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Minimum flow assessment for six Otago streams and rivers

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REPORT

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Summary

Flow assessments were carried out on eight stream reaches in six Otago Rivers. The rivers assessed were: Sow Burn (two sites), Kauru River, Pig Burn, Sutton Stream, Waitahuna River (two sites) and Dunstan Creek.

For each reach, instream habitat (depth, width, velocity and substrate composition) and stream flow was measured and the relationship between stream flow and habitat for fish species present was modelled using RHYHABSIM computer software. For seven of the reaches, habitat models were possible and prediction of changes in Weighted Useable Area (WUA) and the Habitat Suitability Index (HSI) were determined for changing water flows. Habitat predictions were thwarted at one site (Kauru River), due to continuous low or no flows at the study reach.

Optimum and low flows suitable for providing for the fisheries values were determined based on the fish species and life history stages known to be present in the study reaches and the results of the RHYHABSIM models for each study reach. Optimal flows for fish species and size classes ranged from 0.05 m^3/s to 1.4 m^3/s and low flows at which habitat change was most rapid ranged from 0.05 m^3/s to 1.1 m^3/s.

Brown trout was present at all the study reaches and longfin eel was present five of the study sites. For these two species a range of life history stages were modelled at the sites. Other fish species present at least one site were roundhead galaxias, upland bully, lamprey, shortfin eel and rainbow trout.

1.0 INTRODUCTION

1.1 Overview

The Otago Regional Council (ORC) is assessing minimum flows for rivers throughout the region, as part of implementation of its regional plan for water. To assist in determining the appropriate minimum flows to be established on rivers and streams in Otago, a number of river resource surveys are to be conducted. These surveys include fish sampling and instream habitat measurements (i.e., depth, width, velocity and substrate) to assess what species and habitats are present. A standard instream habitat modelling approach (Jowett & Mosley 2004) is being used by ORC to determine the relationship between stream flow and habitat availability at each survey site and therefore determine what flows are required to provide adequate habitat for the fish species present.

1.2 Report Scope

Golder Associates NZ Ltd (Golder) conducted instream habitat surveys at eight sites on six waterways during 2006/2007, as follows:

- Pig Burn.
- Sow Burn.
- Waitahuna River.
- Dunstan Creek.
- Sutton Stream.
- Kauru River.

Field methods used standard ORC field techniques and information on fish populations was provided by ORC and the New Zealand Freshwater Fish Database (NZFFD). Modelling of the relationship between stream flow and habitat availability was conducted using RHYHABSIM modelling software, as required by ORC. This report describes the sites sampled and field methods used, the modelling results and uses the modelling results to recommend flows to provide habitat for the fish fauna known to be present at the sites surveyed. This analysis is restricted to effects on habitat availability; flow-related effects on water quality (e.g., temperature) are outside of the scope of this report.

Additional flow gauging was carried out at five sites established by the ORC and Sow Burn as temporary flow monitoring sites.

The results of this work will be used to assist the ORC in establishing minimum flows on these rivers and streams.

This report provided is subject to the limitations in Appendix 1.

2.0 METHODS

2.1 Study sites

Eight stream reaches were assessed on the six different waterways from across the Otago region (Table 1). All the waterways were relatively small and have existing water takes in the near vicinity. Further site details are provided in Section 3 below.

Table 1: Location of the eight study sites.

River/Stream	Number of sites	Approximate Location
Pig Burn	1	Downstream of H42:833-471
Sow Burn	2	Downstream of H42:785-442 Upstream of H42:786-435
Waitahuna River	2	Upstream of H45:584-643 Upstream of G45:454-484
Dunstan Creek	1	Downstream of H41:565-877
Sutton Stream	1	Vicinity of H43:832-083
Kauru River	1	Downstream of J41:323-641

Appendix 2 includes maps of each sampling site and GPS coordinates for all sampling cross sections.

2.2 Field Sampling

Fieldwork for six sites was undertaken in February and March 2007 (Dunstan Creek, Sutton Stream, Waitahuna River up and downstream sites, Kauru River and Sow Burn upstream site). Very low flows in the Kauru River and variable flows at the cross section sites confounded the assessment for this river. A final set of cross section flow measurements were not carried out at Kauru River due to an extreme flood event that caused major alternations to the river bed and all the established cross sections were lost in the flood. Irrigation abstraction in the Pig Burn site and the Sow Burn downstream site meant that flows at these two sites where highly variable and/or very low in February and March 2007. Both sites were assessed during a declining flow period in September and October 2007.

The study protocol followed that of Jowett (2006) for RHYHABSIM modelling assessments. Briefly, each reach to be modelled was first walked from the start point (Table 1) with the habitat type and the length of each habitat unit (run, riffle and pool) being recorded for approximately two kilometres. The designation of pool, riffle and runs was made in the context of the habitat available in each individual stream and while these habitat units were readily recognisable in each stream, the physical character of each stream lead to some variation in the nature of these habitat units between streams. Additional notes on the character of each stream were made that provided background information on the number of channels, the presence of backwaters, stream stability, channel and riparian vegetation and fish observations. Once the reach had been walked 15 cross sections were selected: five riffle sections, five run sections and five pool sections.

For each cross section the stream width was measured and a series of depth and water velocity measurements made. The number of depth and velocity measurements made on each cross section varied, with larger cross sections having a greater number of measurements. The spacing of measurements was closer in high velocity water areas or areas of variable flow to ensure velocity measurements and subsequent flow calculations were more accurate.

A temporary stage was installed at each cross-section and the water level recorded during the first round of fieldwork. Two follow-up surveys were conducted at each site. For each follow-up survey, stream flow was gauged at one cross section and water levels were recorded from the temporary stage at each cross section.

2.3 Fish Sampling

The NZFFD was searched for fish records and the Otago Regional Council conducted fish surveys at each of the modelling sites in February to April 2007 and the results of the database searches and fish surveys (Table 2) were used to determine which species and when appropriate (and possible) which life history stages to include in the RHYHABSIM modelling. Fish species recorded in the NZFFD that were not in the vicinity of the study reaches were not included in the analysis.

Table 2: Fish species present at modelling sites (data from Otago Regional Council, NZFFD).

River/Stream	Fish species	Life history stages
Pig Burn	Brown trout Longfin eel	Juvenile > 300 mm , < 300 mm
Upper Sow Burn	Brown trout	Juvenile
Lower Sow Burn	Brown trout Longfin eel Chinook salmon	Juvenile > 300 mm , < 300 mm Juvenile
Upper Waitahuna River	Brown trout Lamprey Longfin eel	Juvenile and adult Ammocoetes > 300 mm , < 300 mm
Lower Waitahuna River	Brown trout Lamprey Longfin eel Shortfin eel	Juvenile and adult Ammocoetes 300 mm , < 300 mm
Dunstan Creek	Brown trout Rainbow trout Upland bully Roundhead galaxias	Juvenile, adult Juvenile, adult Adult Juvenile, adult
Sutton Stream	Brown trout Lamprey Longfin eel	Juvenile and adult Ammocoetes > 300 mm , < 300 mm
Kauru River	Brown trout Lowland longjaw galaxias Upland bully Longfin eel	Juvenile and adult Adult Adult > 300 mm , < 300 mm

2.4 RHYHABSIM Modelling

Habitat preference curves for the fish species were selected from the library of preference curves available with RHYHABSIM (Version 6.1). When there was more than one species habitat preference curve available, general habitat preference curves were used rather than site-specific curves derived from other water ways (Table 3, Appendix 3). For consistency with previous RHYHABSIM studies in Otago (e.g., Jowett 2006) preferences curves utilised in these studies were preferred especially when based on fish habitat preference data from New Zealand rivers. For juvenile trout, fry and juvenile habitat preference curves were used to model habitat availability. For adult trout, yearling and adult brown trout habitat preference curves were used. Trout spawning habitat models were applied at all sites that juveniles trout were recorded from.

Table 3: Habitat preference curves used for RHYHABSIM modelling.

Fish species	Life history stage	Preference curve source
Brown trout	Fry	Bovee 1978
	Adult	Hayes & Jowett 1994
	Fry to 15 cm fish	Raleigh et al. 1986
	Yearling	Raleigh et al. 1986
	Spawning	Shirvell & Dungey 1983
Rainbow trout	Fry	Bovee 1978
	Fingerling	Bovee 1978
	Adult	Thomas & Bovee 1993
	Spawning	Jowett et al 1996
Longfin eel	< 300 mm	Jellyman et al 2003
	> 300 mm	Jellyman et al 2003
Shortfin eel	< 300 ml	Jowett & Richardson 1995
Upland bully	Adult	Jowett & Richardson 1995
Lamprey	Ammocoetes	Jellyman & Glova 2002
Roundhead galaxias	Adult	Baker et al 2003
Food producing habitat		Waters et al

The RHYHABSIM modelling procedure followed that recommended by Jowett (2006). All models were run as reach models with habitat units weighted according to their frequency of occurrence in the study reach (i.e., a habitat mapping approach, not a "representative reach" approach). All reaches were modelled for flows lower than the 7 day mean annual low flow (7dMALF) to 2.0 m^3/s.

Minimum flow recommendations for each site were determined by analysing the relationship between stream flow and habitat availability for the species present. Habitat availability was expressed as weighted usable area (WUA; m^2/m) and the habitat suitability index (HSI). The WUA expressed as a proportion of total wetted area, and can be regarded as a measure of habitat "quantity". In general minimum flow recommendations were based on the habitat requirements of key species and, when present, used a point of inflection for target species in the WUA curves as a determining factor.

3.0 STUDY REACHES

3.1 Overview

The 2006/2007 summer period began with above average rainfall in much of Otago. However rainfall declined in mid-summer and lead to average to low flows at the majority of study sites. Habitat surveys were carried out at flows near to low flows for six sites (Kauru River, Waitahuna River, the upper Sow Burn, Dunstan Creek and Sutton Stream). Water abstraction at the Pig Burn and lower Sow Burn gave rise to dry stream sections in the study reaches and these sites were sampled during high but declining spring flows when the study reaches were fully wetted (Table 4).

Table 4: Survey flows and low flow statistics from the study sites (flow statistics provided by the Otago Regional Council).

Site	Survey flow (m^3/s)	Calibration flow 1 (m^3/s)	Calibration flow 2 (m^3/s)	Calibration flow 3 (m^3/s	7dMALF (m^3/s)	Lowest daily flow (m^3/s)
Pig Burn	0.436	0.390	0.332		0.020	0.019
Upper Sow Burn	0.449	0.269	0.259		0.226	0.215
Lower Sow Burn	0.932	0.876	0.918		0.226*	0.215
Upper Waitahuna River	0.816	0.696	0.673	0.905	0.633	0.398
Lower Waitahuna River	0.787	0.726	0.680	0.870	0.633*	0.398
Dunstan Creek	0.622	0.567	0.490		0.660	0.428
Sutton Stream	0.448	0.143	0.164		0.169	0.064
Kauru River	0.521	0.049	0.036	0.370	0.111	0.040

Notes: * Uses flow data from near the upper study reach on this river.

3.2 Pig Burn

The Pig Burn drains the north-western end of the Rock and Pillar Range. The study reach on this stream was located on the lower part of the stream where it flows across the Maniototo Plains. Water abstraction occurs upstream and downstream of the study reach. In summer the reach is a series of intermittently flowing and dry zones, as water abstraction takes 100% of the stream flow at the abstraction sites. The additional flow gauging was undertaken during the summer low flow period (Appendix 4). The cross-section measurements for this site were collected early in the irrigation season (September 2007) when the stream had a moderate flow throughout the length of the study reach. To minimise the effects of abstraction on the flows measured in the stream the study reach was restricted to a reach approximately 1.6 km long between the upper limit of the study reach and the first downstream irrigation abstraction.

The reach studied varied in width from 3 – 7 m and had a maximum depth in the pools of approximately 0.7 m (Table 5). The streambed consisted of gravel and cobble substrates.

Outcrops of mudstone bedrock occur very infrequently where the stream has become incised in the alluvial terraces. Macrophytes were absent from the stream and instream cover was provided almost exclusively by the substrate. The riparian margin is characterized by pasture with patches of gorse and broom and occasional stands of willow. The stream was open to stock throughout the survey reach (Figure 1).

Table 5: Cross section characteristics for the Pig Burn.

Cross section	Pool/ Riffle/ Run	Width (m)	Max Depth (m)	Average Depth (m)	Max Velocity (m/s)	Discharge (m^3/s)
1	Riffle	5.55	0.21	0.12	0.96	0.51
2	Pool	5	0.65	0.33	0.58	0.52
3	Riffle	4.05	0.35	0.16	1.06	0.48
4	Pool	4	0.45	0.27	0.79	0.44
5	Riffle	3.85	0.29	0.14	1.07	0.46
6	Run	3.15	0.52	0.25	0.65	0.45
7	Run	3.65	0.38	0.18	0.85	0.39
8	Pool	5.25	0.67	0.34	0.52	0.47
9	Riffle	4.5	0.23	0.14	1.22	0.47
10	Run	5.8	0.31	0.18	0.66	0.46
11	Pool	6.2	0.39	0.19	0.66	0.44
12	Pool	4.5	0.52	0.30	0.63	0.43
13	Riffle	4.4	0.3	0.14	1.02	0.46
14	Run	4.3	0.3	0.16	1.04	0.44
15	**Run**	**3.95**	**0.35**	**0.16**	**0.82**	**0.44**
Average values						**Percentage of the reach**
Averages for:	**Runs**	4.16	0.37	0.19	0.81	50
	Riffles	4.47	0.28	0.14	1.07	46
	Pools	4.99	0.54	0.29	0.64	4

Figure 1: Pig Burn gauging site (cross section 15).

3.3 Sow Burn

3.3.1 Upper Sow Burn

The upper Sow Burn site is at the lower end of the gorge section where the stream flows down off the Rock and Pillar Range. The lower end of the reach was upstream of a major water abstraction and fish passage ladder and extended upstream to an area where the channel and gorge narrowed significantly leading to a change in stream character. The site visits for this reach were all undertaken in March 2007 together with the additional flow gauging (Appendix 4).

Stream habitat was dominated by riffle and run sections with occasional pools. The stream has a moderately steep gradient and stream substrates are dominated by boulders and cobbles. Schist bedrock outcrops occur occasionally and scour around bedrock banks often created deeper pool habitats. Evidence of previous modifications to the stream channel where present in part of the reach where old gold workings (i.e., tailings) were present. However, this historic gold mining does not appear to be affecting the mix of current habitat types present, with a good variety of habitat types available. Stream width varied from 5 m to 11.5 m and mean water depth was between 0.09 m and 0.73 m at the cross sections assessed (Table 6). Instream cover was provided by the substrate and occasionally by overhanging bank vegetation. The riparian margin was a mix of indigenous shrubs and grasses. There was little stream shade, due to the lack of tall riparian vegetation present and the wide stream channel (Figure 2).

Table 6: Cross section characteristics for the upper Sow Burn.

Cross section	Pool/ Riffle/ Run	Width (m)	Max Depth (m)	Average Depth (m)	Max Velocity (m/s)	Discharge (m^3/s)
1	**Pool**	**6.55**	**0.53**	**0.31**	**0.23**	**0.45**
2	Riffle	7.55	0.41	0.21	0.72	0.46
3	Run	8.6	0.68	0.32	0.40	0.42
4	Riffle	6.2	0.65	0.30	0.82	0.44
5	Run	8	0.42	0.17	0.68	0.39
6	Pool	11.16	0.75	0.31	0.46	0.42
7	Pool	6.9	1.13	0.73	0.25	0.45
8	Riffle	7.2	0.31	0.09	1.17	0.39
9	Pool	5.55	1.1	0.57	0.35	0.36
10	Run	5.28	0.46	0.30	0.46	0.34
11	Riffle	6.6	0.32	0.09	0.86	0.28
12	Run	9.45	0.47	0.19	0.52	0.32
13	Pool	10.6	0.71	0.22	0.32	0.39
14	Run	7.6	0.32	0.16	0.50	0.34
15	Riffle	3.85	0.41	0.16	0.94	0.32
Average values						**Percentage of the reach**
Averages for:	Runs	7.79	0.47	0.23	0.51	32
	Riffles	6.28	0.42	0.17	0.90	59
	Pools	8.15	0.84	0.43	0.32	9

Figure 2: Upper Sow Burn gauging site (cross section 1).

3.3.2 Lower Sow Burn

The lower Sow Burn reach ran upstream from Duffy Road to the Patearoa Road bridge over the Sow Burn. The uppermost cross section was approximately 50 m downstream of a water abstraction at the bridge. Cross sections 13 - 15 were upstream of a further abstraction point that commenced taking water during the study period in September/October 2007. The three upper cross sections were excluded from the RHYHABSIM analysis due to water abstraction resulting in an unpredictable difference in flow from the gauging site (cross section 1).

The stream reach varied progressively upstream from an open channel with a wide scrub-covered flood plain to a stream confined between river banks with the riparian zone comprised of relatively dense willow and scrub. The stream substrate also varied, with the downstream reaches being predominately fine cobble and gravel and the upper parts of the reach having coarser cobbles and boulder with some gravel (Figure 3). Stream habitat was dominated by run sections, with riffle and pool habitat being relatively rare. Pool habitat was more abundant in the upper parts of the reach. Instream cover varied throughout the reach with the lower reaches characterised by limited cover in the substrate and from overhanging banks and vegetation. In the most upstream sections cover was abundant provided by the substrate and overhanging willow trees and root wads on the riparian margin. Deep pools were all associated with the areas of the stream with dense riparian plantings of willow; these deep pools were generally scour pools. Stream width ranged from 5 m to 9.5 m and average water depths ranged from 0.17 m to 0.54 m (Table 7).

Figure 3: Lower Sow Burn gauging site (cross section 1).

Table 7: Cross section characteristics for the lower Sow Burn.

