaked below the naturalised 7dMALf and the habitat available at the naturalised 7dMALF could be provided at lower flows.

If longfin eel and brown trout are used as the key fish species to provide habitat for the 1.5 m^3/s, 1.7 m^3/s and 2.0 m^3/s flow scenarios provide the best habitat outcomes. However, if food supply considerations are included in the assessment, then the higher flow scenarios provide significantly higher diatom and invertebrate habitat and has the potential to support healthier eel and trout populations as the increase in food supply benefits the fish with increased growth rate and condition. In addition, the increased invertebrate abundance has the potential to benefit insectivorous birds that feed along the riverbed and riparian margin.

Due to the variable nature to the Manuherekia River flow upstream of the Galloway reach the scenario model outcomes reported here are restricted to this reach of the river. The habitat available upstream of this reach at the seven minimum flow scenarios has not been assessed due to this flow variability.

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Appendix A

Algal habitat preferences

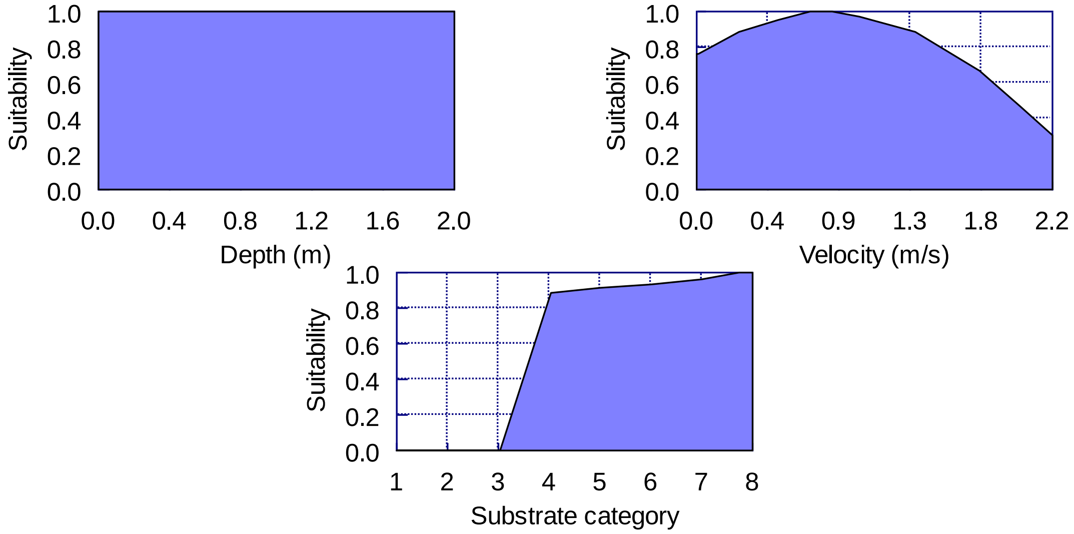

Figure A1: habitat preferences for Phormidium.

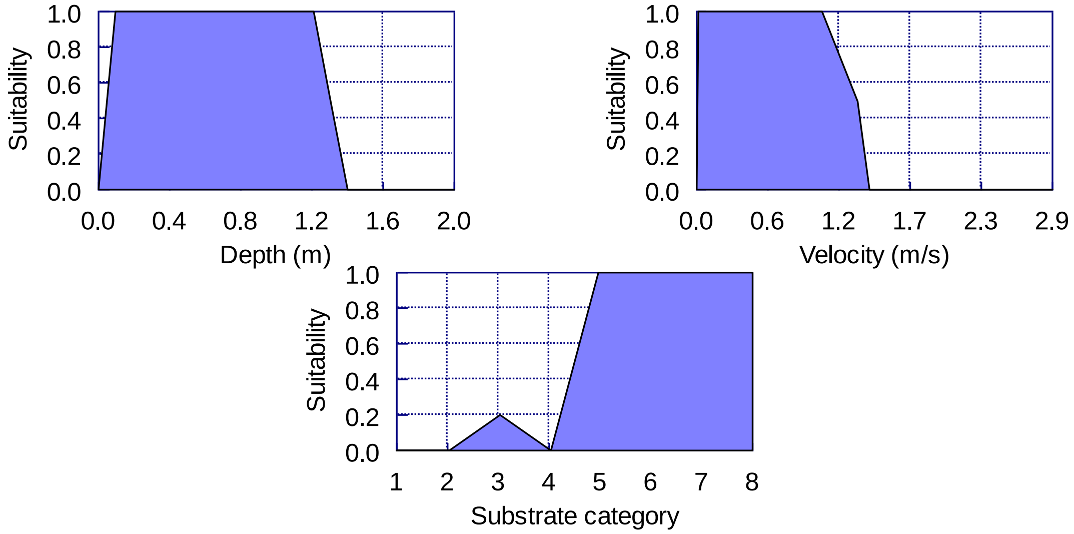

Figure A2: Habitat preferences for Didymo.

