Jowett Consulting Ltd.

Proposed Hydro-electric Project Inangahua River: Assessment of Hydrological and Environmental Effects

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Proposed Hydro-electric Project Inangahua River: Assessment of Hydrological and Environmental Effects

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Prepared for

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Executive summary

The Reefton power scheme was first constructed in 1888 and was subsequently modified in 1908 and 1935. It was located on the south bank of the Inangahua River and was a run-of-river hydro power scheme which diverted part of the river flow at an intake at Blacks Point and discharged water back into the Inangahua River opposite Reefton township.

There is a community initiative to reinstate the power scheme with a single turbine producing a maximum of 154 KW and discharging up to 3.5 m^3/s.

This assessment of environmental effects assumes a maximum generation flow of 3.5 m^3/s and minimum generation of 1.4 m^3/s with a minimum flow of 2 m^3/s in the 2 km of river between the intake and tailrace. It has also been assumed that generation ceases when the instantaneous river flow exceeds 50 m^3/s.

With a minimum generation flow of 1.4 m^3/s and a minimum flow of 2 m^3/s for the river, the natural river flow will have to be greater than 3.4 m^3/s to operate. The power station will operate for 70% of the time and the residual river will be at or less than 2 m^3/s for 22% of the time. Both generation flows and residual flows would be higher in the winter than summer - a seasonal pattern similar to that in the natural river flows. The mean daily flow will be reduced from 16.33 m^3/s to 14.09 m^3/s and the median daily flow will be reduced from 8.09 m^3/s to 4.59 m^3/s, as shown below. The average number of days per year at or below mean annual low flow (MALF) will increase from 14.4 to 88.

Statistic	Natural river flow (m^3/s)	Generation flow (m^3/s)	Residual river flow (m^3/s)
Mean	16.33	2.24	14.09
Median	8.09	3.50	4.59
Minimum	1.363	0	1.36
Maximum	278.54	3.50	278.54
Mean annual 7 day low flow (MALF)	2.30	0.01	1.94
Frequency of freshes > 3 times median (FRE3)	16.67	-	17.01

Floods and freshes are frequent in West Coast rivers and this frequency is substantially unchanged by the proposed hydro-electric scheme. Flows greater the FRE3 (Frequency of floods > 3 times median flow) should occur every 10 days on average and these will help prevent accumulation of filamentous algae and fine sediment.

The Inangahua River is a popular brown trout angling river, and the affected reach contains high numbers of young trout and variable numbers of adult trout. The reach is about 90 km from the sea and this affects the native fish species likely to be present. Brown trout, torrentfish, longfin eels and upland bullies have been found in the main stem of the river between Reefton and Blacks Point. Two of these species (torrentfish and longfin eels) are diadromous and migrate from the sea as juveniles. The other species (upland bullies and brown trout) spend their entire lives in freshwater.

The quality of the macroinvertebrate community is high with stoneflies, mayflies and caddisflies (EPT taxa) comprising an average of 83% of the total number of macroinvertebrates collected and an average Macroinvertebrate Community Index (MCI) score of about 120. The mayfly *Deleatidium* was the most common species, followed by riffle beetles (Elmidae) and the mayfly *Nesameletus*.

Because of the numbers of trout in the affected reach and the popularity of the Inangahua River as an angling river, the suggested minimum flow is the flow that retains about 90% of the habitat available at the MALF.

A minimum flow of 2 m^3/s will provide at least 88% of habitat for brown trout (<100mm, juvenile and adults), as well as at least 90% of benthic invertebrate and food producing habitat. A flow of 2 m^3/s provides over 100% of the amount of habitat at the MALF for brown trout < 100 mm, 95% of the habitat at the MALF for juvenile brown trout, and over 96% of habitat at the MALF for *Deleatidium* and *Nesameletus*. Theoretically, a change in available habitat will only result in a population change when all available habitat is in use (Orth 1987). Populations are probably at less than maximum levels because flows and available habitat are varying all the time. A 10% reduction in habitat at the MALF for native fish is unlikely to affect their numbers. This is because the densities of native fish, particularly torrentfish, are low and a habitat loss of 10% would maintain existing population levels, whereas habitat loss of 50% might result in some effect on populations, especially where densities were high.

Although a flow of 2 m^3/s retain 88% of trout habitat, the reduction in median flow will reduce the food producing capacity of the affected section of river and this is likely to reduce the number of adult trout. The brown trout model (Jowett 1992) predicts the number of adult trout (> 20 cm) using river and catchment characteristics including adult brown trout habitat at MALF and food producing habitat at median flow. With a minimum flow of 2 m^3/s, the number of adult trout in the affected reach could be reduced by up to 28%.