Cross section	Pool/ Riffle/ Run	Width (m)	Max Depth (m)	Average Depth (m)	Max Velocity (m/s)	Discharge (m^3/s)
1	**Run**	**6.9**	**0.47**	**0.27**	**0.56**	**0.94**
2	Run	5.9	0.36	0.17	1.68	0.99
3	Pool	6.25	0.7	0.37	0.58	1.02
4	Pool	5.45	0.66	0.44	0.53	0.93
5	Riffle	6.3	0.37	0.23	0.89	1.10
6	Run	9.25	0.3	0.20	0.56	1.04
7	Pool	8.9	0.53	0.27	0.62	1.00
8	Riffle	6.9	0.35	0.17	1	0.97
9	Run	5.78	0.52	0.29	0.78	0.96
10	Run	6.7	0.43	0.23	0.84	1.05
11	Pool	7.13	0.66	0.37	0.53	0.92
12	Riffle	3.37	0.43	0.23	1.77	1.11
13	Pool	9.25	1.35	0.54	0.48	1.09
14	Riffle	7.77	0.4	0.22	1.18	0.94
15	Run	9.72	0.29	0.19	0.77	1.04
Average values						**Percentage of the reach**
	Runs	7.38	0.40	0.23	0.87	57
	Riffles	6.09	0.39	0.21	1.21	36
	Pools	7.40	0.78	0.40	0.55	7

3.4 Waitahuna River

3.4.1 Upper Waitahuna River

The upper Waitahuna River reach extended from the Waitahuna Golf Course upstream for approximately 1.7 km. The site was sampled in February and March 2007.

The upper Waitahuna River reach was characterised by long slow flowing pools and run sections interspersed with short riffles. River width varied from 5 m to nearly 19 m and depths averaged between 0.16 m to 0.78 m on the cross sections (Table 8). The stream bed substrate was variable with some schist bedrock exposure in riffles and runs. Cobble and boulder particles were also generally restricted to the high water velocity habitats and the pools substrates were dominated by mud, sand and fine gravel. Instream cover was provided by the cobble and boulder substrate of riffles and by marginal vegetation along the reach. Deep water in some pool areas also provided some cover simply due to its depth. The reaches ran through pastoral land with well grazed riparian margins, apart from the golf course area where the banks were rank grasses. Occasional willow trees and small shrubs provided the only stream shade. The stream banks also showed signs of erosion with steep, eroding, vegetation-free banks occurring throughout the reach (Figure 4).

Table 8: Cross section characteristics for the upper Waitahuna River.

Cross section	Pool/ Riffle/ Run	Width (m)	Max Depth (m)	Average Depth (m)	Max Velocity (m/s)	Discharge (m^3/s)
1	Run	7.55	0.39	0.24	0.50	0.82
2	Riffle	8.55	0.39	0.20	0.73	0.81
3	Pool	12.1	0.68	0.46	0.35	0.83
4	Riffle	12.41	0.28	0.16	0.77	0.77
5	Run	10.6	0.39	0.28	0.31	0.80
6	Riffle	5.91	0.29	0.18	1.07	0.92
7	Pool	15.2	0.65	0.37	0.32	0.82
8	Run	8.48	0.47	0.28	0.58	0.76
9	Pool	18.63	1.16	0.78	0.07	0.72
10	Run	13.8	0.5	0.34	0.52	0.86
11	Pool	9.95	0.9	0.61	0.17	0.83
12	Riffle	10.8	0.26	0.16	1.00	0.80
13	Run	6.25	0.82	0.45	0.37	0.76
14	Riffle	5.1	0.38	0.20	1.20	0.79
15	Pool	10.15	0.81	0.43	0.16	0.82
Average values						**Percentage of the reach**
Averages for:	Runs	9.34	0.51	0.32	0.46	37
	Riffles	8.55	0.32	0.18	0.95	25
	Pools	13.21	0.84	0.53	0.21	38

Figure 4: Upper Waitahuna River gauging site (cross section 15)

3.4.2 Lower Waitahuna River

The lower Waitahuna River reach extended from the Clutha Valley Road upstream for approximately 1.9 km, continuing upstream past the end of Queen Hills Road. The site was sampled in February and March 2007.

The lower Waitahuna River reach is an incised reach that has cut a channel through alluvial sediment deposits down to the schist bedrock. It was dominated by long run habitats interspersed with short riffle sections and rare pool habitats. River width varied from 4 m to nearly 12 m and depths averaged between 0.17 m to 0.85 m on the cross sections (Table 9). Some deeper water habitat was present in one or two pool sections. The stream bed substrate was variable with some schist bedrock or mudstone exposure in riffles and runs. Cobble and, in particular, boulder particles were rare and restricted to the high water velocity habitats. Substrates in runs and pools were dominated by mud, sand and gravel. Instream cover for much of the reach was limited, riparian vegetation and occasional log jams where the predominant form of cover. The instream substrate did provide cover for smaller fish in some riffle areas where substrates were large enough. The reach ran through pastoral land with a well grazed riparian margin on the true left bank. Crack willow trees lined this bank for the full length of the study reach (Figure 5). The true right bank was ungrazed along most of Queens Hill Road, but it was grazed in the upper 500 m of the reach. Trees were (willow or black popular) uncommon along this bank. The true left stream bank was stable with no signs of erosion. Conversely, the true right bank which was much steeper had occasional active erosion areas.

Table 9: Cross section characteristics for the lower Waitahuna River.

Cross section	Pool/ Riffle/ Run	Width (m)	Max Depth (m)	Average Depth (m)	Max Velocity (m/s)	Discharge (m^3/s)
1	run	7.75	0.89	0.39	0.55	0.77
2	riffle	4.05	0.6	0.33	1.02	0.69
3	**run**	**5.15**	**0.61**	**0.40**	**0.37**	**0.78**
4	pool	7.33	1.03	0.63	0.24	0.89
5	pool	8.75	1.04	0.64	0.20	0.85
6	riffle	3.7	0.54	0.33	0.88	0.86
7	riffle	6.1	0.54	0.22	0.85	0.77
8	run	4.85	0.69	0.56	0.57	0.86
9	pool	11.42	1.02	0.57	0.27	0.93
10	pool	6.75	1.12	0.74	0.20	0.80
11	riffle	5.65	0.38	0.17	1.01	0.86
12	run	8.93	0.59	0.33	0.32	0.85
13	pool	10.2	1.21	0.85	0.25	0.83
14	run	6.36	0.76	0.46	0.34	0.74
15	riffle	5.47	0.34	0.21	0.87	0.82
Average values						**Percentage of the reach**
Averages for:	Runs	6.61	0.71	0.43	0.43	75
	Riffles	4.99	0.48	0.25	0.93	15
	Pools	8.89	1.08	0.69	0.23	10

Figure 5: Lower Waitahuna River gauging site (cross section 3).

3.5 Dunstan Creek

The Dunstan Creek reach extended downstream from Loop Road (near St Bathans) for approximately 2 km. The site was sampled in March 2007.

The reach sampled was an alluvial flood plain with the stream largely restricted to a single channel during low flows. The stream was wide and shallow for most of the reach sampled, with the width varying from 4 m to 12.5 m and average depths across the cross sections varying from 0.1 m to 0.62 m (Table 10). Bed sediments were dominated by coarse gravel and cobble with some boulder. Riffle and run habitat dominated the reach with pool habitat making up 3% of the available habitat. The riparian margin was vegetated with a mix of rank grasses, scrub (mainly broom) and occasional willow trees with some low intensity grazing. Throughout the reach the stream banks where often exposed gravel and cobble substrate with active erosion occurring in many areas as the stream reworked previously deposited alluvial gravel and cobbles (Figure 6). Pool habitat was almost exclusively associated with willow trees and all the pools were scour pools, some with a mudstone bedrock bottom and often with relatively high water velocities Instream cover was provided by the substrate in riffle and run areas. The pool habitat that was associated with the riparian willows often had fish cover amongst willow root systems and associated woody debris. Occasionally pieces of overhanging vegetation also provided important cover in some pools and deeper run habitats. Backwater habitats were present and were generally located at the downstream end of flood flow channels where the channels merge, or at scour areas alongside eroding terraces.

Figure 6: Dunstan Creek gauging site (cross section 1).

Table 10: Cross section characteristics for the Dunstan Creek.

Cross section	Pool/ Riffle/ Run	Width (m)	Max Depth (m)	Average Depth (m)	Max Velocity (m/s)	Discharge (m^3/s)
1	**run**	**8.6**	**0.36**	**0.156**	**0.559**	**0.62**
2	riffle	5.8	0.26	0.15	1.37	0.51
3	pool	5.3	1.25	0.62	0.50	0.64
4	run	4.07	0.47	0.26	1.17	0.62
5	pool	5.9	0.69	0.28	0.86	0.56
6	pool	7.8	0.64	0.28	0.49	0.71
7	run	5.8	0.34	0.16	0.88	0.72
8	pool	6.25	0.71	0.40	0.54	0.62
9	run	6.02	0.44	0.23	0.68	0.75
10	pool	7.5	0.64	0.24	0.50	0.64
11	riffle	9.8	0.25	0.13	0.74	0.79
12	riffle	9.2	0.45	0.16	1.08	0.70
13	riffle	12.4	0.25	0.10	0.86	0.80
14	riffle	8.55	0.27	0.10	1.13	0.81
15	run	7.6	0.43	0.18	0.65	0.82
Average values						**Percentage of the reach**
Averages for:	Runs	6.42	0.46	0.23	0.75	48.5
	Riffles	9.15	030	0.13	1.04	48.5
	Pools	6.55	0.79	0.36	0.58	3

3.6 Sutton Stream

The Sutton Stream reach was split with approximately 1 km upstream of the SH 58 road bridge and another 1 km downstream of the bridge. The site was sampled in February and March 2007.

The reach was generally confined in an incised channel, with a high proportion of the stream bed also being bedrock. The width of the stream varied from 4.5 m to 13 m and the average depth at cross sections varied from 0.1 m to 0.67 m deep (Table 11). The habitat was predominately run habitat interspersed with pools, and riffles were rare. The habitat was modified in three areas with vehicle crossings; areas around these crossings were excluded from the reach analysis and no cross sections were placed on the crossing. Two gauging sites were used on this stream as there was a water take operating intermittently on the reach between cross sections six and seven. The riparian margin was a combination of rank pasture grass and willow trees. Willows were present in all areas apart from riparian areas that were bedrock (Figures 7 and 8). Willow root systems and woody debris accumulations provided abundant cover, and were also often associated with undercut banks.

Table 11: Cross section characteristics for the Sutton Stream.

Cross section	Pool/ Riffle/ Run	Width (m)	Max Depth (m)	Average Depth (m)	Max Velocity (m/s)	Discharge (m^3/s)
1	run	5.85	0.23	0.15	0.84	0.53
2	riffle	6.65	0.18	0.11	0.88	0.48
3	pool	10	0.82	0.46	0.12	0.42
4	**run**	**6.8**	**0.36**	**0.24**	**0.32**	**0.45**
5	pool	8.88	1.06	0.66	0.11	0.38
6	riffle	5.4	0.43	0.18	0.61	0.40
7	pool	12.95	0.99	0.44	0.28	0.40
8	riffle	6.49	0.24	0.12	1.10	0.45
9	pool	8.71	1.14	0.67	0.09	0.37
10	run	5.21	0.64	0.40	0.32	0.38
11	riffle	4.83	0.26	0.11	0.96	0.41
12	**run**	**4.64**	**0.55**	**0.35**	**0.27**	**0.37**
13	riffle	6.35	0.21	0.10	0.87	0.37
14	pool	8.23	0.89	0.59	0.16	0.33
15	run	3.25	0.7	0.48	0.28	0.36
Average values						**Percentage of the reach**
Averages for:	Runs	5.15	0.496	0.324	0.406	60
	Riffles	5.944	0.264	0.124	0.884	15
	Pools	9.754	0.98	0.564	0.152	25

Figure 7: Sutton Stream gauging site 1 (cross section 4)

Figure 8: Sutton Stream gauging site 2 (cross section 12)

3.7 Kauru River

The Kauru River reach extended 2.5 km from approximately 300 m upstream of Kinnmont Ford to approximately 500 m upstream of the Kakanui Valley Road bridge. The reach assessment excluded habitat immediately upstream of the Kinnmont Ford, as the large pool present at the ford was considered a man-made structure and not typical of the study reach. A second large pool immediately downstream of the study reach was also avoided as this area of riverbed had previously been modified by gravel abstraction.

The study reach was an open river bed with a small 5 - 20 m wide stream within a 50 - 100 m gravel flood plain. The bed had been colonised in many areas by pasture grasses, weeds and some woody vegetation (Figure 9). The reach was dominated by run sections with shorter riffle sections dispersed amongst the runs. Pool habitat was rare and generally associated with instream obstacles such as trees, around which scour pools formed. The rarity of pool habitat (<3% of the stream reach) lead to no cross sections being placed in pools. The stream bed substrate varied in the reach and particle size declined in a downstream direction, with large basalt boulders in the upper parts of the reach becoming less frequent and eventually absent in the lower part of the reach. Smaller greywacke cobbles and gravel were the dominant substrate in the mid and lower part of the reach. Instream cover was provided by the substrate. In the course of the investigation flows in the river receded to very low levels and some cross sections became dry (Figure 10). At other cross sections, water depths became so too shallow for accurate flow assessment. Therefore, no instream habitat modelling analysis was undertaken for the Kauru River site.

Figure 9: Kauru River gauging site (cross section 1), 6 February 2007, flow approximately 0.5 m^3/s.

Figure 10: Kauru River gauging site (cross section 1) downstream view, 27 February 2007, flow approximately 0.03 m^3/s.

4.0 RHYHABSIM ANALYSIS

4.1 Pig Burn

The RHYHABSIM analysis of WUA showed a very similar distribution of habitat with flow for the five habitat preference curves used. Peak habitat availability (WUA) occurred at a flow of 0.15 m^3/s (Figure 11). Above this flow, WUA declined steeply for brown trout fry and slowly for juvenile, yearling and spawning habitat for brown trout and for large longfin eels. For smaller longfin eels WUA increased rapidly from zero flow to 0.1 m^3/s and then continued to rise with flow at a lower rate, giving no maximum WUA. WUA declined steeply below 0.1 m^3/s towards no WUA available for juveniles, yearlings, trout spawning habitat and for small and large longfin eels at no flow. Some habitat remains for fry at zero flow presumably in pool areas. This would continue to provide some habitat for fry at no flow although the suitability of this habitat is likely to decline as water temperatures rise in the unshaded areas.

The HSI for brown trout fry, juveniles, yearlings and spawning where higher at the lower end of the flow range modelled (Figure 12). Two of the three curves modelled for brown trout juveniles peak around 0.15 m^3/s and one closer to 0.20 m^3/s that includes larger trout up to 15 cm. The HSI declines rapidly for brown trout once the flow falls below 0.1 m^3/s. For longfin eel the HSI declines with flow for large eel, but improves with increasing flow for smaller eels throughout the range of flows modelled.

Observations in the Pig Burn in February and March 2007, when the stream was a series of isolated sections due to abstraction, also revealed that the stream gained flow from groundwater outflows in the study area. Downstream of each water abstraction point the stream rapidly recovered from no flow to a stream c 1 -2 m wide. It is not clear without further investigation what the volume of ground water inflows are and the distribution of these inflows.

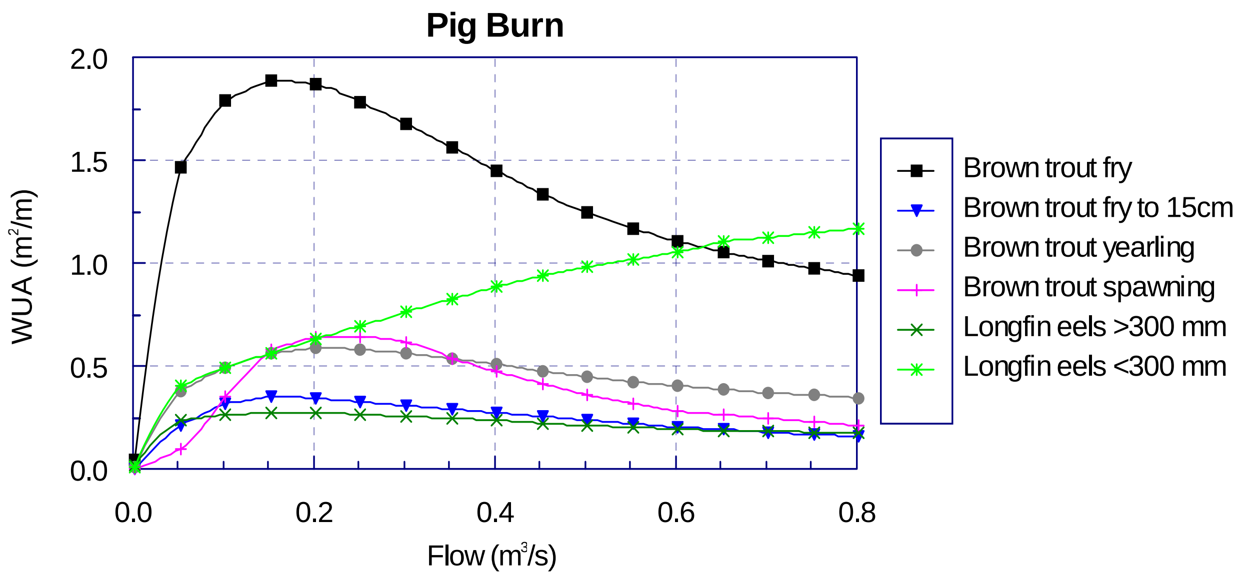

Figure 11: WUA curves for fish in Pig Burn

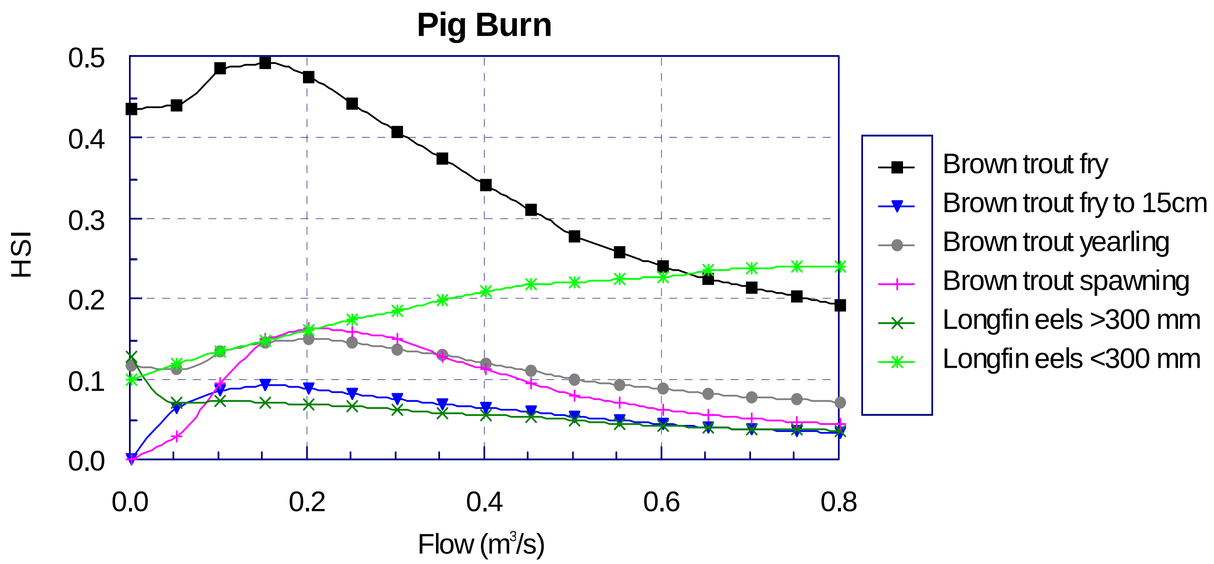

Figure 12: HSI curves for fish in Pig Burn

It is concluded that, based on the habitat modelling results and the abundance of brown trout (common, data from NZFFD) verses longfin eel (rare, data from NZFFD) that flows appropriate for brown trout are most important for this reach. If the stream is to provide good habitat for juvenile brown trout, a higher flow of 0.15 m^3/s will provide good habitat for the newly hatched fry, fingerlings, large juvenile trout and longfin eels. However, as the current 7dMALF flow is 0.020 m^3/s the optimal flow is not achievable and even the 0.080 m^3/s flow below which WUA and HSI decline rapidly is not achievable. However the flow in the study reach has the potential to be higher than the gauged flows as the gauging site is upstream of the study reach and if ground water inflows are significant in the study reach the flow here may be higher than upstream.