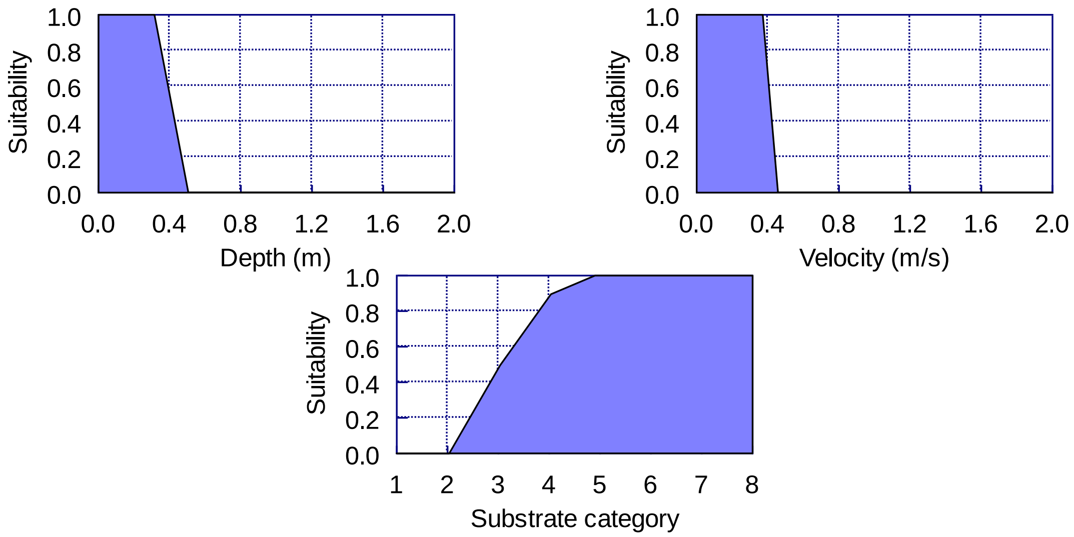

Figure A3: Habitat preferences for long filamentous algae.

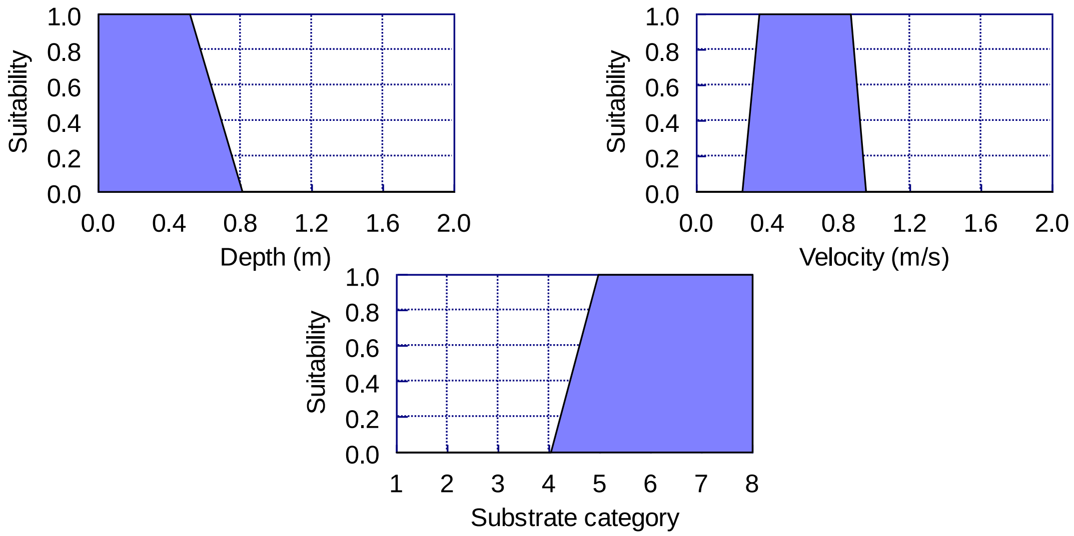

Figure A4: Habitat preferences for short filamentous algae.

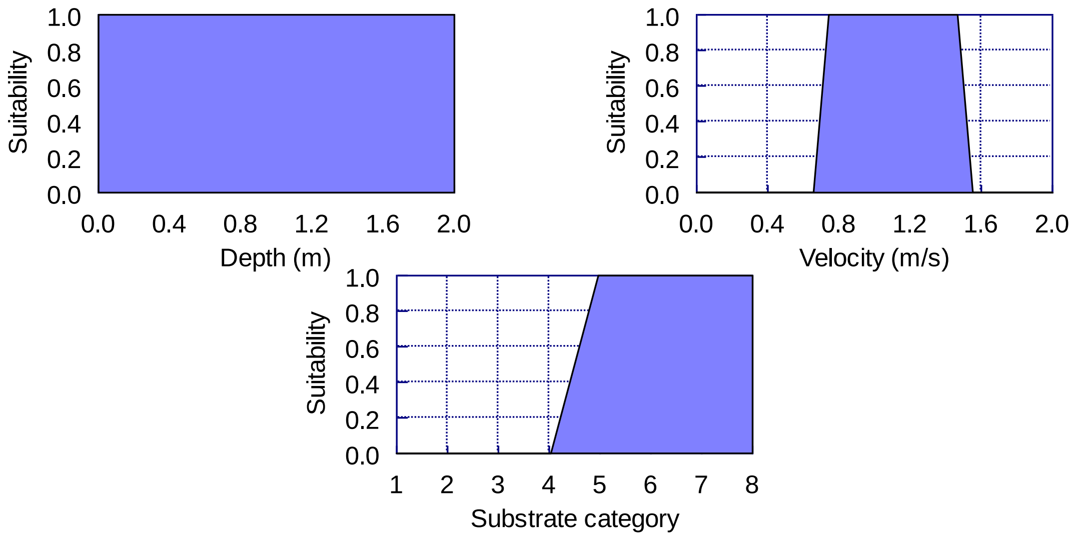

Figure A5: Habitat preferences for diatoms.