The survival rate of adult trout and eels passing through turbines would be low, so that it would be necessary to screen the intake to avoid entrainment. The suggested bar spacing is 10 mm with an approach velocity of less than 0.3 m/s. This should prevent the entrainment of adult eels and trout > 100mm. Because the head on the turbine is low (5 m), smaller fish should pass through the turbine with at least 85% survival. Given the high natural mortality of juvenile trout, this mortality is not expected to affect adult trout numbers in the remainder of the Inangahua River.

The key points of this proposal are that it only affects a short section (2 km) of the Inangahua River. The main effect will be on adult trout where the number of adult trout could be reduced by up to 28%, mainly as a result of the reduction in food (benthic invertebrate) production.

1 Proposed hydro-electric project

The Reefton Power Station was initially completed 4 August 1888 and became the first public electricity supply in New Zealand and the southern hemisphere. This hydro scheme diverted water from Inangahua River between Blacks Point and Reefton. It was decommissioned in 1961 and has been registered by the New Zealand Historic Places Trust as a Category 2 historic place.

As part of the 125th anniversary of Reefton Power Station, it is proposed that this hydro scheme be reinstated as a community initiative to promote tourism in the area as well as generate revenue from hydroelectricity.

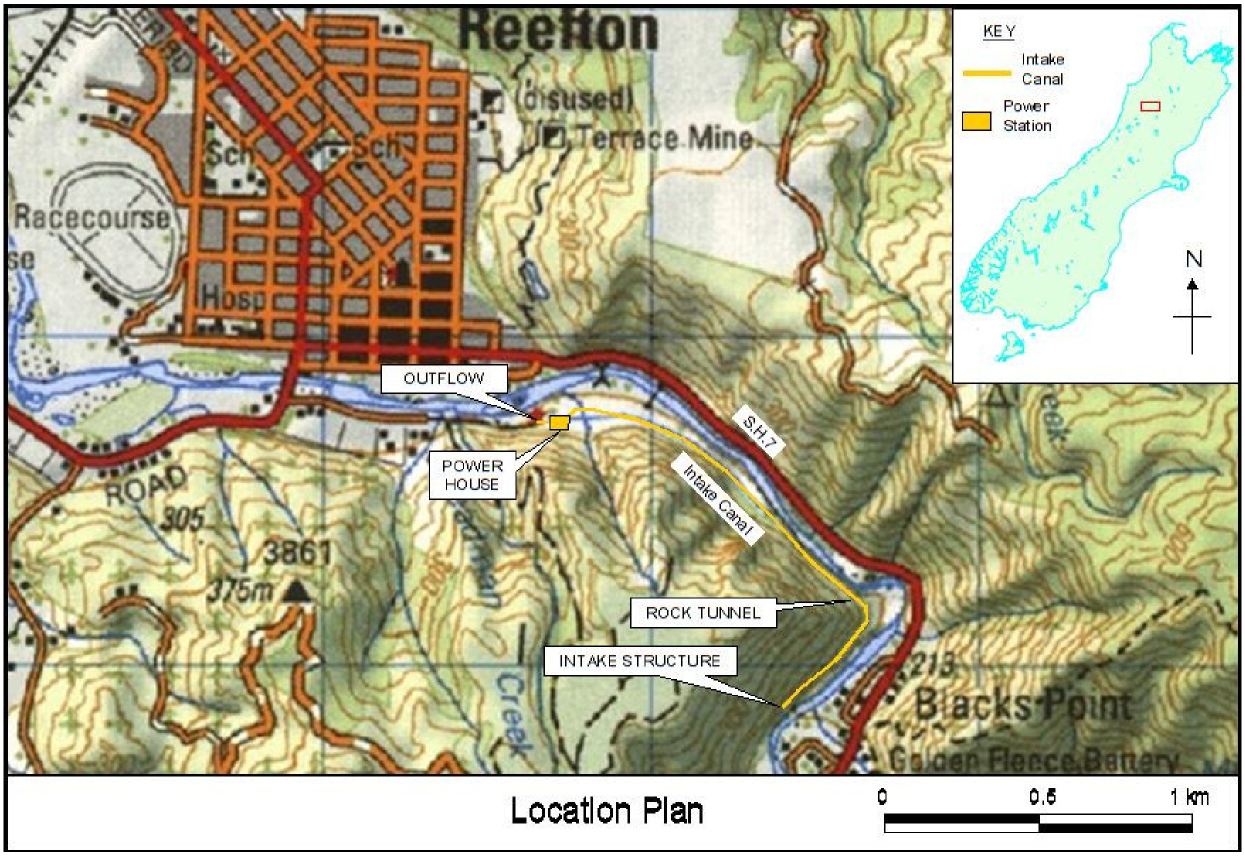

Figure 1: Location of proposed Reefton Power Scheme showing the intake location and power station site, and the 2 km of river where flows will be reduced when the power scheme is operating.