4.2 Sow Burn

4.2.1 Upper Sow Burn

The WUA curves for juvenile brown trout in the upper Sow Burn peaked at flows between 0.4 m^3/s and 0.7 m^3/s (Figure 13). The curves however are relatively flat and the WUA available for fry in the range from 0.3 m^3/s to 0.8 m^3/s is relatively stable. For larger fingerling and juvenile fish there is also a wide range of flows that provide similar WUA, although the flows are slightly higher than those for fry. This should be expected as the larger juvenile fish are capable of occupying higher velocity areas and prefer deeper water. Brown trout spawning habitat is not as abundant as the fry and juvenile habitat. It also begins to decline 0.6 m^3/s and WUA for spawning habitat is nearly zero at flows of approximately 0.1 m^3/s. The 0.1 m^3/s is also the flow at which fry and yearling habitat begins to decline rapidly.

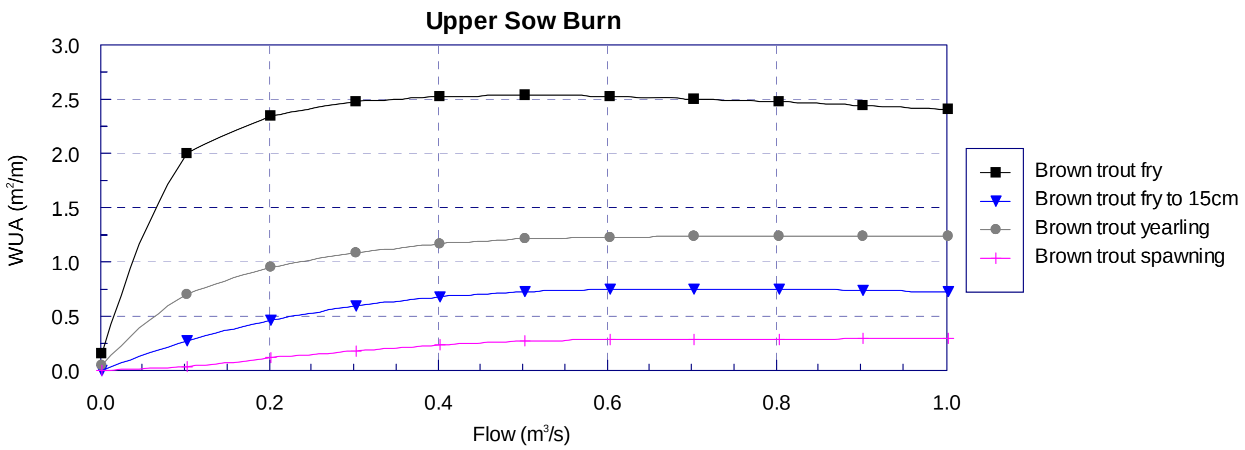

Figure 13: WUA curves for fish in upper Sow Burn.

The HSI curves for the brown trout juveniles increase from very low suitability at 0.1 m^3/s up to 0.5 m^3/s. From 0.5 m^3/s upwards the HSI for juvenile brown trout very slowly declines. However, the decline is gentle and any flow from 0.3 m^3/s to 2 m^3/s is likely to provide similar quality habitat. For brown trout fry a similar range of preferred flows are apparent. Habitat suitability for fry is predicted to decline significantly below 0.2 m^3/s (Figure 14).

An optimum flow for this reach that is most suitable for fry and juvenile brown trout is 0.4 m^3/s to 0.6 m^3/s. This flow provides the largest area of habitat as WUA and the highest HSI. More weight should be given to the fingerlings and large juvenile fish at this site as low flows are likely to occur in summer when brown trout have grown though the fry stage and are larger. A minimum flow for this reach would be 0.1 m^3/s where the steep declines in habitat (WUA) for all brown trout life history stages occurs. The minimum flow would provide also most no spawning habitat, however, as spawning habitat is utilised in late autumn and winter and the minimum flow (if due to irrigation abstraction) is likely to occur in summer and the lack of spawning habitat at the minimum flow should have limited effects on spawning later in the year.

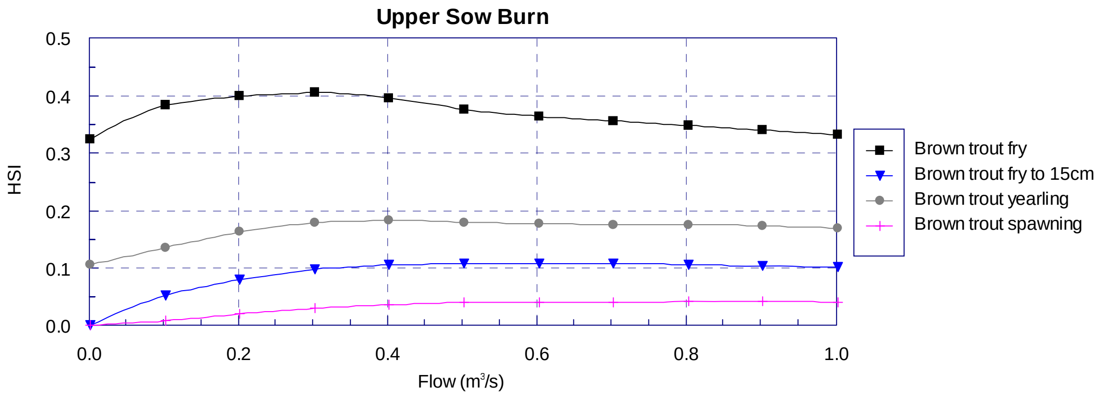

Figure 14: HSI curves for fish in Upper Sow Burn

4.2.2 Lower Sow Burn

WUA increased with flow for all fish species/life stages modelled for the lower Sow Burn (Figure 15). Adult brown trout habitat is rare, but becomes more common as flow increase well above the 7dMALF. For brown trout fry and juveniles WUA declines with declining flow but critical flow points below which WUA declines more rapidly are not obvious. The WUA curve for brown trout fry declines most steeply in the range of flows from 0.0 m^3/s to 0.2 m^3/s. Spawning habitat WUA peaks at 0.6 m^3/s and declines slowly with flow to zero WUA at 0.04 m^3/s.

For longfin eel (<300 mm long) a prominent inflection point in the WUA curve is present at 0.120 m^3/s, and above this point WUA increases slowly but steadily. For larger eels the increase in flow is predicted to lead to a slow and steady increase in habitat.

The HSI models show a more complex relationship with flow than the WUA model (Figure 16). For brown trout fry habitat suitability peaks between 0.5 m^3/s and 0.8 m^3/s. The longfin eel and brown trout juvenile and adult HSI curves have no distinct peak and the HSI is stable or increases with flow. Brown trout spawning habitat has a peak HSI at 0.55 m^3/s and suitability declines most rapidly between 0.1 m^3/s and 0.2 m^3/s.

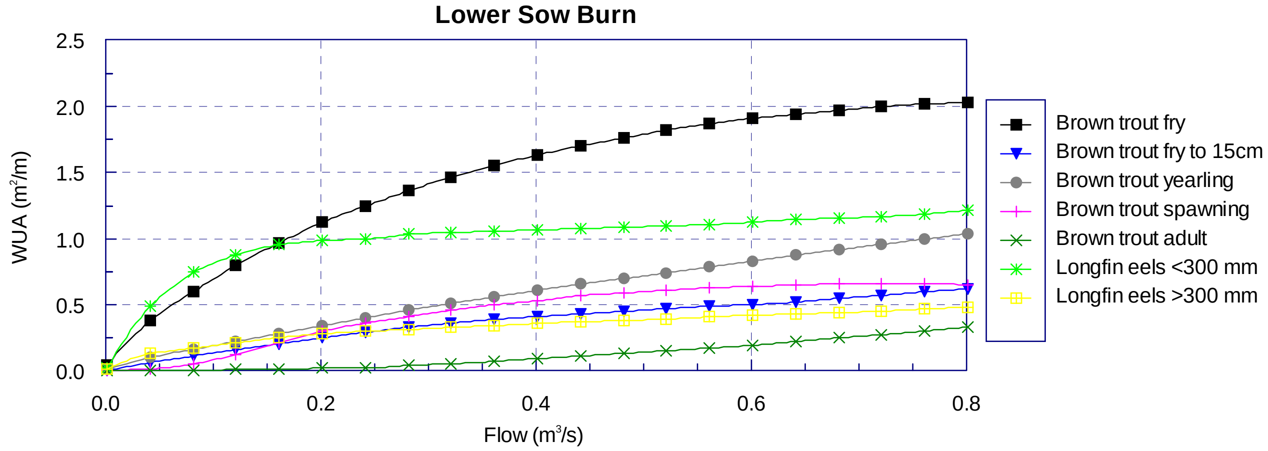

Figure 15: WUA curves for fish in lower Sow Burn

For the lower Sow Burn an optimal flow is not apparent with WUA for all species and life history stages tending to increase with flow. The stream has abundant brown trout fry in the upper part of this sampling reach and a flow in the order of 0.6 m^3/s might be considered optimal as the HSI peaks at this flow and the rate of WUA increases declines at this flow. For a minimum flow the WUA curves and HSI curves do show that longfin eel have a distinct increase in decline at 0.150 m^3/s and for brown trout fry the most rapid decline in WUA comes below 0.2 m^3/s.

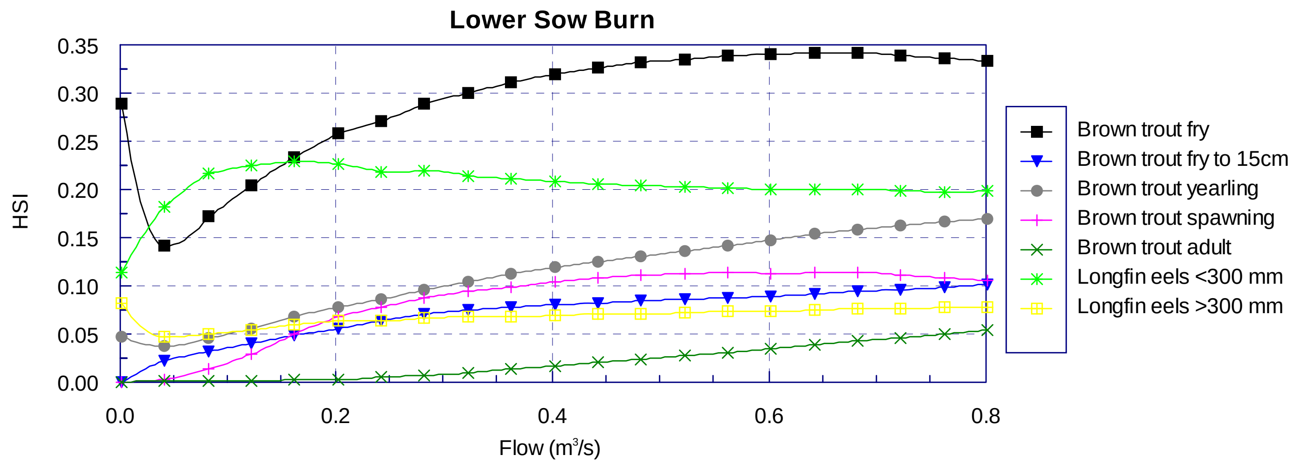

Figure 16: HSI curves for fish in Lower Sow Burn

4.3 Waitahuna River

4.3.1 Upper Waitahuna River

The WUA modelling of the upper Waitahuna River reach predicts a varied response to flow changes. WUA curves for brown trout fry, juveniles, and yearlings display relatively gradual changes in habitat availability with changes in flow (Figure 17). At very low flows under 0.1 m^3/s the habitat declines rapidly, but it increases at a gentle rate as flow increases from 0.1 to 0.7 m^3/s.

For large and small longfin eels and adult brown trout WUA continues to increase with increasing flow above 0.7 m³/s. For the smaller brown trout size classes modelled WUA either declines at flows above 1 m^3/s or stabilises in the 1 m^3/s to 2 m^3/s range modelled. Brown trout spawning habitat is not relatively abundant and it also declines most rapidly as flows decline below 0.6 m^3/s. WUA for lamprey is relatively insensitive to the flow range modelled. The gentle and steady decline in WUA for adult brown trout with declining flow is considered significant in respect to the recreational trout fishery, as it is likely that larger fish in this reach will move downstream as flow and habitat availability declines.

HSI curves show relatively gradual changes in habitat suitability with flow (Figure 18) and only at very low flows, 0.1 m^3/s do rapid changes in HSI occurs for some species. As with WUA, HSI for lamprey is relatively insensitive to changes in flow. The brown trout size classes show little change in HSI from 1.2 to 1.8 m^3/s, but show gentle but significant declines in HSI as flow declines further. For the key recreational fishery classes of brown trout (yearlings and adults), the decline in the HSI becomes steeper below flows of 0.7 to 0.8 m^3/s.

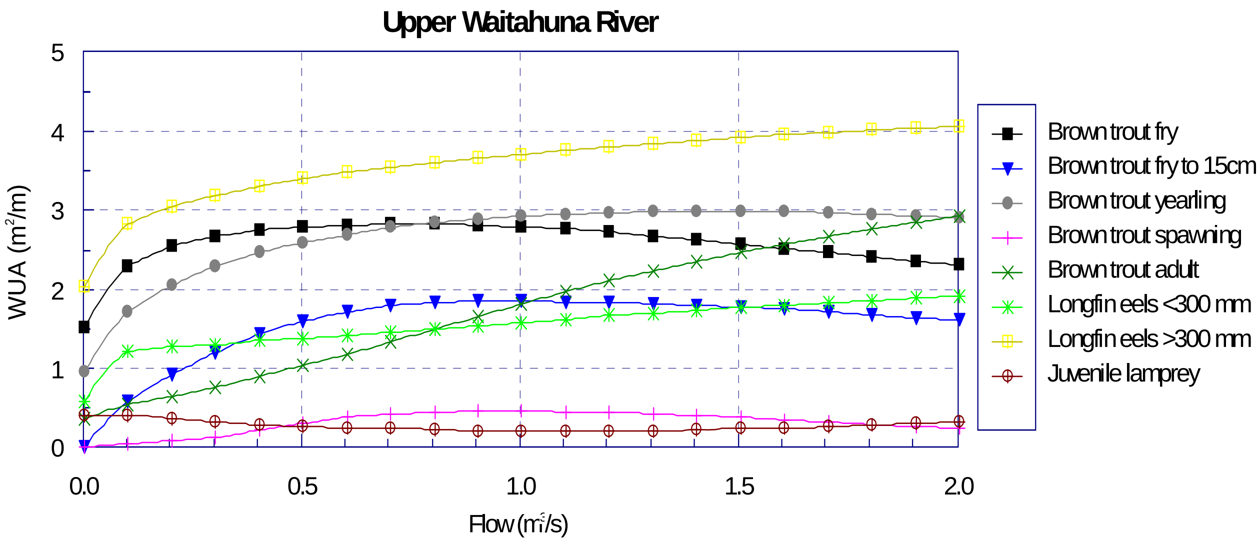

Figure 17: WUA curves for fish in upper Waitahuna River.

The relatively gradual changes in WUA and HSI at this site mean no minimum or optimum flows are obvious. Consideration of the slow but continuous decline in WUA and HSI for the larger brown trout size classes has to be undertaken, the decline in adult longfin eel habitat (a threatened species) and the rapid changes in WUA and HSI at 0.1 m^3/s. A minimum flow of between 0.6 m^3/s and 0.7 m^3/s (about the 7dMALF), while allowing some decline in WUA and HSI, would still provide relatively good habitat for adult brown trout. This minimum flow also recognises that the decline in WUA and HSI begins to occur at flows higher than natural summer low flow observed at the this site during this study and as such there is a natural decline in WUA and HSI each summer as flows recede in the river. For the juvenile and fry classes of brown trout a lower minimum flow of 0.4 m^3/s to 0.5 m^3/s would be considered appropriate. A final consideration is that invertebrate food resources in riffle habitat will decline (Figure 19) and while habitat for fish remains at low flows invertebrate food may be lacking. The most rapid reduction in food producing habitat occurs at 0.5 m^3/s.