Invertebrate habitat preference curves

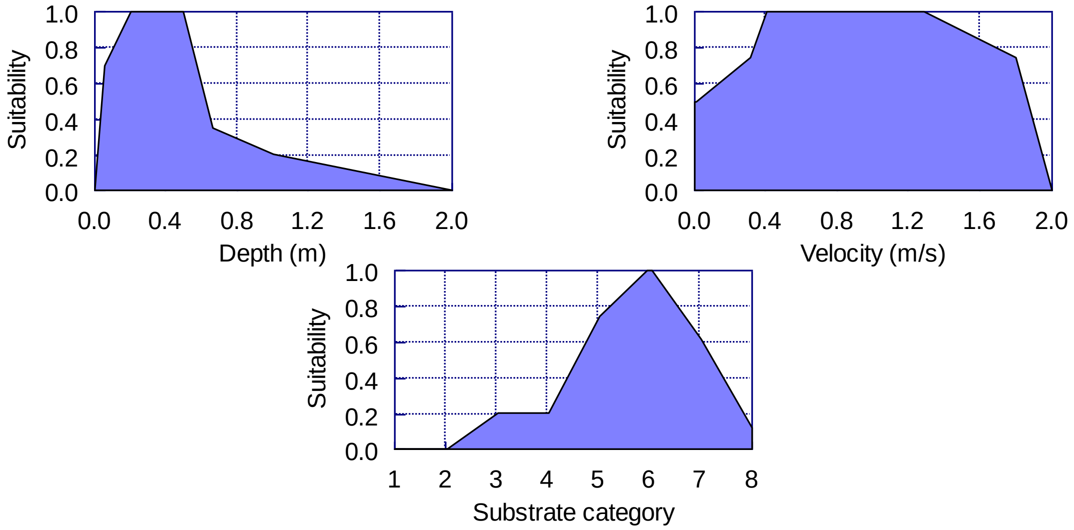

Figure A6: Habitat preferences for Deleatidium.

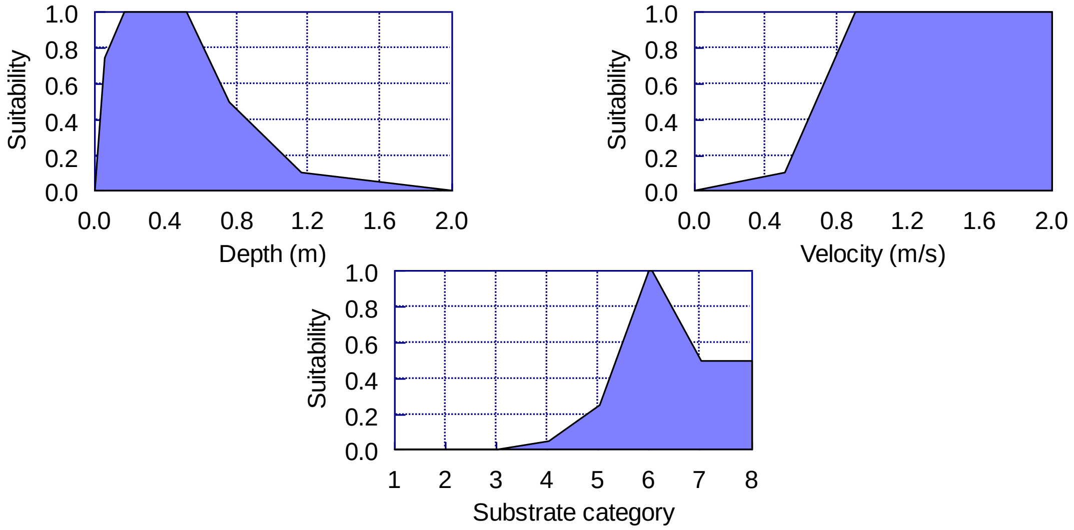

Figure A7: Habitat preferences for Aoteapsyche.

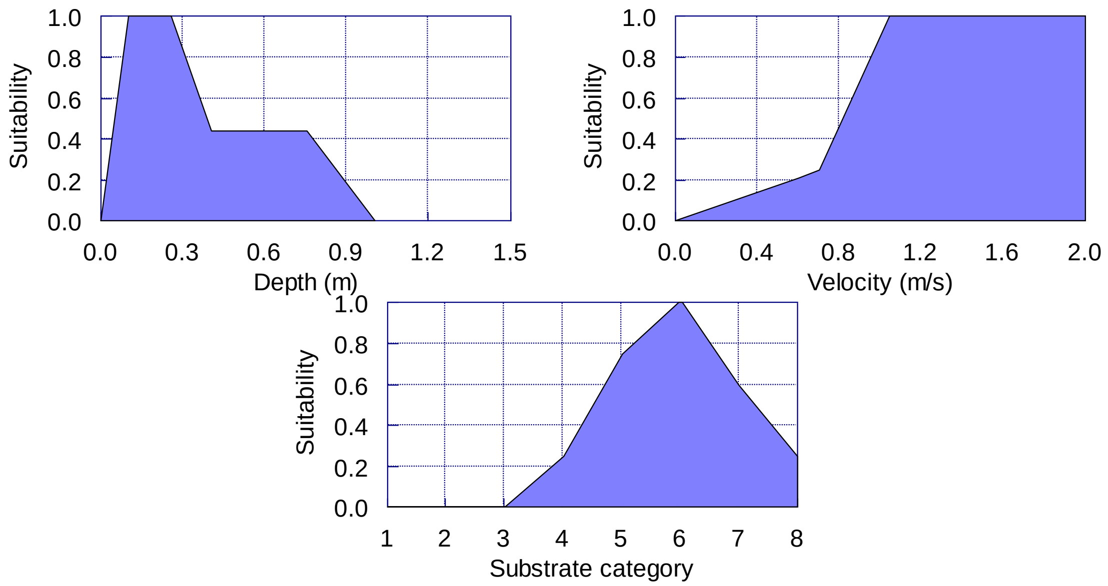

Figure A8: Habitat preferences for Maoridiamesa.