2 Inangahua River

The Inangahua River flows about 30 km through native bush from its headwaters near Rahu Saddle. It then flows through a short (6 km) open section where the valley floor is farmed before entering a more constrained section of valley from about 3 km above Blacks Point to Reefton. It joins the Buller River at Inangahua Junction about 70 km from its headwaters. The Inangahua River is excluded from the Buller Conservation Order.

The proposed power scheme will divert water from the river at the existing intake at Blacks Point and discharge it back into the river about 2 km downstream. This section of river comprises long sections of run habitat (50%) and pools (35%) interspersed with short sections of boulder/cobble riffles (15%). The banks are generally either scrub or exposed cobbles.

2.1 Instream values

Native Fish

The number of native fish species present in the Inangahua River at Blacks Point is limited by its distance from the sea (> 90 km). NIWA's freshwater fish database has 50 records of fish in the Inangahua catchment of which 5 records are in the main stem of the Inangahua River (Table 1). Longfin eels, upland bullies and brown trout are the most common fish species in the Inangahua catchment. Brown trout, torrentfish, longfin eels and upland bullies have been found in the main stem of the river between Reefton and Blacks Point (Jowett & Richardson 1996). Two of these species (torrentfish and longfin eels) are diadromous and migrate from the sea as juveniles. The other species (upland bullies and brown trout) spend their entire lives in freshwater. The density of fish sampled by electro-fishing in the reach between Blacks Point and Reefton was low (9.1 fish / 100 m^2) and was the 4th lowest density compared to 38 other New Zealand rivers (Jowett & Richardson 1996), most of which were closer to the sea.

Table 1: NIWA freshwater database records for the Inangahua River.

Species	Scientific name	Number of records of species found in Inangahua catchment	Number of records of species found > 84 km from sea
Koura	*Paranephrops*	4	2
Longfin eel	*Anguilla dieffenbachii*	20	6
Shortfin eel	*Anguilla australis*	1	
Brown trout	*Salmo trutta*	35	12
Upland bully	*Gobiomorphus breviceps*	19	5
Redfin bully	*Gobiomorphus huttoni*	3	
Torrentfish	*Cheimarrichthys fosteri*	2	1

Dwarf galaxias	*Galaxias divergens*	1	

Note: There are 50 records of fish species in the catchment and 19 records of species were more than 84 km from the sea.

Trout

The Inangahua River is an important brown trout angling river. Angler surveys in 1994/95, 2001/02 and 2007/08 (Unwin & Brown 1998, Unwin & Image 2003, Unwin 2009) rank the Inangahua River 6th out of 111 recognised angling rivers in the West Coast Fish and Game District.

Drift dive surveys of the Inangahua River have been carried out by the Ministry of Agriculture and Fisheries (Teirney & Jowett 1990) and West Coast Fish & Game (Unpublished data). These show an average of 285 small (10-20 cm) brown trout per km, 124 medium (20-40 cm) brown trout, and 11 large (>40 cm) brown trout per km (Table 2). The darting and schooling behaviour of the small and medium-sized trout when they are in high numbers makes accurate counts difficult. The high numbers of small trout and variable numbers of large trout (4-40 per km) indicate that this section of river is primarily a nursery and rearing area, with adult fish moving upstream to spawn in winter and gradually moving downstream, through the reach, in spring and summer as flows reduce. Below Reefton, the number of large trout will tend to increase and the number of small trout decrease. For example, at Inangahua Landing, Teirney & Jowett (1990) reported 30 large brown trout per km and 16 small trout per km and considered that they had only covered 75% of the river width in the drift-dive.

Table 2: Brown trout numbers counted by drift-diving in the Inangahua River between Blacks Point and Reefton.

Date	Reach Length (km)	Width (m)	Black Disk visibility (m)	L	M	S	L/km	M/km	S/km
18/02/1986	1.8	18.5	6.5	8	47	368	4.44	26.11	204.44
7/03/1991	1.7	18		7	283	174	4.12	166.47	102.35
14/02/1992	1.7	18		7	287	774	4.12	168.82	455.29
18/02/1993	1.7	18		11	145	674	6.47	85.29	396.47
16/02/1994	1.7	18		9	127	452	5.29	74.71	265.88
13/02/1995	1.7	18		25	293	339	14.71	172.35	199.41
14/02/1996	1.7	18		10	204	396	5.88	120.00	232.94
18/03/1997	1.7	18		72	392	356	42.35	230.59	209.41
7/02/2001	1.7	18	4.5	15	93	264	8.82	54.71	155.29
12/02/2003	1.7	18	6	33	198	683	19.41	116.47	401.76
12/02/2003	1.7	18	5	26	335	1021	15.29	197.06	600.59
12/02/2003	1.7	18	3.5	16	250	623	9.41	147.06	366.47

16/02/2012	1.7	18	5.8	13	83	205	7.65	48.82	120.59

Note: L is the number of large (>40 cm) trout observed, M is the number of medium (20-40 cm) trout, S is the number of small (10-20 cm) trout. Data since 1986 were supplied by West Coast Fish & Game.