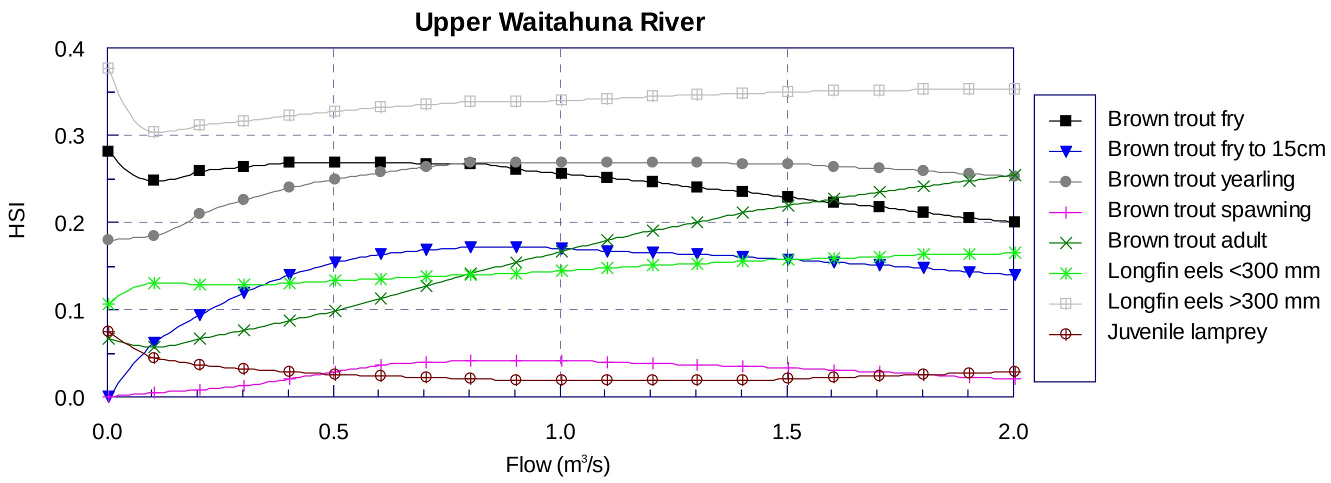

Figure 18: HSI curves for fish in upper Waitahuna River.

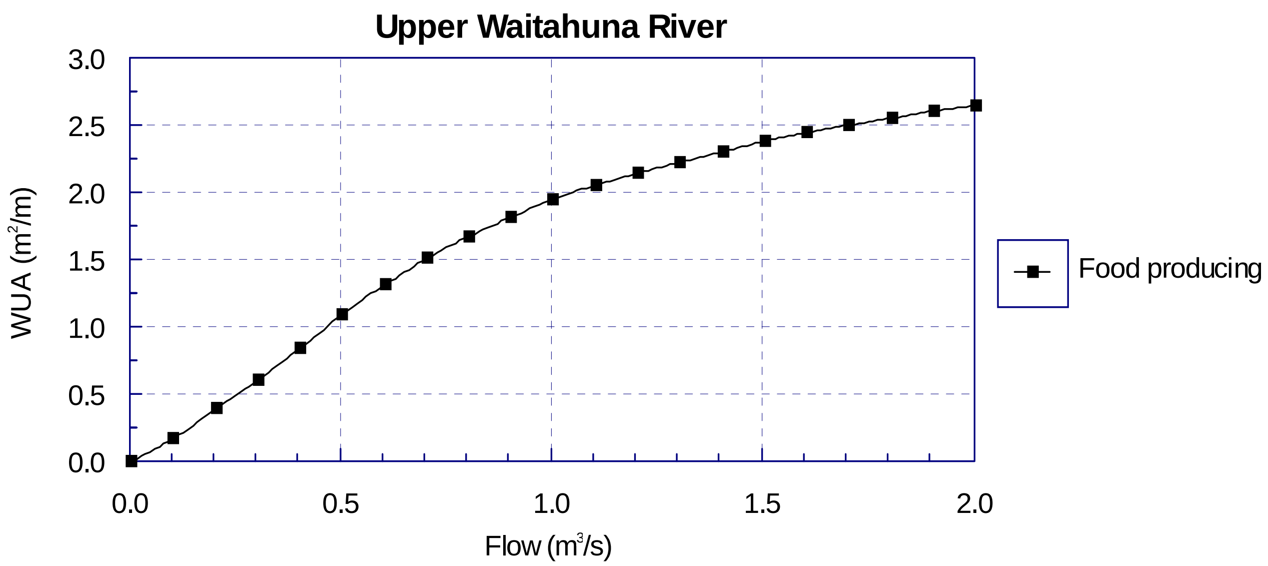

Figure 19: WUA curve for food producing habitat in the upper Waitahuna River.

4.3.2 Lower Waitahuna River

The WUA predictions for the wide range of fish present in the lower Waitahuna River display a range of responses to increasing flow. For longfin eel and lamprey, WUA increases with increasing flow, although not rapidly for most of the flow range modelled. WUA for shortfin eel changes little across the range of flows modelled. However for the eels and lamprey WUA does decline very rapidly as flow declines from 0.1 m^3/s to zero. The various size classes and habitat preference curves for brown trout show the greatest response to changing flow. WUA for brown trout fry peaks at 0.4 m^3/s, for fry to 15 cm fish at 0.7 m^3/s, for yearlings at 0.9 m^3/s and for adults at 1.9 m^3/s (Figure 20).

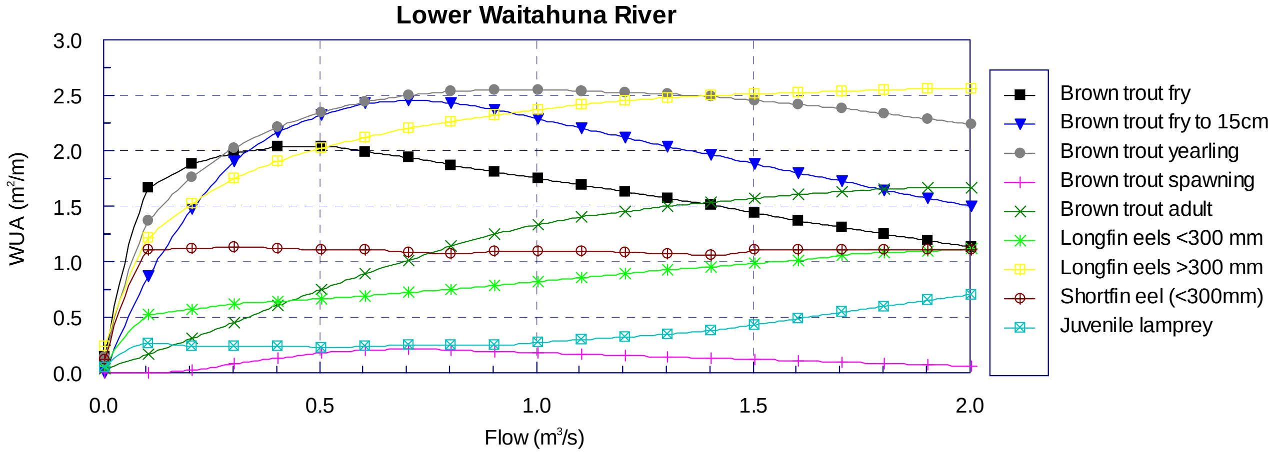

Figure 20: WUA curves for fish in lower Waitahuna River.

The HSI for fish in the lower Waitahuna River is variable (Figure 21), peak HSI occurs for brown trout fry at 0.4 m^3/s, for fry to 15 cm fish at 0.7, for yearling fish at 0.8 m^3/s and adults at 1.4 m^3/s. Shortfin eel and trout fry show declining HSI with increasing flow across the range of flows modelled. Conversely, lamprey and small longfin eels have a slow but continuous improvement on HSI across the flow range modelled. Large longfin eel have a peak HSI at 0.8 m^3/s to 0.9 m^3/s.

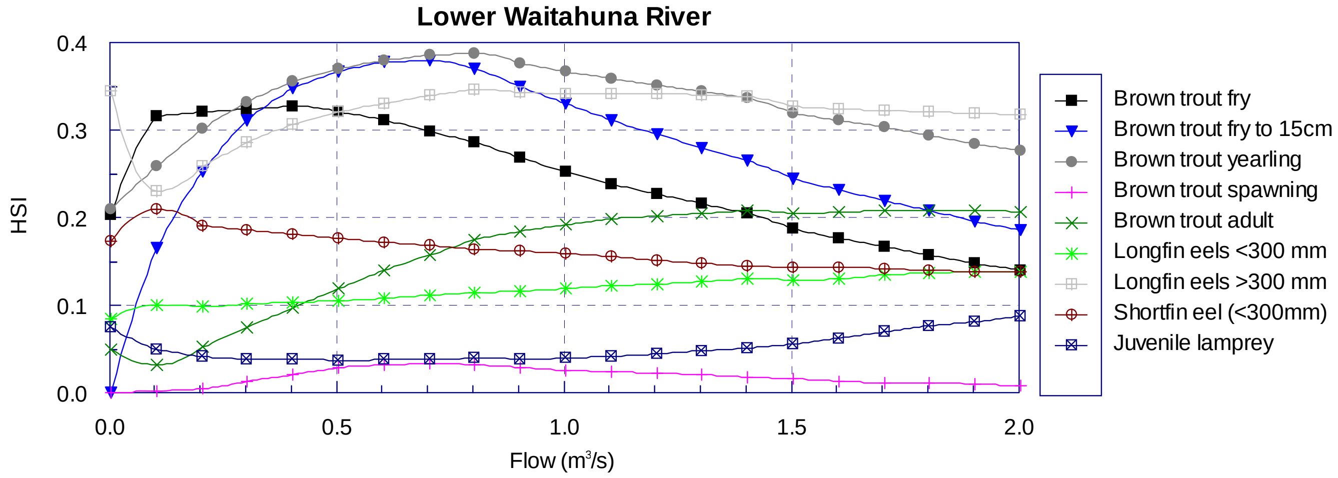

Figure 21: HSI curves for fish in lower Waitahuna River

The combination of the predicted WUA and HSI changes indicate that flows less than 0.5 m^3/s will lead to declines in habitat (WUA) and habitat quality (HSI) for the key species, brown trout and longfin eel and also for food producing habitat (Figure 22). Retention of flows greater than 1.0 m^3/s will not provide further rapid gains in adult brown trout habitat and will lead to declines in habitat availability and quality for fry and juvenile brown trout. However, longfin eel would continue to benefit from increasing flow as its habitat increases. A minimum flow of 0.5 m^3/s would appear to provide for the juvenile brown trout stages and spawning habitat, and while not providing the maximum longfin eel habitat, it does avoid the low flows where habitat and habitat quality diminish more rapidly. It is also important to note that this reach provides good instream cover for longfin eels and this is likely to be a key habitat factor for the eels. The availability of this cover amongst woody debris and undercut banks will not be affected by the minimum flow.

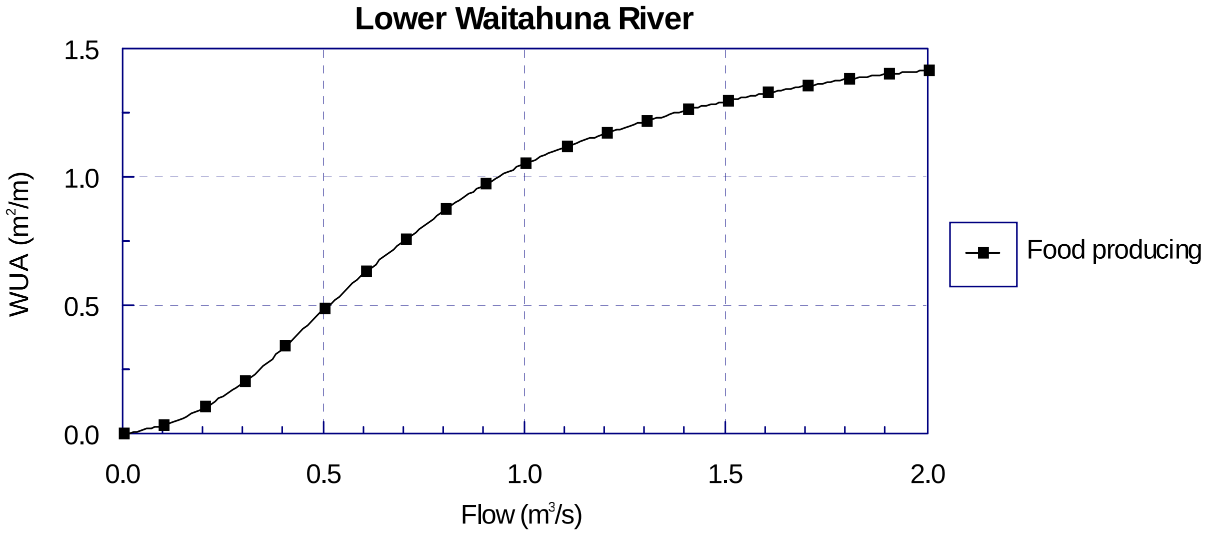

Figure 22: WUA curve for food producing habitat in the upper Waitahuna River.

4.4 Dunstan Creek

The WUA plots for Dunstan Creek for brown and rainbow trout, except brown trout fry, show similar patterns of change in WUA. WUA increases relatively rapidly from 0 to 0.2 m^3/s and most WUA curves then continue to increase at a slower rate or stabilise in the range to flows from 0.2 m^3/s to 0.6 m^3/s. The WUA predicted for brown trout fry has a similar pattern to the other trout curves but substantially greater WUA exists for fry. WUA begins to decrease for most of thee trout life history stages above 0.6 m^3/s and for all above 0.8 m^3/s. The two native fish roundhead galaxias and upland bully have their peak WUA at 0.15 m^3/s and 0.3 m^3/s respectively (Figure 23).

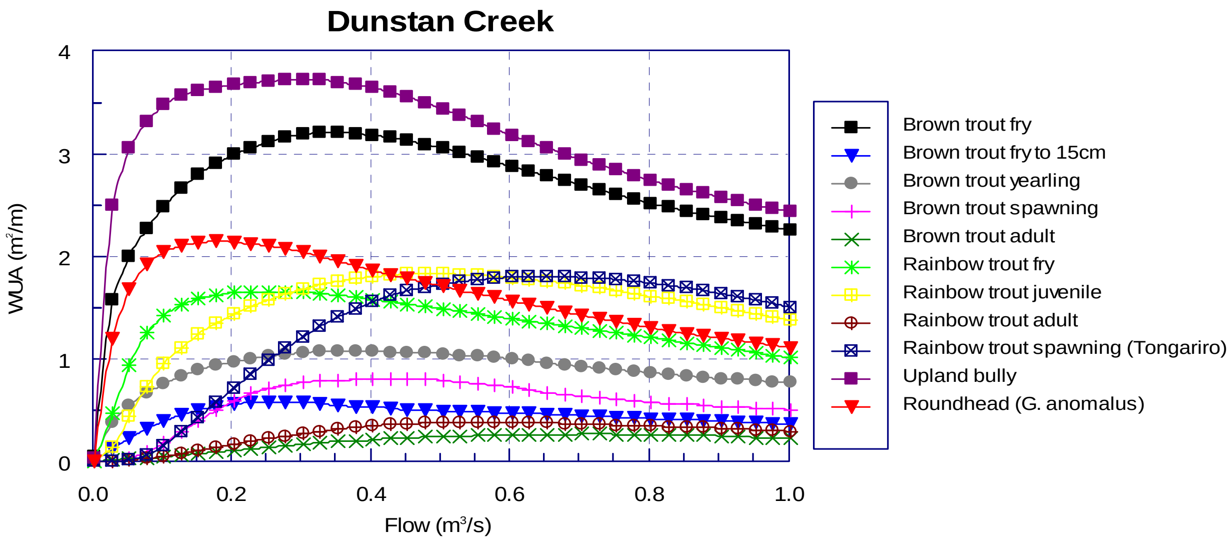

Figure 23: WUA curves for fish in Dunstan Creek

HSI curves show a very consistent pattern of relatively stable habitat quality with increasing flow for nearly all trout size classes modelled from 0.2 m^3/s upwards. Rainbow trout juveniles and brown trout fry differed from the other trout models with high HSIs at low flows that decrease more rapidly as flow increases above 0.2 m^3/s. Upland bully and roundhead galaxias had peaks in the HSI at 0.1-0.15 m^3/s and 0.1 m^3/s respectively and their HSI as flow increased above 0.15 m^3/s (Figure 24).

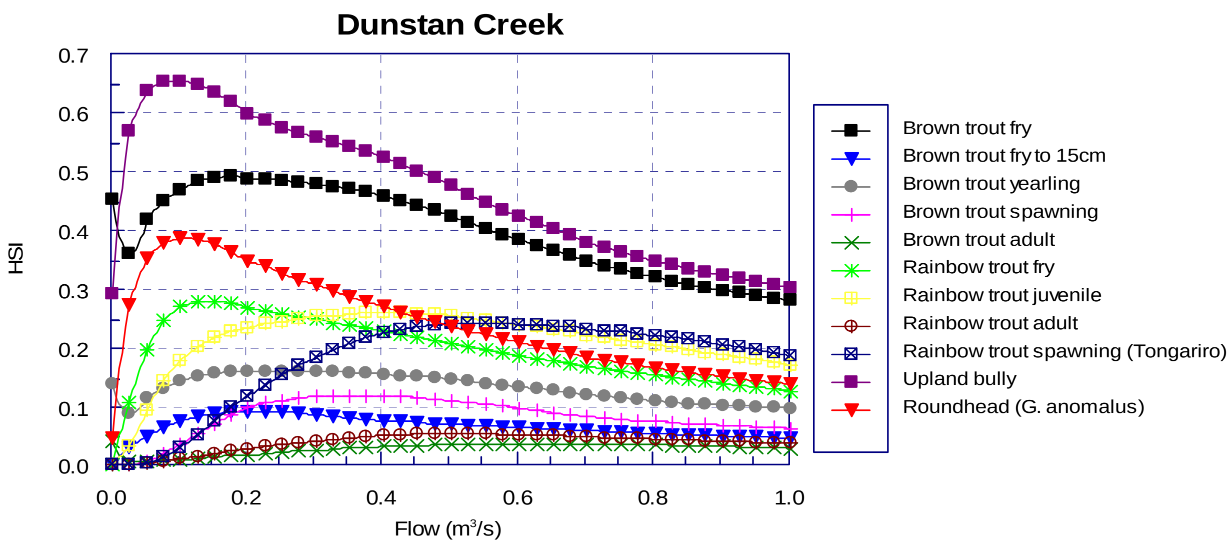

Figure 24: HSI curves for fish in Dunstan Creek.

Analysis of WUA and HSI curves for this stream reach indicate that flows of 0.3 m^3/s or greater would be appropriate for brown trout and all the rainbow trout size classes except rainbow trout juveniles. For the two native fish a flow of 0.15 m^3/s to 0.2 m^3/s would provide optimal habitat.