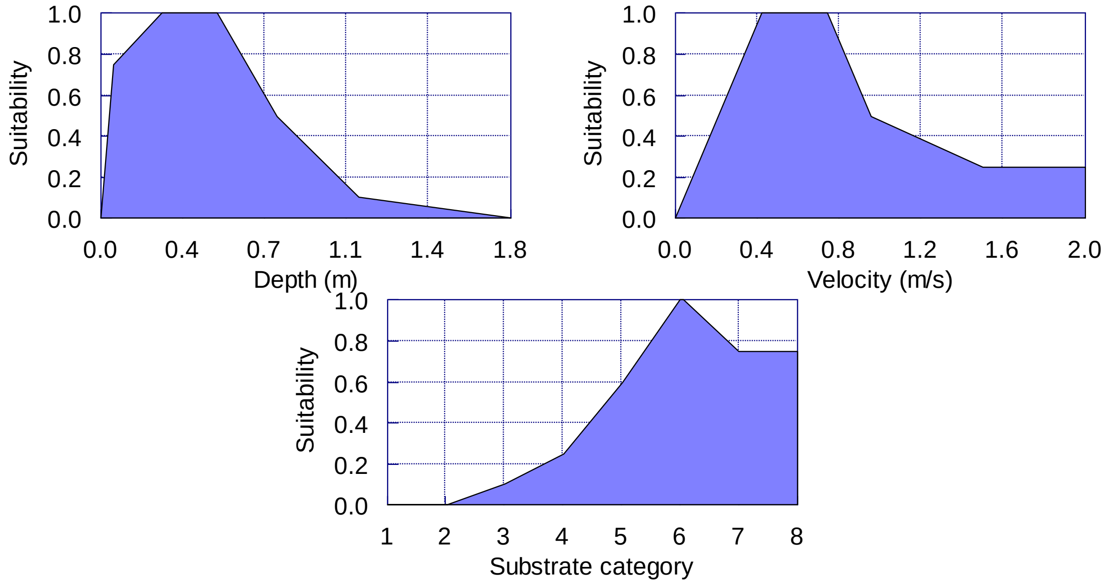

Figure A8: Habitat preferences for Pycnocentrodes.

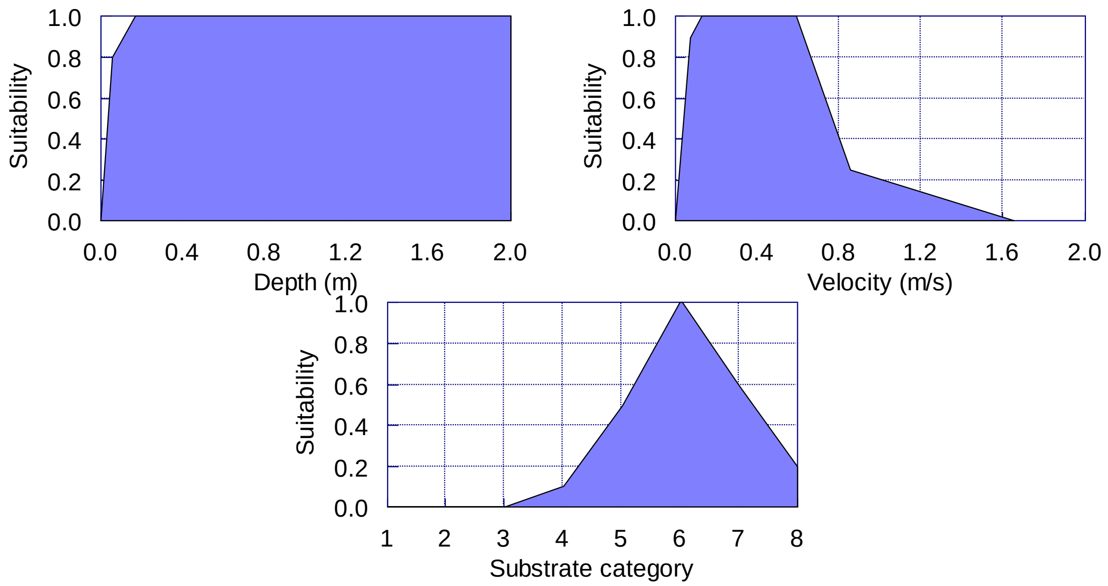

Figure A9: Habitat preferences for Nesameletus.

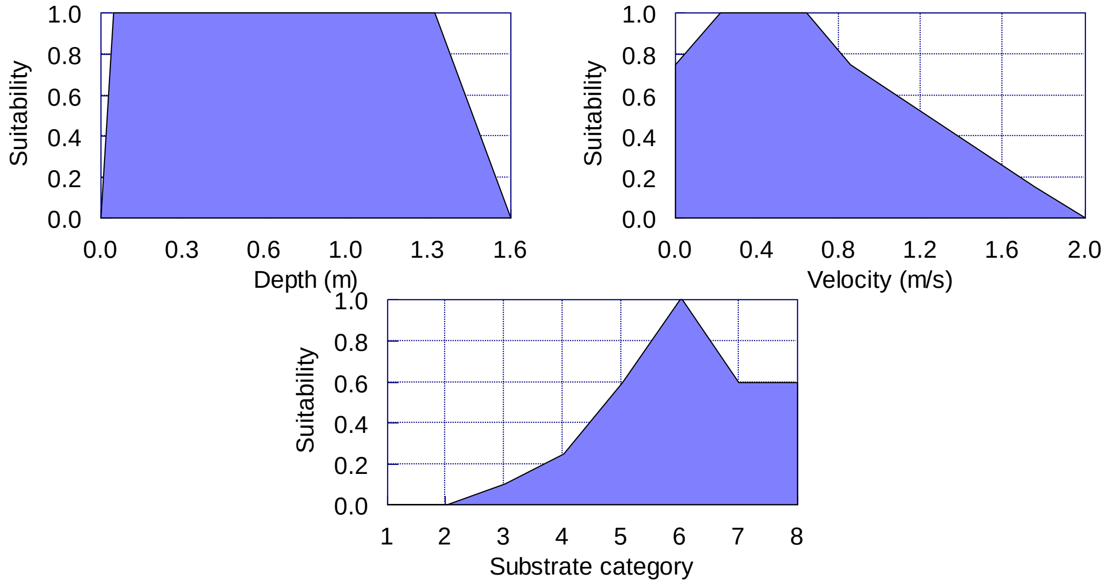

Figure A10: Habitat preferences for Olinga.