One important factor not considered in this analysis is fish passage for adult brown and rainbow trout. During the habitat surveys adult trout (approximately 50 cm long) were observed in the pool and deep run habitats and consideration of their habitat use and passage to spawning areas could be appropriate. These fish appeared restricted to the rare areas of deeper water for resting and/or feeding habitat and many of the riffle and run areas were shallow (riffle average depth 0.13 m Table 10), potentially presenting upstream fish passage difficulties for these fish if they were spawning adults migrating upstream to spawning habitat. If sufficient freshes occur in Dunstan Creek, upstream movement may be relatively simple but if low flows are sustained for long periods in late summer and autumn any spawning migration may be restricted.

4.5 Sutton Stream

The relationship between WUA and flow for brown trout in Sutton Stream varied with the age and size class of the fish. The fry and juvenile size classes had WUA peaks at flows at 0.1 m^3/s. Yearling brown trout had a peak for WUA at the higher flow of 0.5 m^3/s, and decline in WUA as the flow declined below 0.3 m^3/s. Adult brown trout WUA increased with flow throughout the range of flows from zero to 1.0 m^3/s, with the most rapid increases in WUA occurring between zero and 0.2 m^3/s. Spawning habitat WUA is low for this reach, (probably due to the stream bed substrate being unsuitable for spawning) and declines to zero at 0.3 m^3/s. Longfin eel WUA peaked at higher flows but significant declines in WUA for large eels did not occur until the flow dropped below 0.1 m^3/s. For the smaller longfin eel and lamprey, WUA declines more rapidly as the flow drops below 1.0 m^3/s, and again drops very rapidly as the flow declines to less than 0.1 m^3/s (Figure 25).

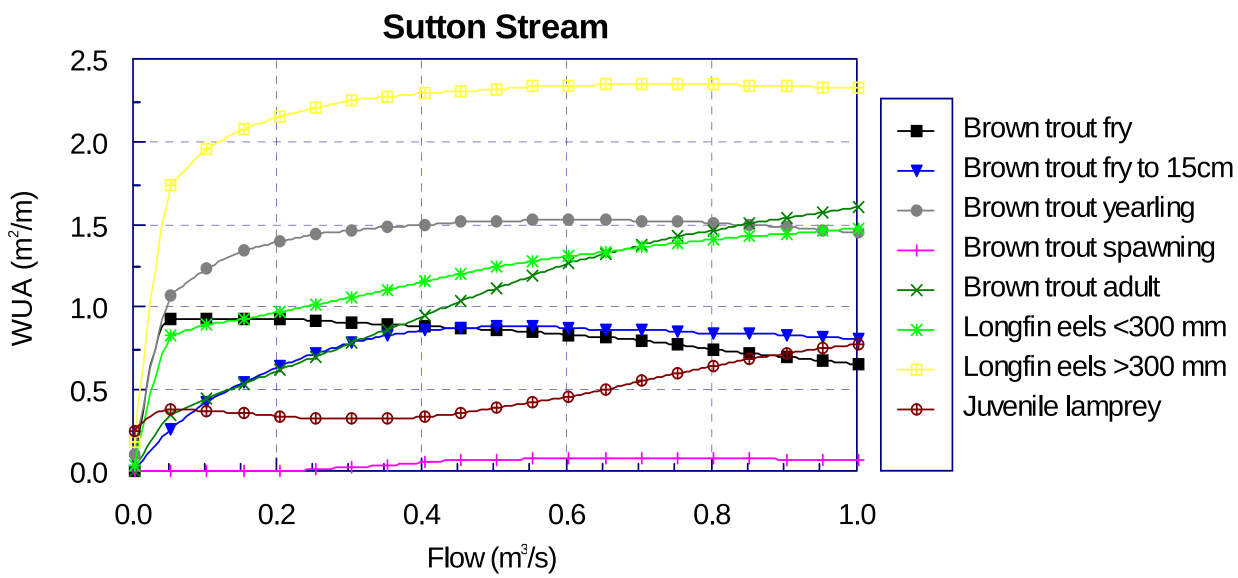

Figure 25: WUA curves for fish in Sutton Stream.

Habitat quality (HSI) for most species and sizes classes changes significantly at a flow of 0.05 m^3/s (Figure 26). Lamprey and large longfin eels have rapid increases in habitat quality below 0.05 m^3/s, whereas brown trout has a rapid decline in HSI below 0.05 m^3/s. The HSI for adult brown trout increases with flow through the range from zero to 1.0 m^3/s, although the rate of increase slowly declines with increasing flow. Brown trout spawning HSI is very low and declines to zero at a flow of 0.3 m^3/s. HSI for both size classes of longfin eel is relatively stable across the 0.1 m^3/s to 1.0 m^3/s flow range with only rapid and substantial changes occurring at flows less than 0.05 m^3/s.

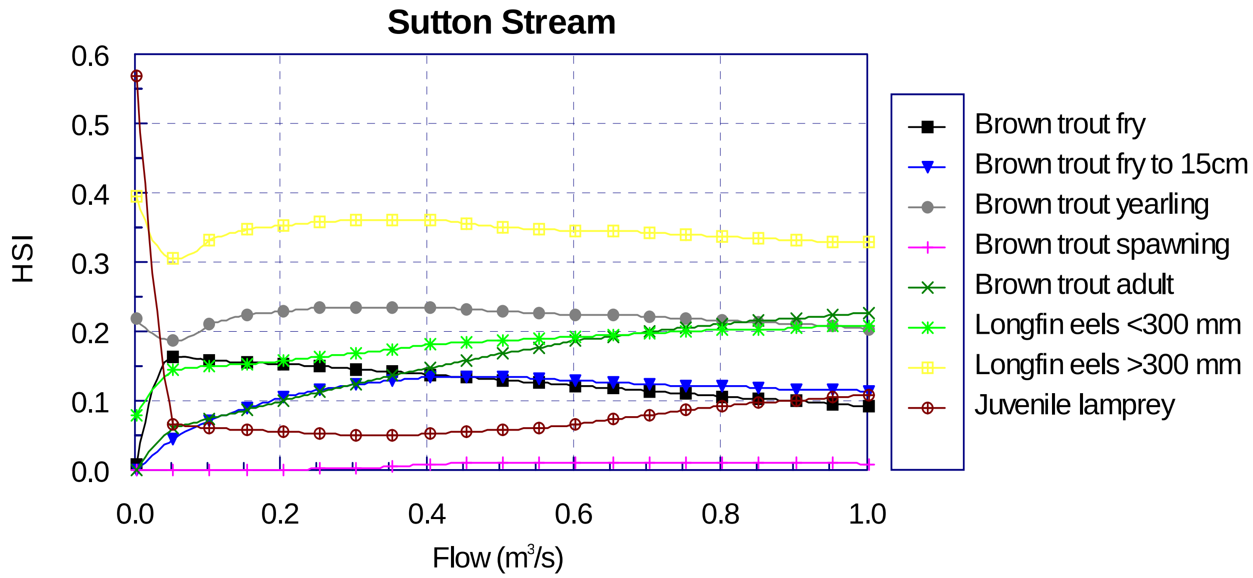

Figure 26: HSI curves for fish in Sutton Stream

For Sutton Stream a minimum flow below 0.1 m^3/s would significantly reduce WUA for juvenile and adult brown trout and longfin eel. Similarly a 0.1 m^3/s flow would avoid the large changes in HSI that occur closer to 0.05 m^3/s and provide relatively good habitat.

4.6 Kauru River

No RHYHABSIM model was produced for the Kauru River.

5.0 FLOW SUMMARY

Based on the habitat modelling undertaken, a range of optimal flows have been given and range of low flows at which habitat loss is most rapid are provided (Table 12). These flows range from 0.05 m^3/s to 1.6 m^3/s (Table 12).

It is important to note that these flow recommendations are based solely on instream habitat modelling for the fish known to be present at the study reaches and do not include explicit consideration of flow effects on temperature or other water quality parameters. It is also acknowledged that these minimum flow recommendations relate only to fish, and not to other instream values (e.g., invertebrates, periphyton, cultural, landscape, and marginal plant species) that may have alternative flow requirements.

Table 12: Key flow levels for fish from seven study reaches

Stream	Species	Life history stage	Flow below which rapid decline occurs (m^3/s)*	Optimal flow m^3/s*	7dMALF (ORC data) m^3/s
Pig Burn	Brown trout Longfin eel	Fry Juvenile Spawning > 300 mm < 300 mm	0.1 0.1 0.15 0.05 0.05	0.15 0.2 0.2 n/a 0.05	0.020
Upper Sow Burn	Brown trout	Fry Juvenile Spawning	0.1 0.1 0.1	0.4 0.6 0.6	0.226
Lower Sow Burn	Brown trout Longfin eel	Fry Juvenile Adult Spawning > 300 mm < 300 mm	0.2 0.15	0.6 n/a n/a n/a 0.6	0.226
Upper Waitahuna River	Brown trout Lamprey Longfin eel	Fry Juvenile Adult Spawning Ammocoetes > 300 mm < 300 mm	0.4 0.4 1.1 0.6 n/a 0.1 0.1	0.7 0.9 1.4 0.9 0.0 or 2.0 n/a n/a	0.633
Lower Waitahuna River	Brown trout Lamprey Longfin eel Shortfin eel	Fry Juvenile Adult Spawning Ammocoetes > 300 mm < 300 mm	0.1 0.3 0.1 0.1 0.1 0.1 0.1 0.1	0.4 0.7 1.9 0.7 2.0 n/a n/a n/a	0.633
Dunstan Creek	Brown trout Rainbow trout Upland bully Roundhead galaxias	Fry Juvenile Adult Spawning Fry Juvenile Adult Spawning Adult Adult	0.2 0.2 0.3 0.3 0.1 0.25 0.25 0.25 0.1 0.05	0.45 0.4 0.65 0.45 0.5 0.8 0.75 0.8 0.3 0.15	0.660
Sutton Stream	Brown trout Lamprey Longfin eel	Fry Juvenile Adult Spawning Ammocoetes > 300 mm < 300 mm	0.05 0.05 0.05 0.35 0.05 0.05 0.05	0.05 0.5 n/a 0.6 n/a 0.6 n/a	0.169

Notes: * The flows for the high rate of change flow and optimal flow are from the study reach and are not necessarily the flows at the reference flow gauging sites.

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APPENDIX 1

Report limitations

APPENDIX

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APPENDIX 2

Study reaches and cross section locations

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1.0 SITE MAPS

1.1 Pig Burn

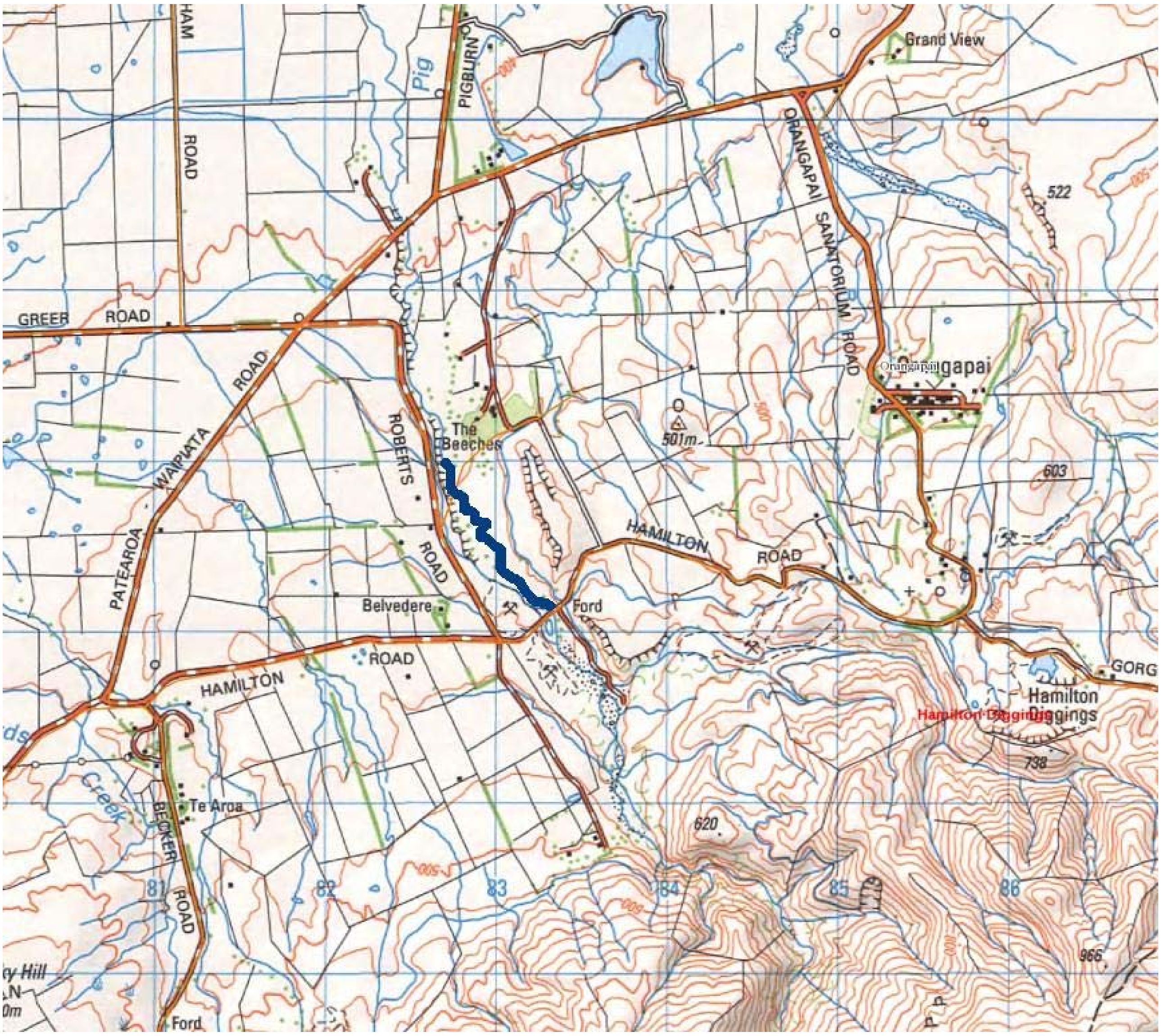

Figure 1: Pig Burn study reach (dark blue stream section)