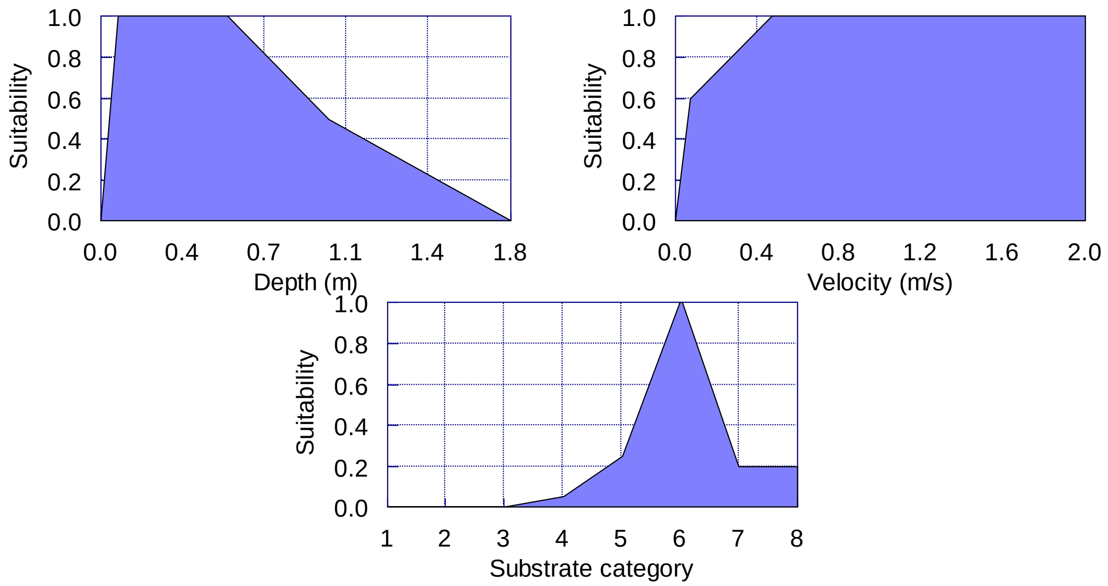

Figure A11: Habitat preferences for hydrobiosids.

Fish habitat preference curves

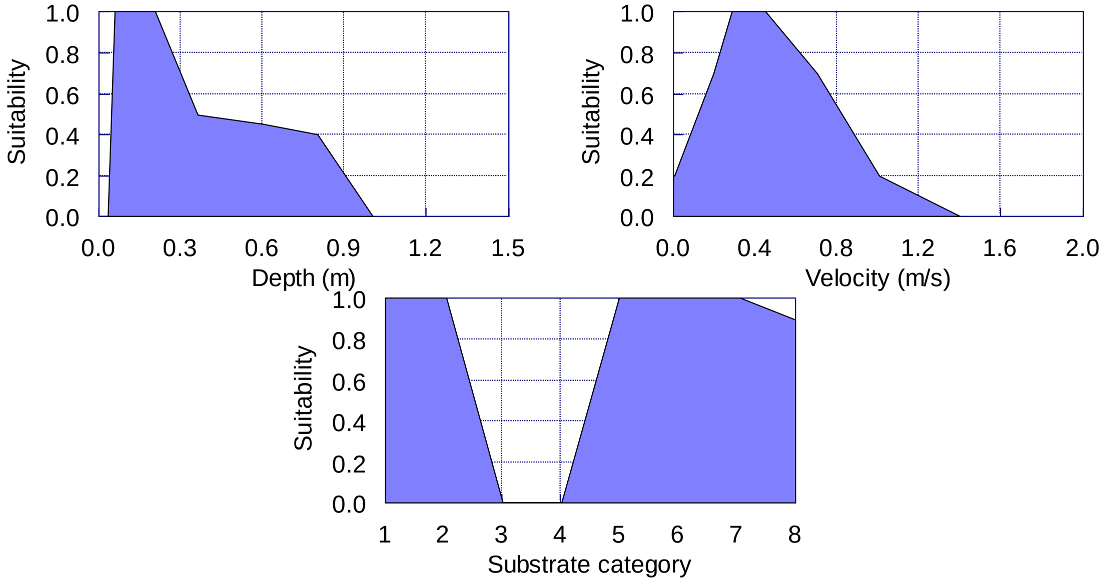

Figure A12: Habitat preferences for longfin eel < 300 mm.

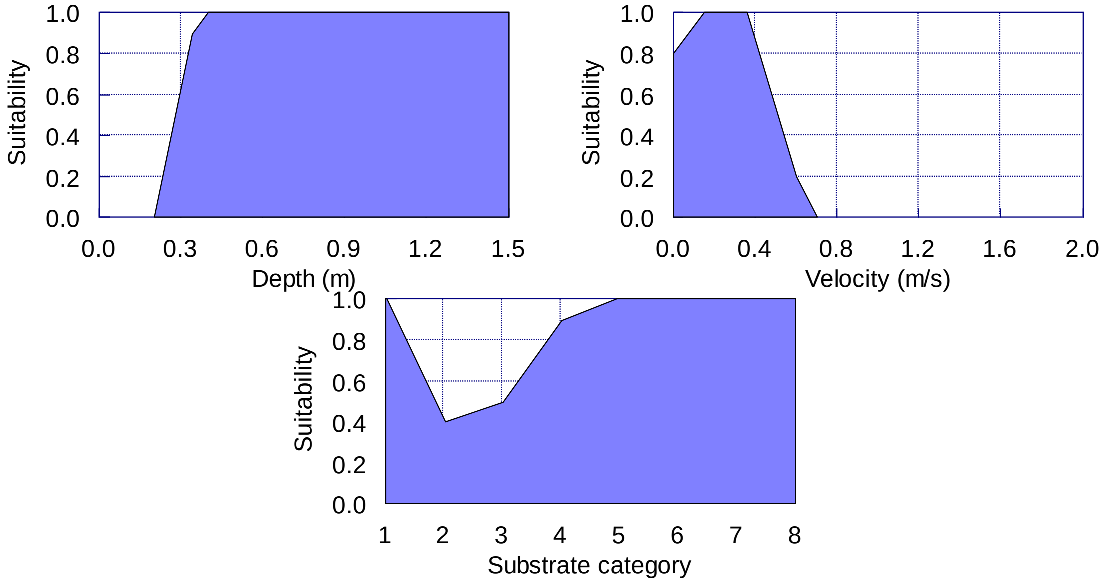

Figure A13: Habitat preferences for longfin eel > 300 mm.