1.2 Upper Sow Burn

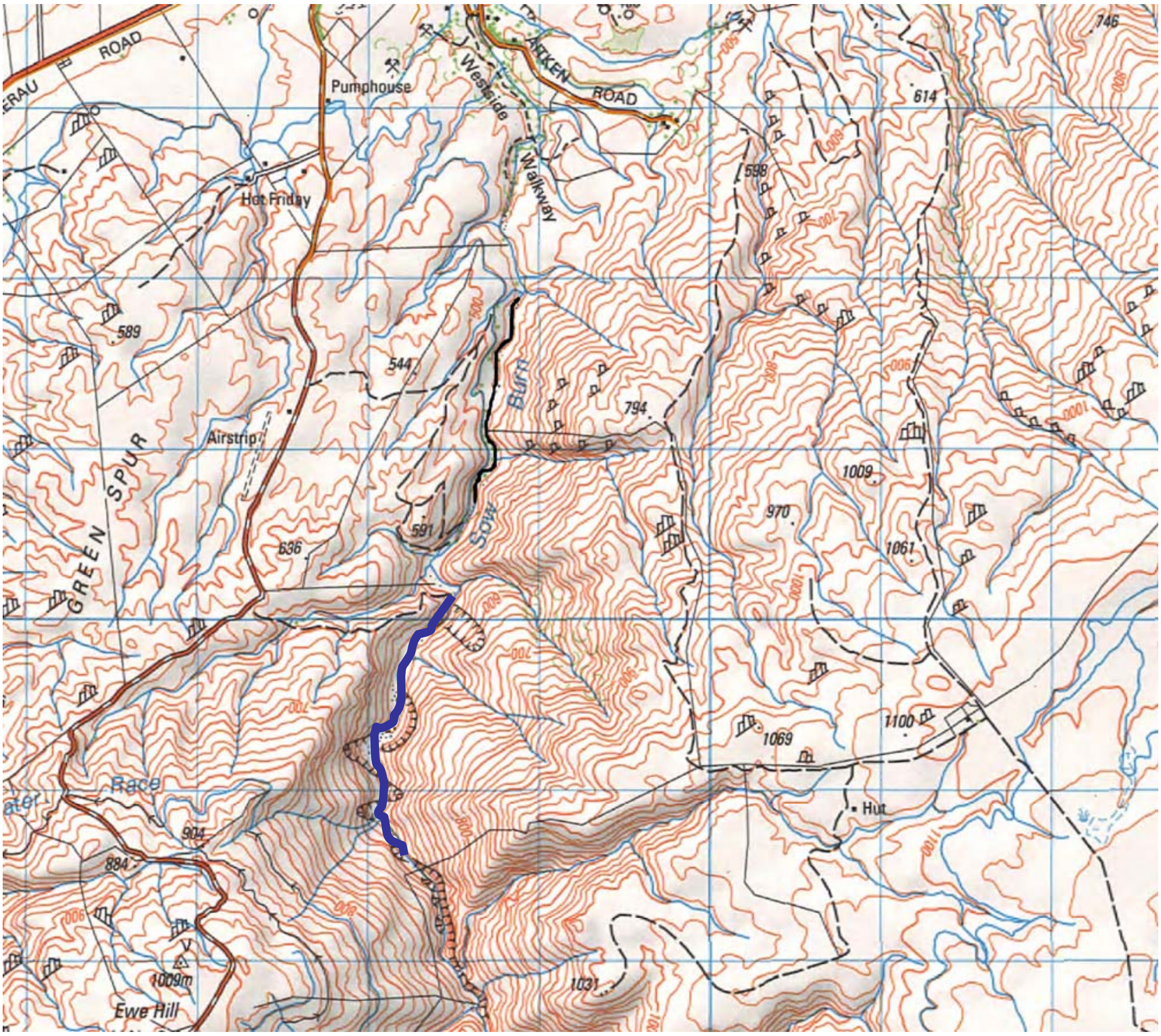

Figure 2: **Upper Sow Burn study reach (dark blue stream section)**

1.3 Lower Sow Burn

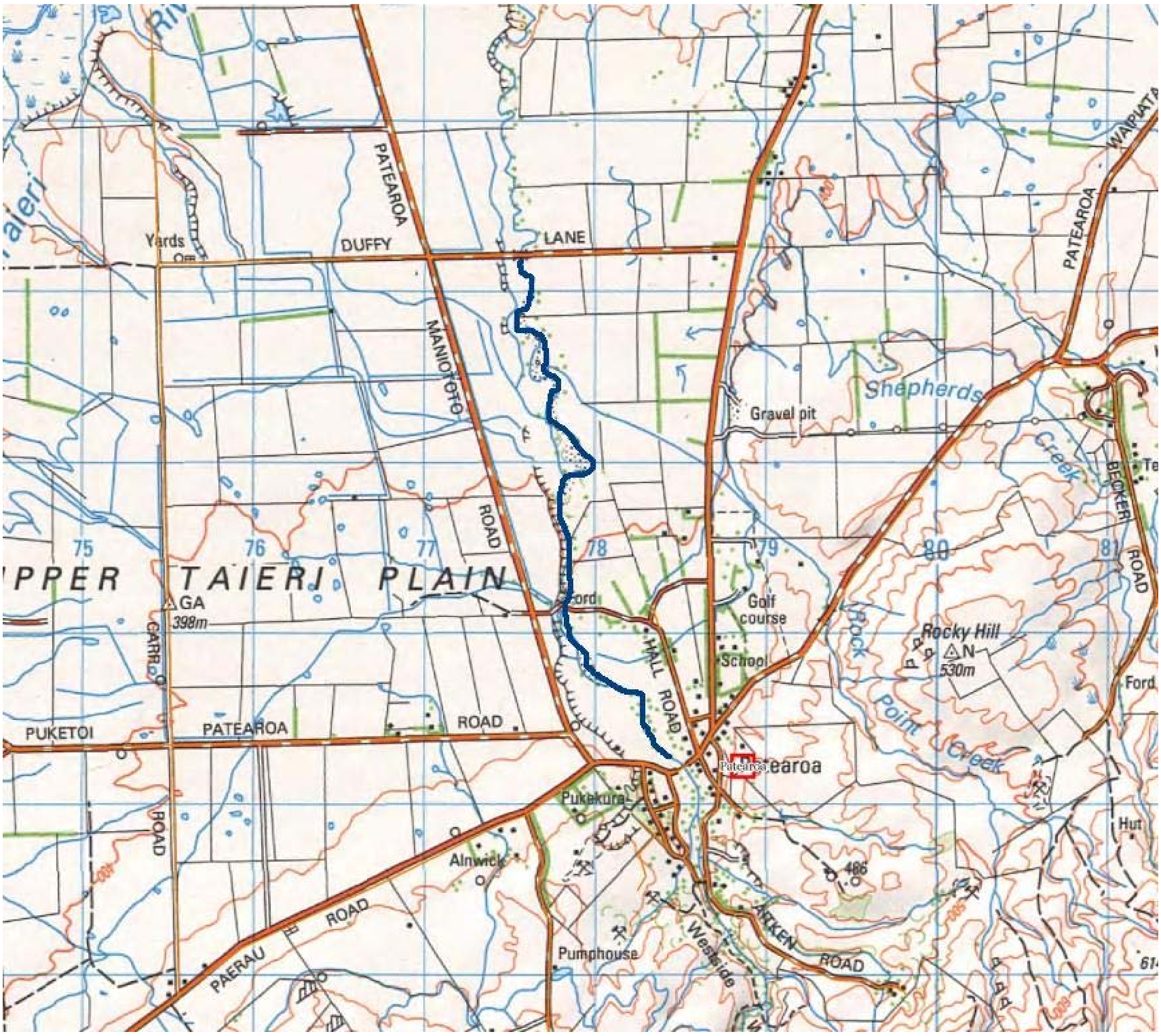

Figure 3: Lower Sow Burn study reach (dark blue stream section)

1.4 Upper Waitahuna River

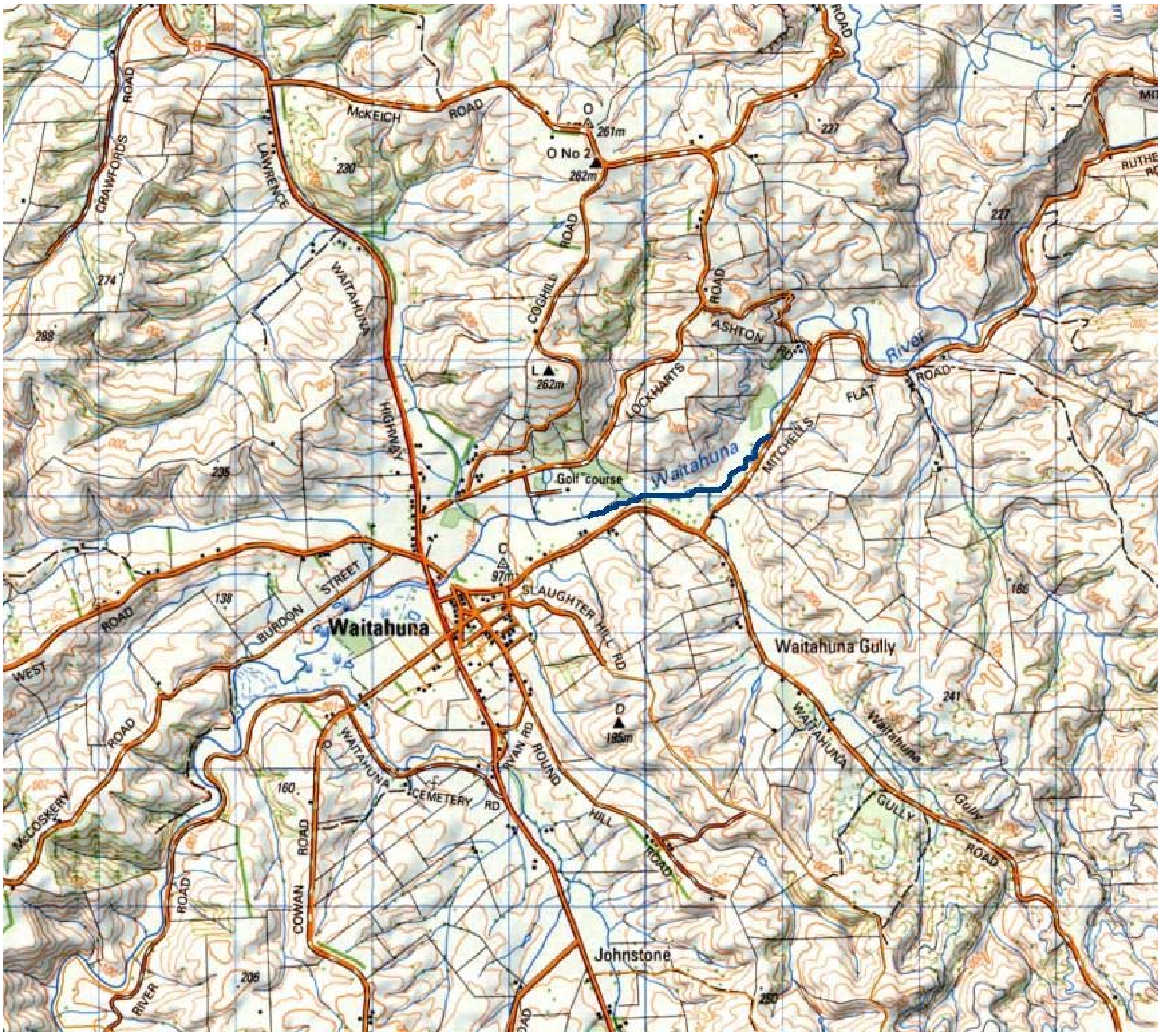

Figure 4: **Upper Waitahuna River study reach (dark blue stream section)**

1.5 Lower Waitahuna River

Figure 5: Lower Waitahuna River study reach (dark blue stream section)

1.6 Dunstan Creek

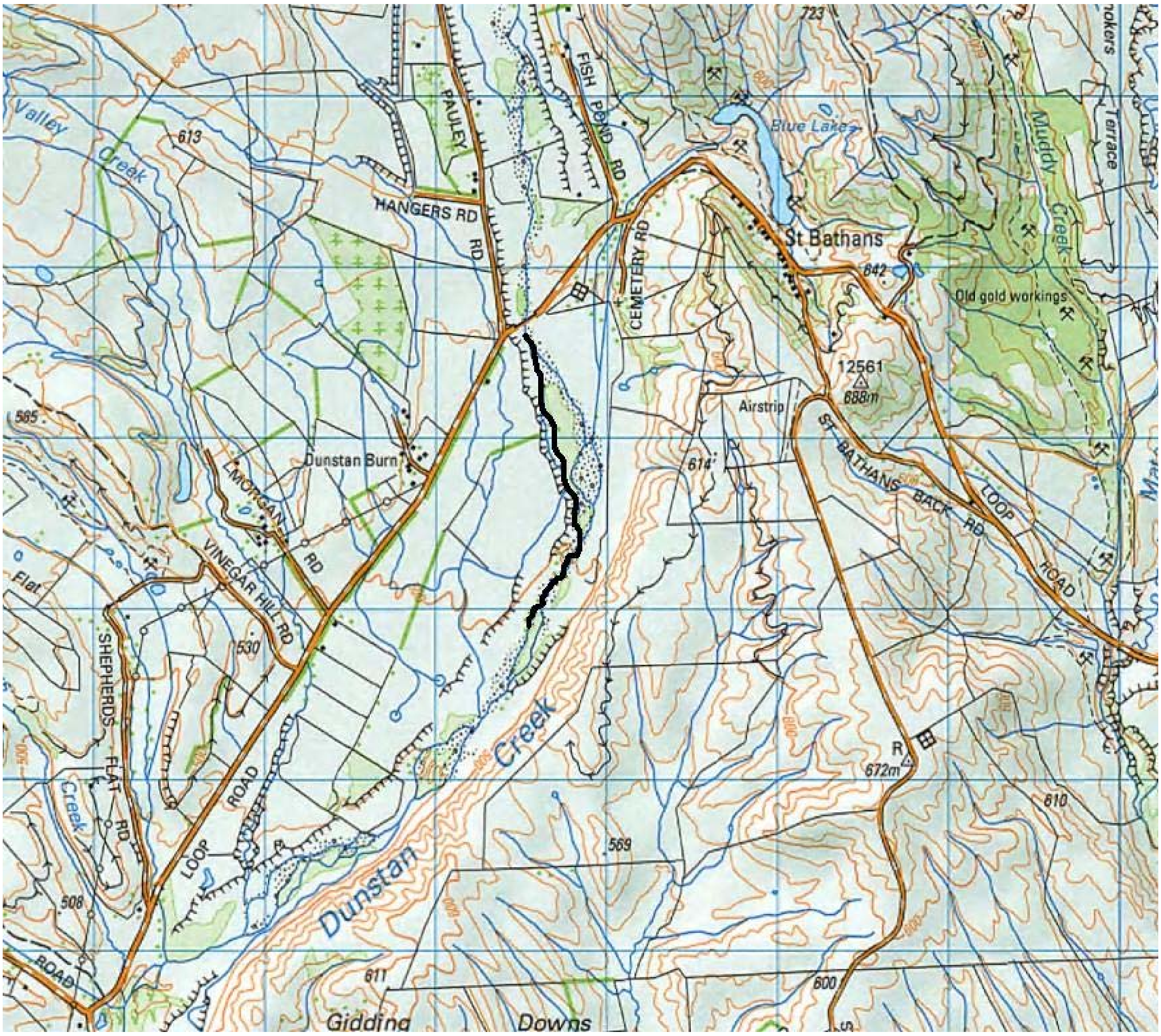

Figure 6: Dunstan Creek study reach (dark blue stream section)

1.7 Sutton Stream

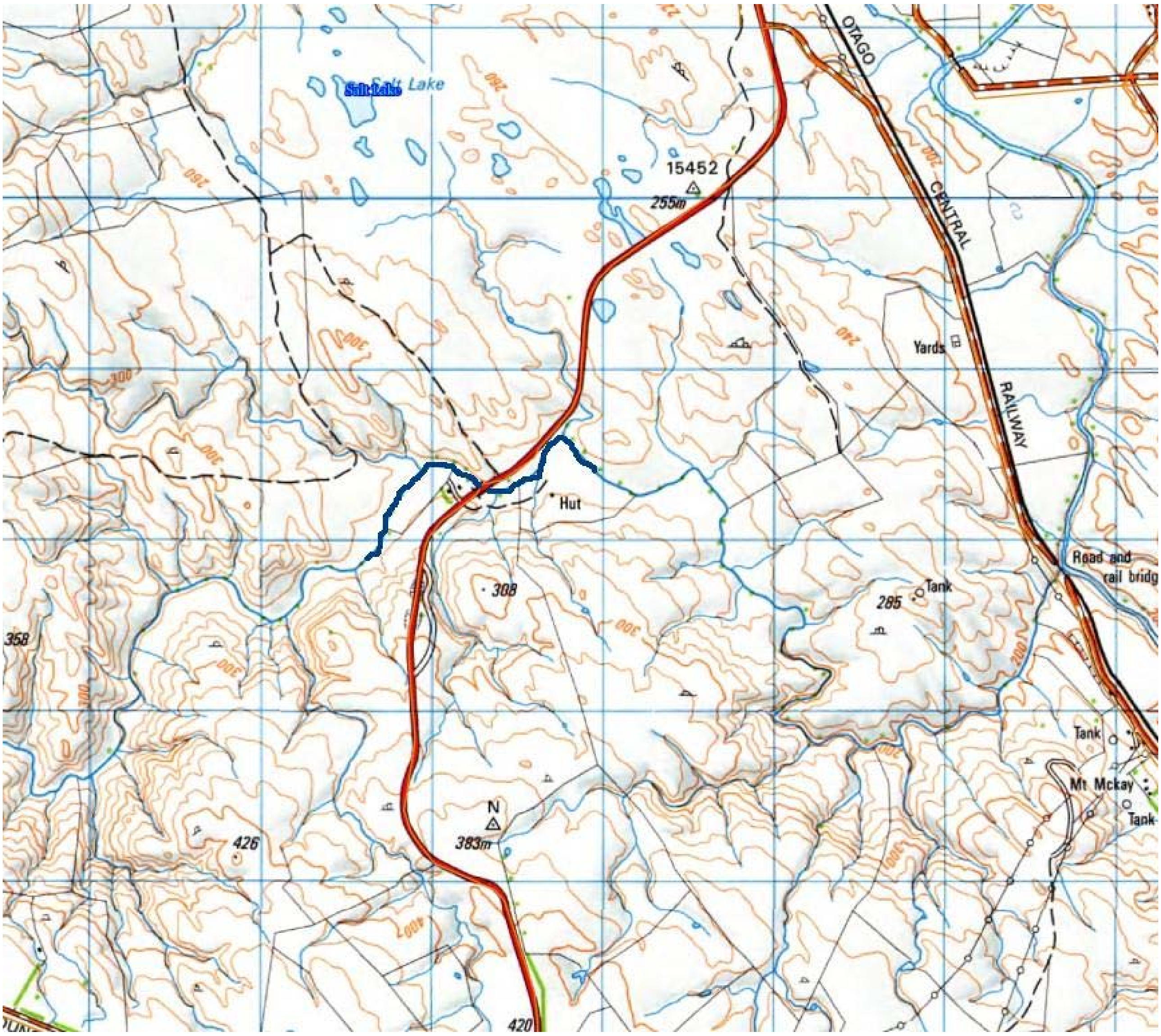

Figure 7: Sutton Stream study reach (dark blue stream section)

1.8 Kauru River

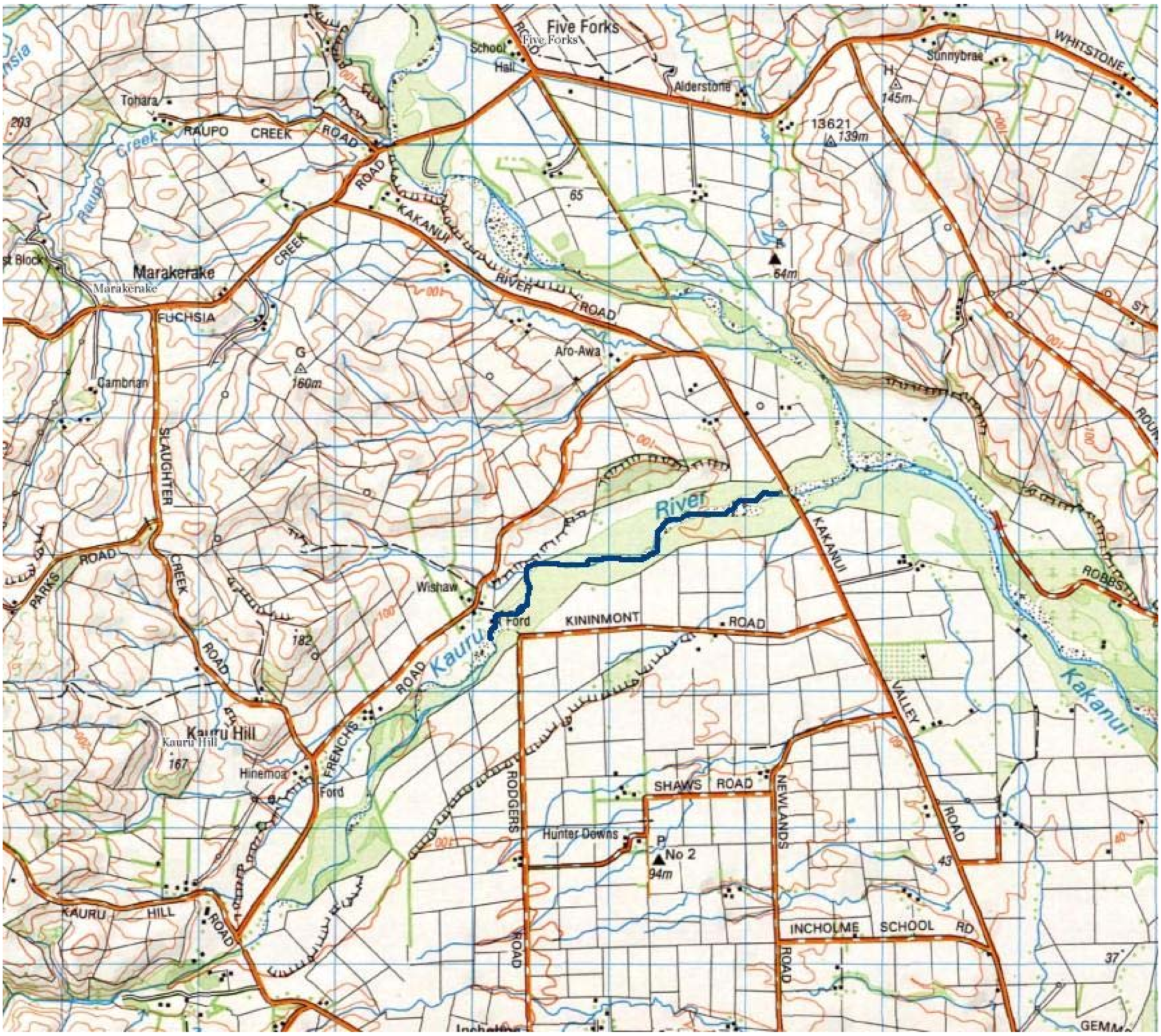

Figure 8: Kauru River study reach (dark blue stream section)