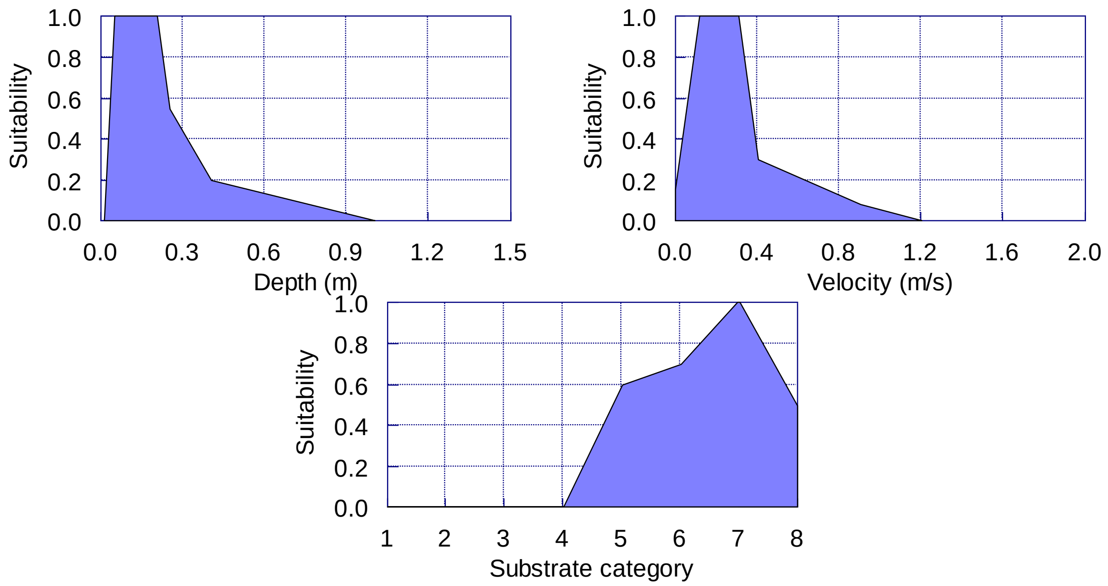

Figure A14: Habitat preferences for adult Central Otago roundhead galaxias.

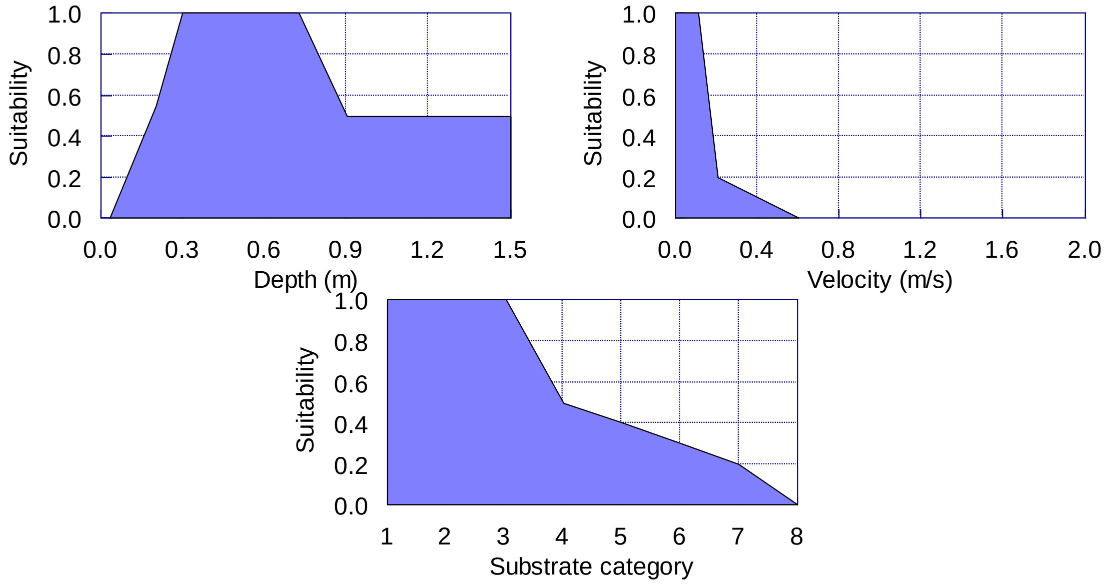

Figure A15: Habitat preferences for juvenile Central Otago roundhead galaxias.

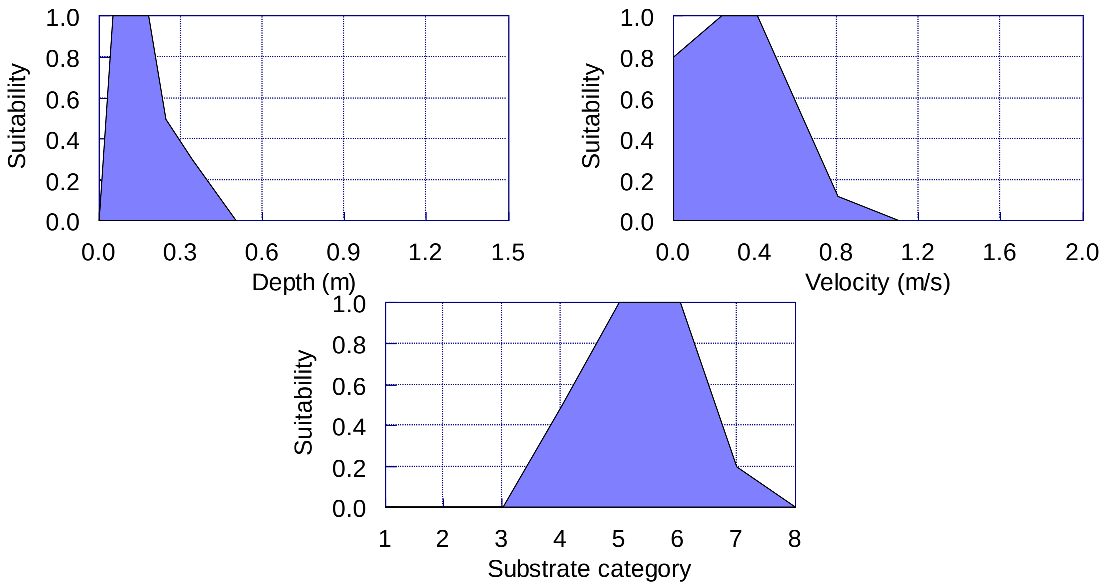

Figure A14: Habitat preferences for upland bully.

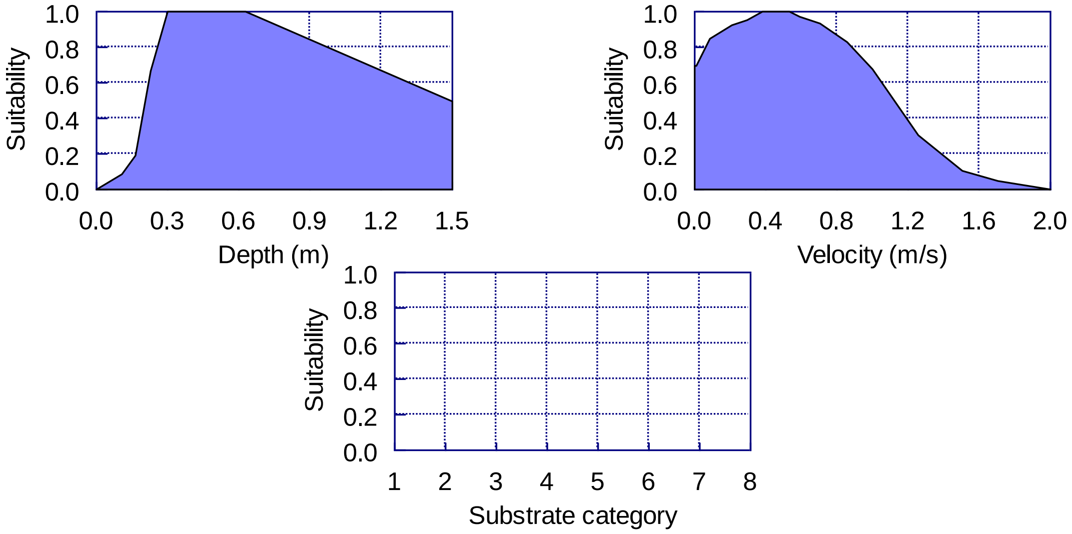

Figure A15: Habitat preferences for juvenile brown and rainbow trout.