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1.9 Stream cross section GPS coordinates

Table 1: NZMG references for all cross section sites

Cross section	Pig Burn		Dunstan Creek		Sutton Stream		Kauru River	
1	2282751	5547822	2256627	5586009	2283874	5508483	2335867	5567298
2	2282804	5547738	2256624	5586038	2283657	5508516	2335632	5567356
3	2282840	5547727	2256601	5586055	2283619	5508416	2335623	5567347
4	2282868	5547701	2256589	5586070	2283575	5508362	2335455	5567295
5	2282949	5547551	2256723	5586136	2283477	5508319	2335381	5567210
6	2282973	5547521	2256780	5586347	2283363	5508289	2335260	5567038
7	2283015	5547476	2256844	5586610	2283031	5508450	2335381	5567210
8	2283042	5547392	2256782	5586663	2282964	5508423	2334884	5566897
9	2283071	5547369	2256782	5586663	2282905	5508393	2334765	5566903
10	2283082	5547345	2256760	5586712	2282842	5508297	2334735	5566894
11	2283102	5547302	2256737	5586733	2282812	5508263	2334468	5566707
12	2283153	5547247	2256698	5586886	2282764	5508193	2334410	5566628
13	2283232	5547206	2261979	5590404	2282747	5508161	2334354	5566605
14	2283286	5547169	2256583	5587432	2282722	5508005	2334129	5566383
15	2283310	5547143	2256580	5587451	2282652	5507911	2334057	5566316
Cross section	**Upper Sow Burn**		**Lower Sow Burn**		**Upper Waitahuna River**		**Lower Waitahuna River**	
1	2278498	5540115	2277630	5546596	2259555	5464845	2245480	5448427
2	2278479	5540057	2277623	5546497	2259568	5464855	2245609	5448568
3	2278437	5539974	2277930	5546048	2259626	5464862	2245667	5448630
4	2278360	5539927	2277803	5545619	2259819	5464957	2245868	5448708
5	2278288	5539899	2277854	5545522	2259886	5464989	2245963	5448786
6	2278285	5539894	2277839	5545414	2259962	5465023	2246064	5448863
7	2278229	5539806	2277820	5545220	2259938	5465009	2246149	5449142
8	2278168	5539663	2277842	5544964	2260017	5465024	2246192	5449192
9	2278197	5539513	2277887	5544918	2260124	5464976	2246179	5449299
10	2278199	5539494	2278014	5544658	2260244	5465000	2246242	5449559
11	2278145	5539403	2278235	5544654	2260360	5465074	2246384	5449703
12	2278108	5539366	2278277	5544616	2260454	5465071	2246382	5449716
13	2278074	5539345	2278335	5544354	2260614	5465154	2246385	5449739
14	2278028	5539289	2278431	5544290	2260710	5465248	2246463	5449815
15	2278056	5539115	2278432	5544264	2260768	5465348	2246493	5449845

2.0 FLOW GAUGING SITES

2.1 Pig Burn

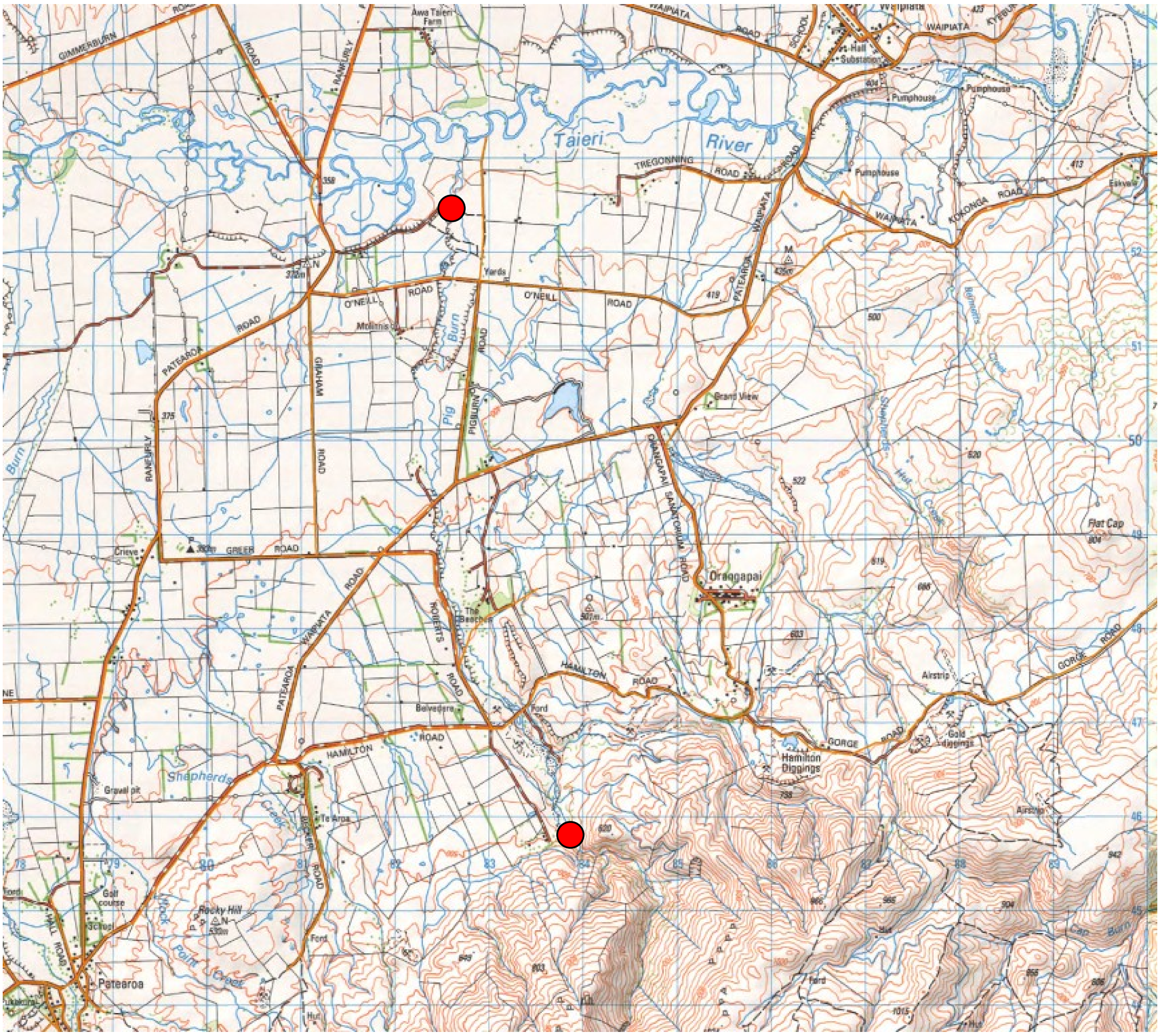

Figure 9: Pig Burn flow monitoring sites (red circles)

2.2 Sow Burn

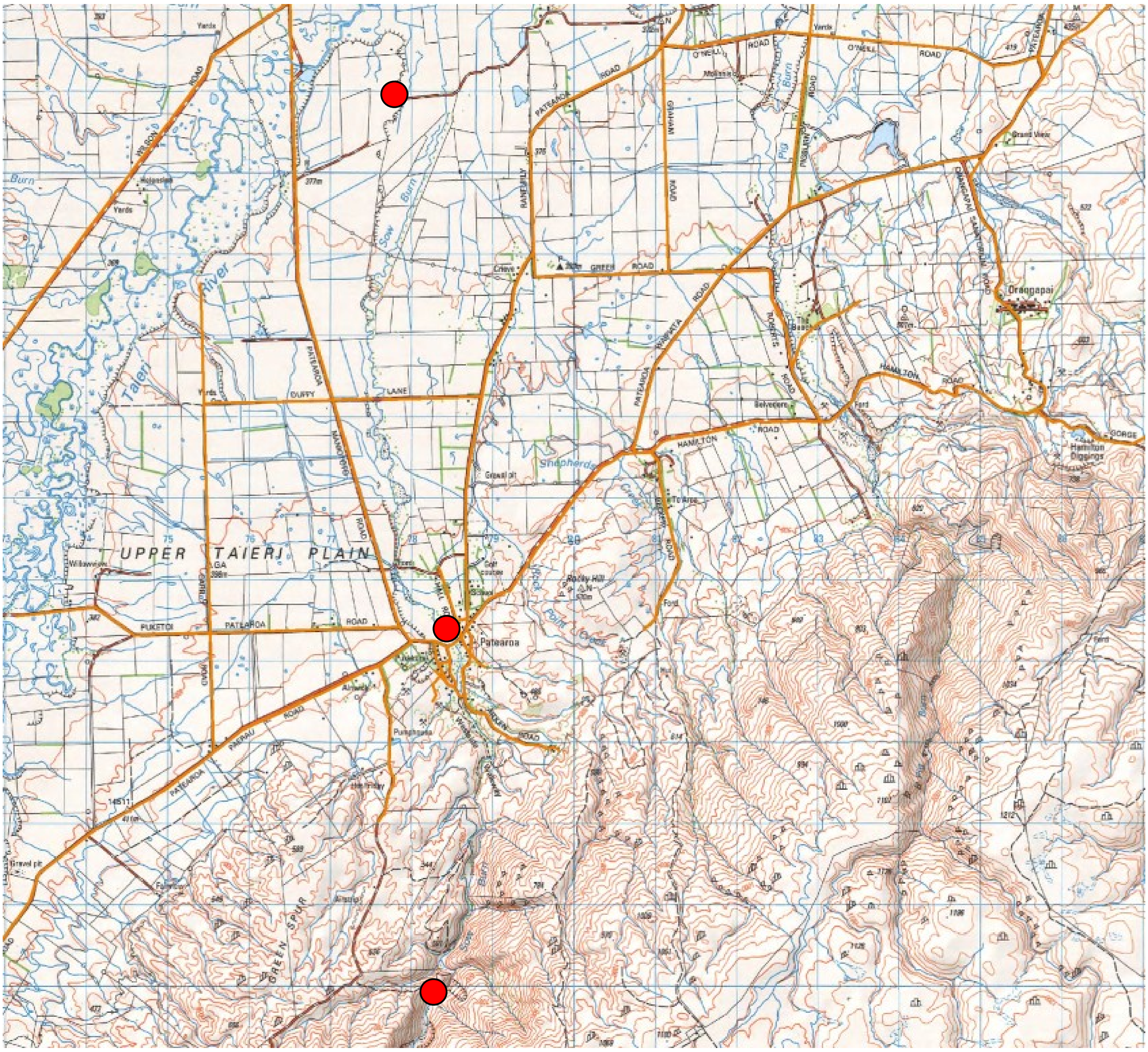

Figure 10: Sow Burn flow monitoring sites (red circles)

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APPENDIX 3

Habitat preference curves

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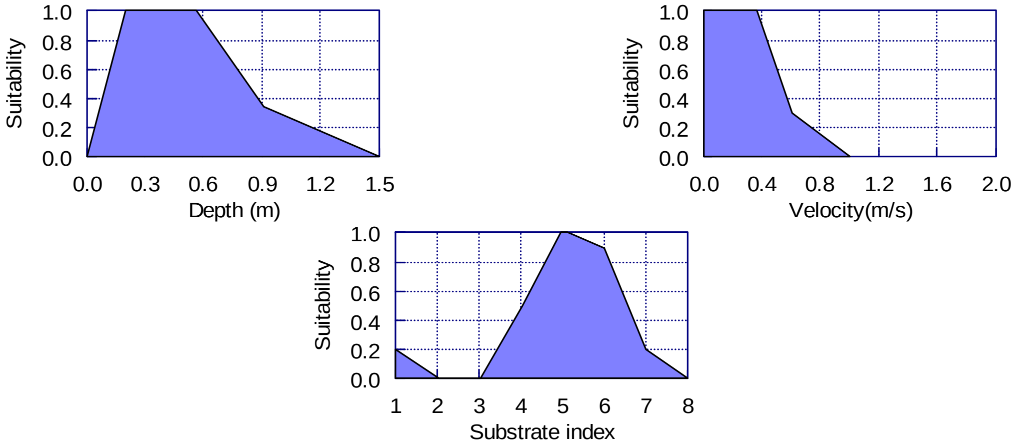
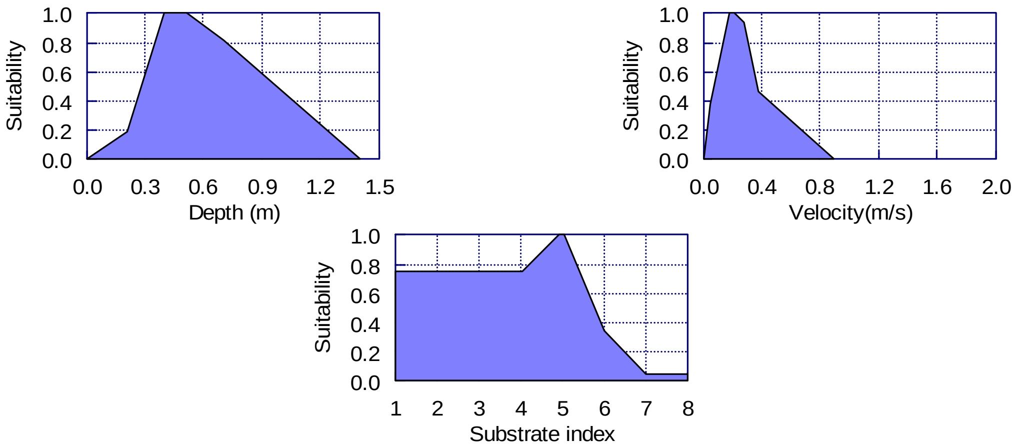
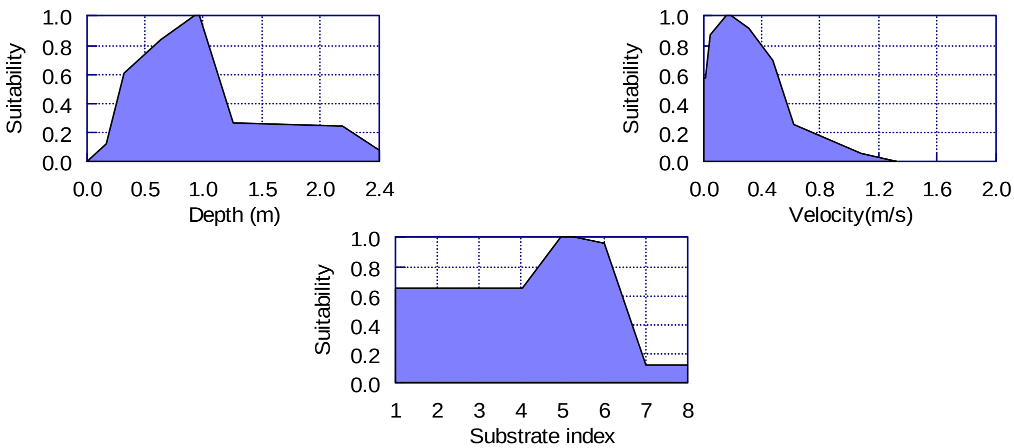
Brown trout fry (Bovee 1978)



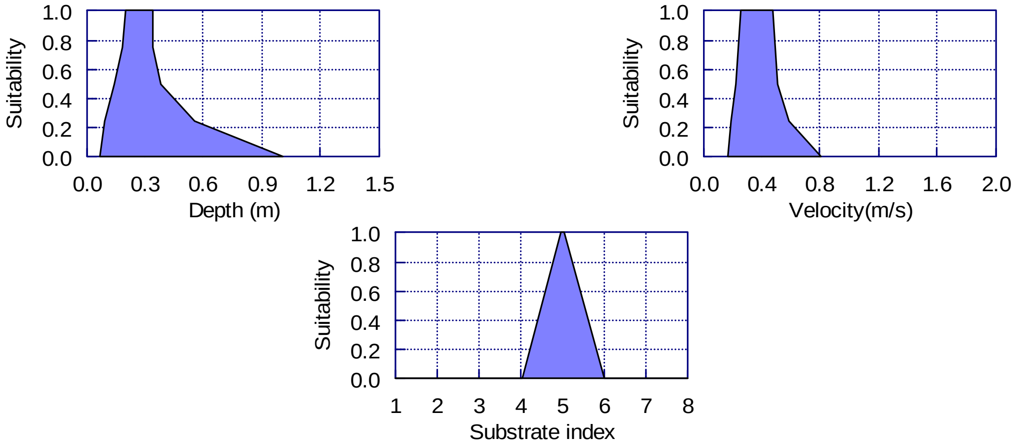
Brown trout fry to 15cm (Raleigh et al 1986)



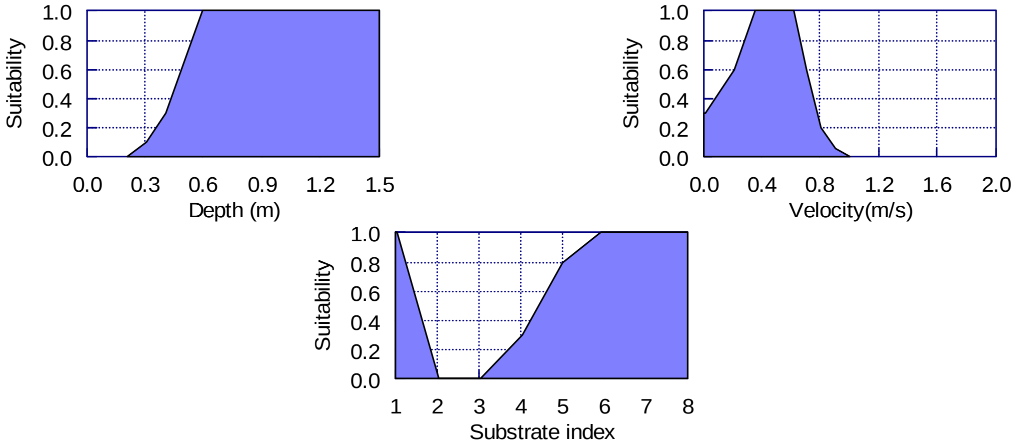
Brown trout yearling (Raleigh et al 1986)