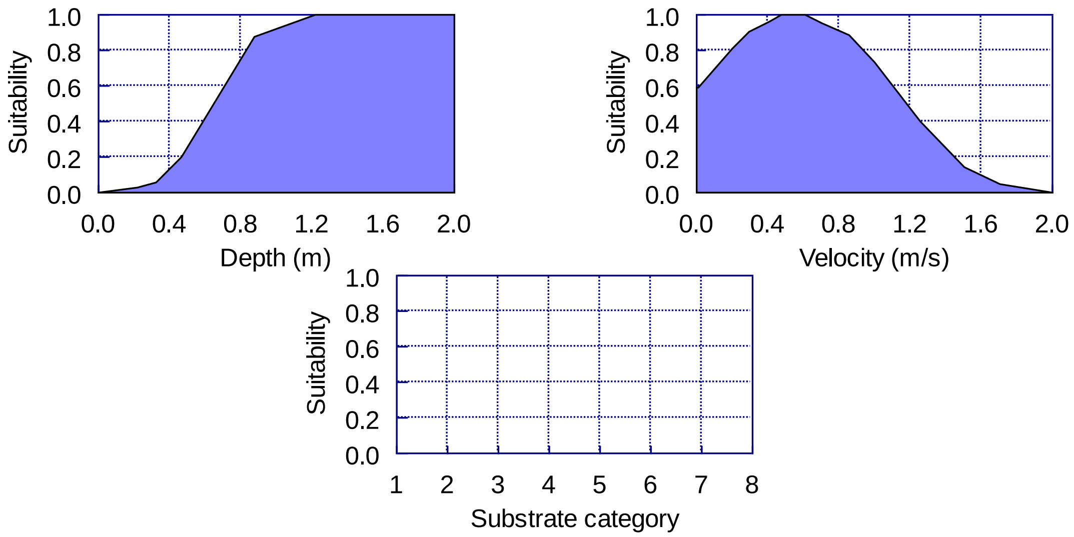

Figure A16: Habitat preferences for adult rainbow and brown trout

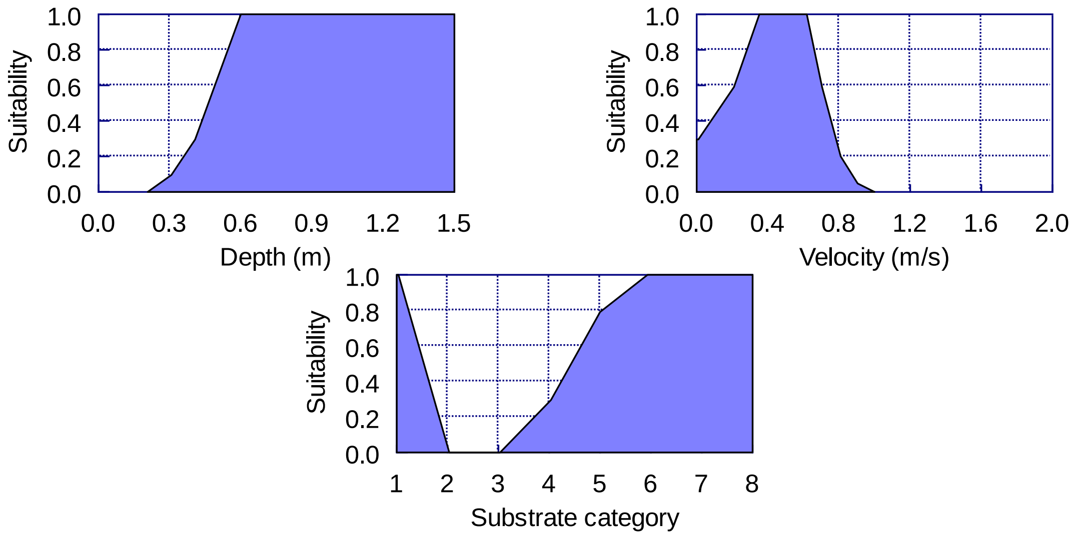

Figure A17: Habitat preferences for adult brown trout.

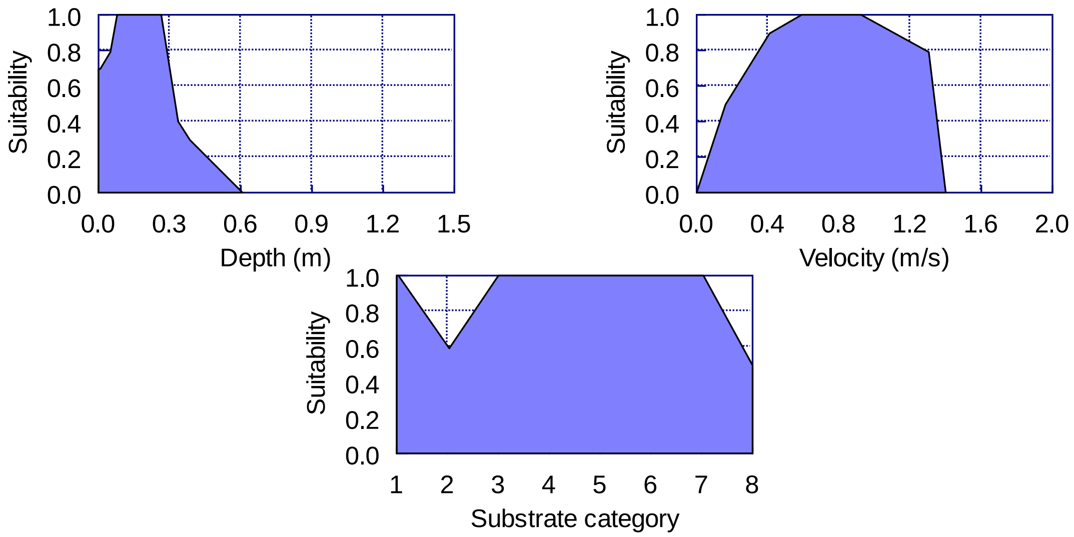

Figure A18: Habitat preferences for brown trout < 100 mm.

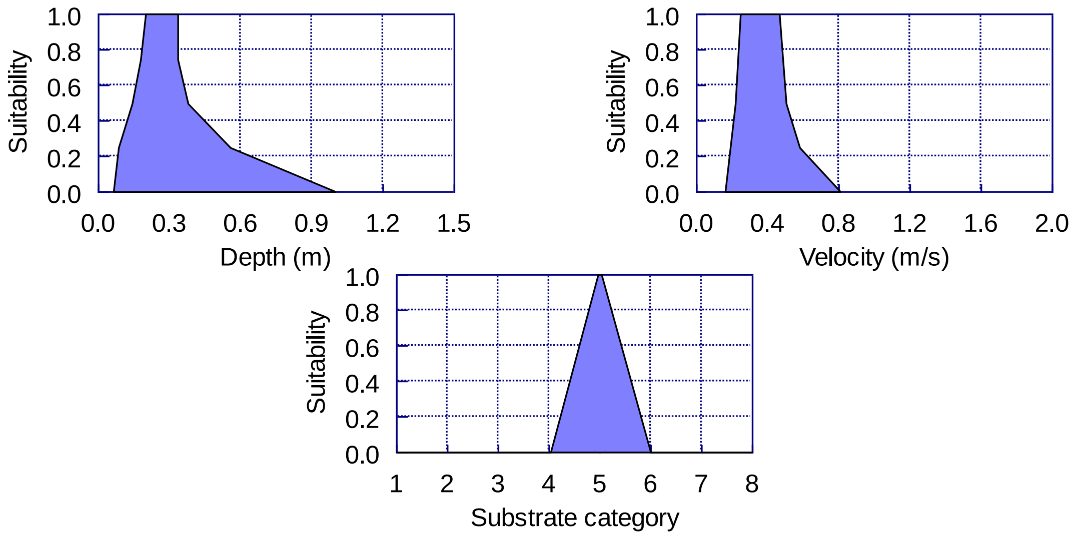

Figure A19: Habitat preferences for brown trout spawning