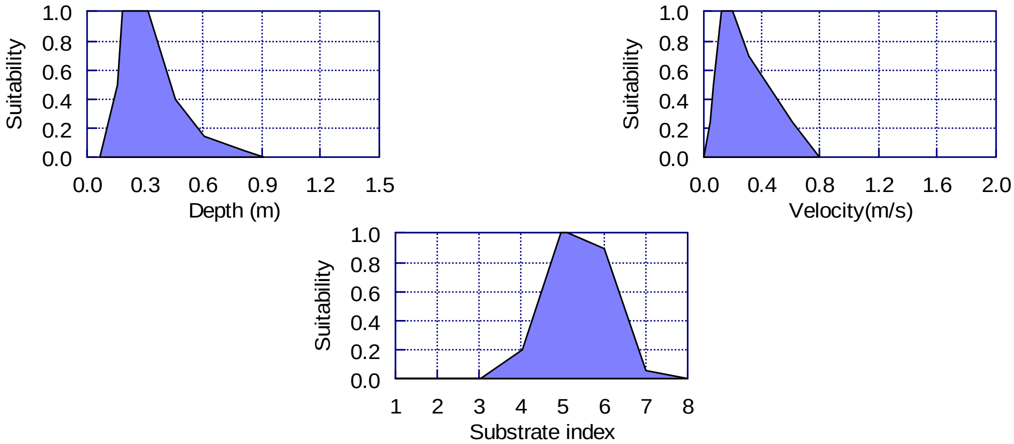
Brown trout spawning (Shirvell and Dungey 1983)



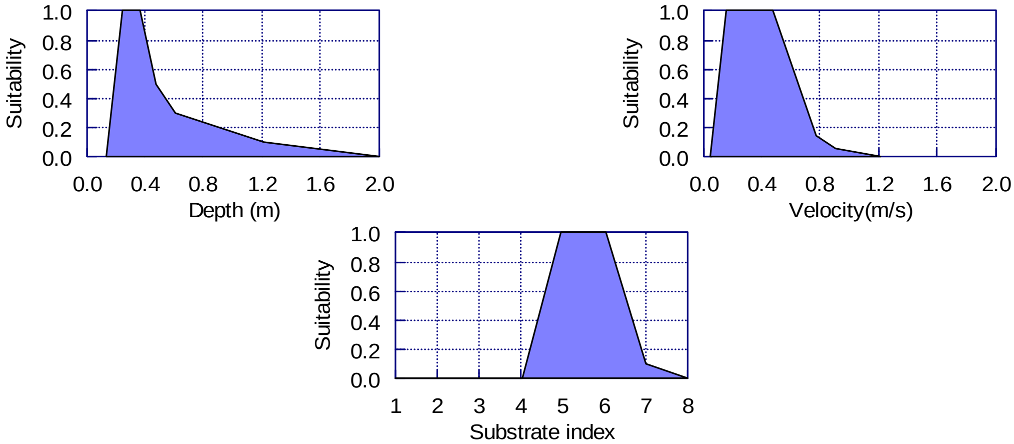
Brown trout adult (Hayes and Jowett 1994)



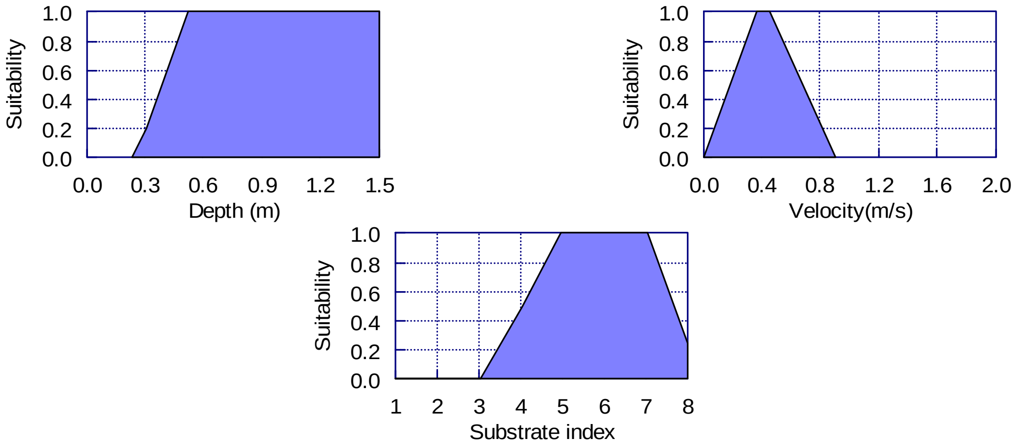
Rainbow trout fry (Bovee 1978)



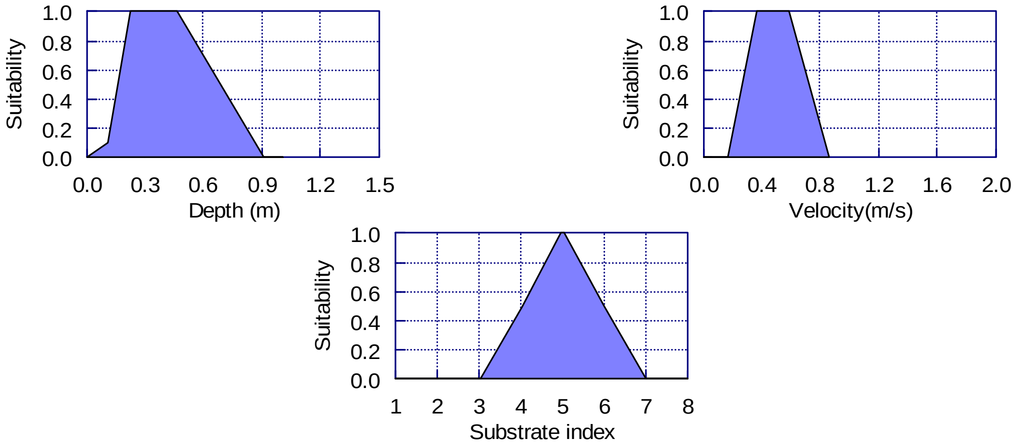
Rainbow trout juvenile (Bovee 1978)



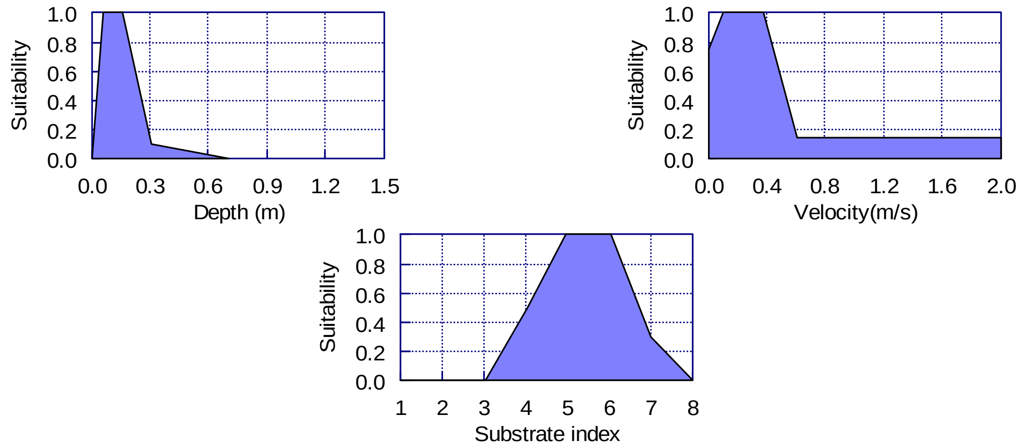
Rainbow trout adult (Bovee 1978)



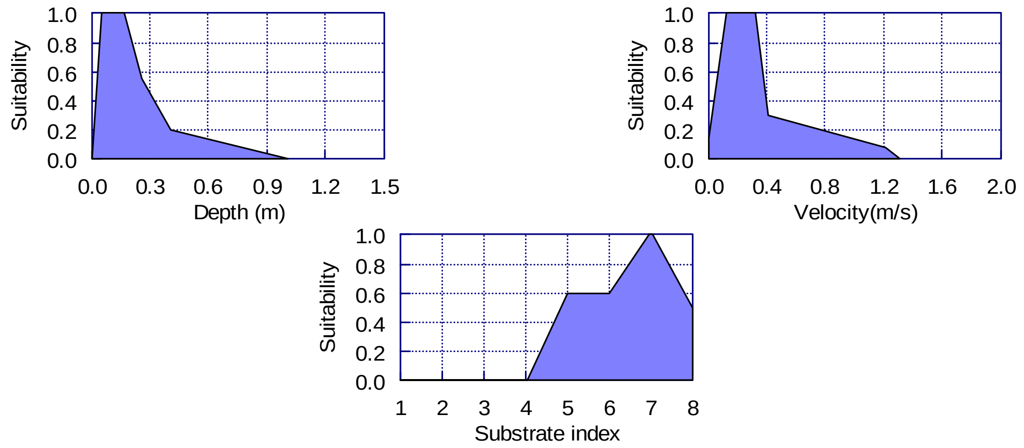
Rainbow trout spawning (Tongariro) (Jowett et al. 1996)



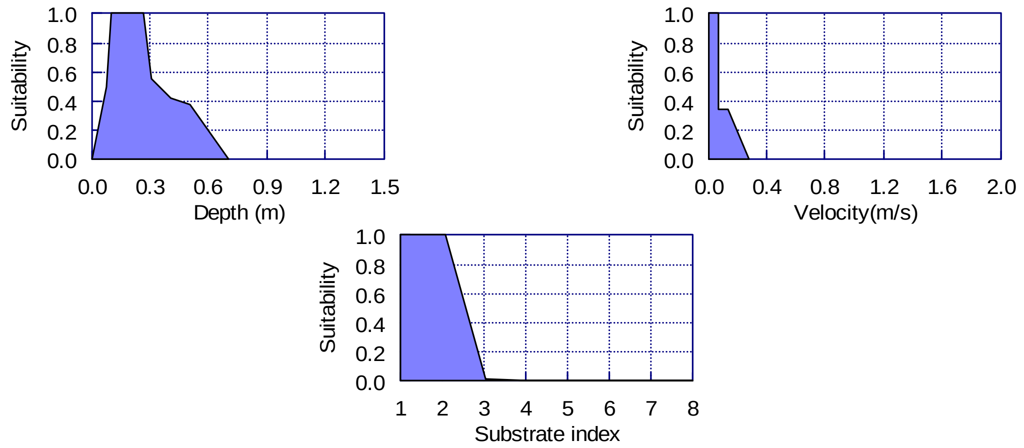
Upland bully (Jowett and Richardson 1995)



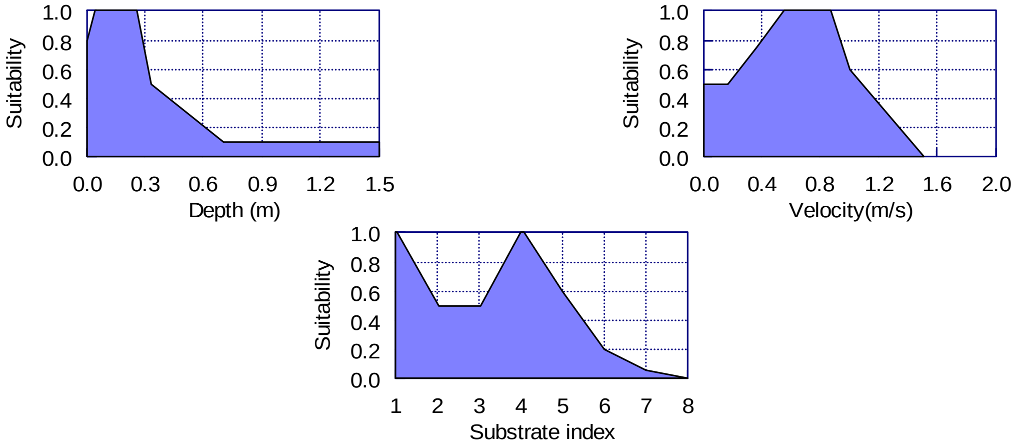
Roundhead (G. anomalus) (Baker et al. 2003)



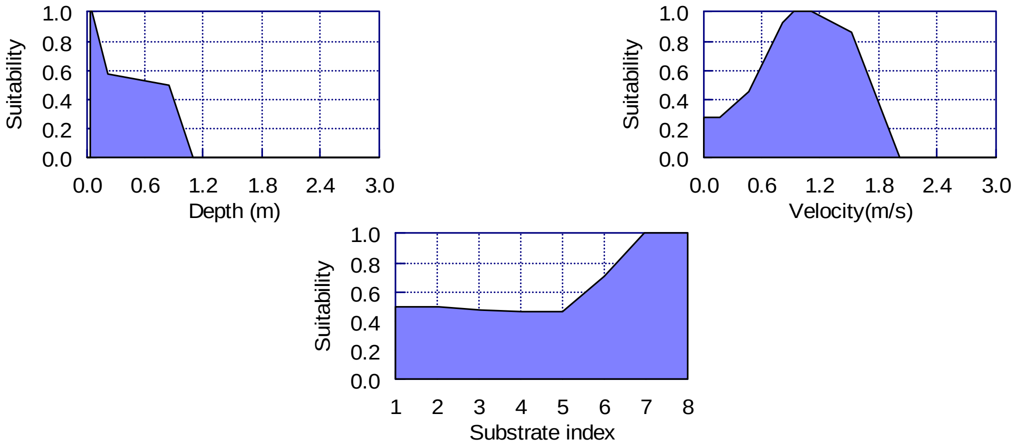
Juvenile lamprey (Jellyman & Glova 2002)



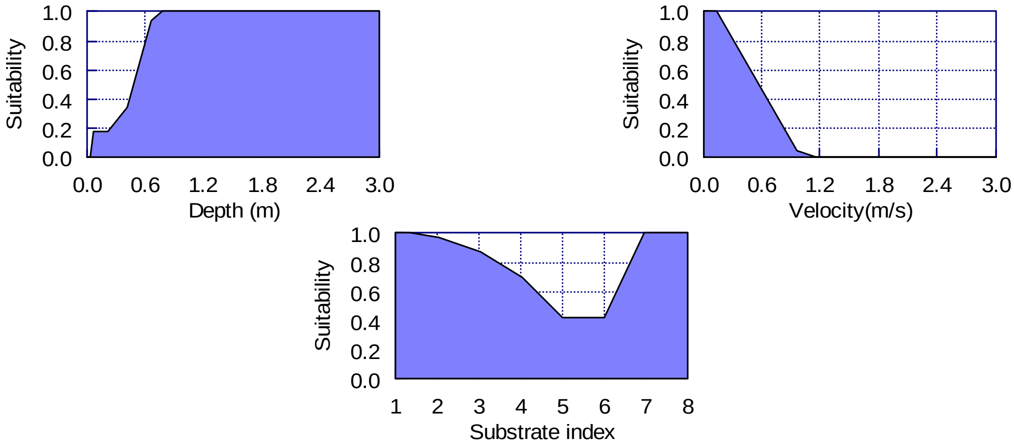
Shortfin eel (<300mm) (Jowett and Richardson 1995)



Longfin eels <300 mm (Jellyman et al. 2003)



Longfin eels >300 mm (Jellyman et al. 2003)



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APPENDIX 4

Additional flow gauging

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1.0 ADDITIONAL FLOW MEASUREMENTS

1.1 Introduction

To determine the flow regimes and hydrology of the Pig Burn and Sow Burn, ORC placed water level sensors at five sites: three in the Sow Burn and two in the Pig Burn. At each site flow gaugings were undertaken in February and March to allow the development of a rating curve for each site. Golder's staff under took three gauging at each site.

1.2 Pig Burn

The upper flow monitoring site in the Pig Burn placed upstream of all abstractions and the downstream site was placed below all abstraction sites and the bywash inflow site from the Maniototo Irrigation Scheme (Table 12, Appendix A). Flow at the upstream site ranged from 0.056 m^3/s to 0.032 m^3/s and at the downstream site from 0.002 m^3/s to a flow to low to measure for the three flow gauging under taken.

Table 1: Flows measured at the Pig Burn flow monitoring sites

Site	Easting	Northing	Date	Time	Flow (m^3/s)	Water Level (m)
Upper Pig Burn	2283943	5545736	15/03/07	13:45	0.056	-
			20/03/07	17:15	0.032	9.329
			4/04/07	15:25	0.045	9.347
Lower Pig Burn	2282684	5552455	15/03/07	15:45	0.002	-
			20/03/07	16:10	0.001	9.385
			4/04/07	16:45	Not measurable	9.378

1.3 Sow Burn

The upper flow monitoring site in the Sow Burn placed upstream of all abstractions in the lower part of the Sow Burn gorge. A second monitoring site was placed approximately 100 m downstream of the Sow Burn bridge at Patearoa. The third and most downstream site was placed below all abstraction sites immediately downstream of Sangster's Bridge on the Sow Burn (Table 13, Appendix A). Flow at the upstream site ranged from 0.449 m^3/s to 0.259 m^3/s; at the Patearoa site from 0.044 m^3/s to 0.029 m^3/s and at the downstream site from 0.103 m^3/s to 0.094 m^3/s for the three flow gauging under taken.

Table 2: Flows measured at the Sow Burn flow monitoring sites

Site	Easting	Northing	Date	Time	Flow (m^3/s)	Water Level (m)
Upper Sow Burn	2278496	5540109	16/03/07	9:45	0.449	9.614
			20/03/07	9:35	0.269	9.555
			23/03/07	10:20	0.259	9.550
Mid Sow Burn	2278421	5544294	15/03/07	16:05	0.044	9.198
			20/03/07	13:00	0.029	9.187
			23/03/07	13:40	0.031	9.188
Lower Sow Burn	2278420	5550981	15/03/07	17:30	0.103	-
			20/03/07	14:15	0.094	9.502
			23/03/07	15:45	0.099	9.505

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