Macroinvertebrates

The macroinvertebrate community in the river has been sampled at three locations between Blacks Point and Reefton. The mayfly *Deleatidium* was the most common species, followed by riffle beetles(Elmidae) and the mayfly *Nesameletus*. The community indices were high with stoneflies, mayflies and caddisflies (EPT taxa) comprising an average of 83% of the total number of macroinvertebrates collected and an average MCI (Macroinvertebrate Community Index, Stark 1985) score of about 120.

2.2 Habitat suitability curves

The fish species likely to be present and affected by the operation of the power scheme are longfin eel, torrentfish, upland bully ,and brown trout. The fish habitat suitability curves used are from Jowett & Richardson (2008). These habitat suitability curves were based on data from 124 different rivers with 5,000 sampling locations and 21,000 fish. Adult brown trout (> 40 cm) habitat criteria are based on Hayes & Jowett (1994). Juvenile brown trout (7 - 17 cm) criteria are based on Thomas & Bovee (1993). Benthic invertebrate habitat suitability curves for *Deleatidium* and *Nesameletus* are based on data described in Jowett et al. 1991 and food producing habitat curves were from Waters (1976).

2.3 Instream Habitat

The instream habitat survey was carried out in the section of river of river between Blacks Point and Reefton (Fig. 2.1) on 2-3 February 1987 at a flow of 7.6 m^3/s. Thirty-two cross-sections were measured over a reach length of about 500 m. Water velocities and depths were measured and substrate assessed visually at an average spacing of 1.3 m. Calibration measurements were made at the downstream cross-section at flows of 2.03 m^3/s and 15.67 m^3/s. Water levels at upstream cross-sections were predicted using water surface profile modelling (Jowett 1989) and relationships between predicted water level and flow were developed from levels predicted at flows of 2.03 m^3/s and 15.67 m^3/s and measured at a flow of 7.6 m^3/s.

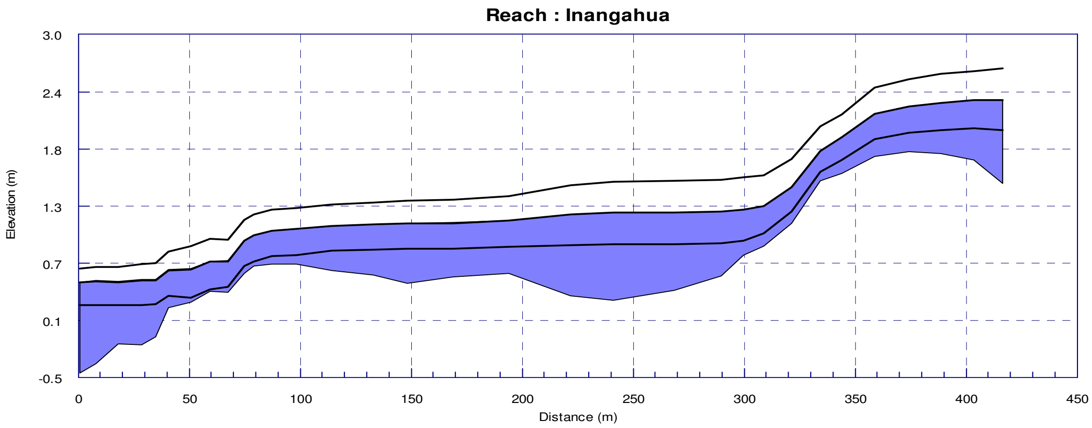

Figure 2: Longitudinal profile of the instream habitat survey reach showing water levels at 2.03 m^3/s, 7.6 m^3/s and 15.67 m^3/s and mean bed level.

River morphology is controlled by the flows, river gradient, sediment supply and the strength of the bank material. Although the instream habitat survey was made in 1987, there is no reason to believe that the factors that determine river morphology have changed, so that the 1987 survey will still be representative of the river between Blacks Point and Reefton.

Flows of up to the median flow (7.7 m^3/s) were modelled to show the overall effect of flow changes on instream habitat.

Water depths and velocities were computed at each measurement point across each cross-section for a range of modelled flows, and the habitat suitability index (HSI) was evaluated (see Figure A1.2 in Appendix 7.I) at each measurement point from habitat suitability curves for each fish species.

The weighted usable area (WUA) for each modelled flow was calculated as the sum of the habitat suitability indices across each cross-section, weighted by the proportion of the reach which each cross-section represented in the river.

WUA was plotted against flow and the resulting curves examined to determine the flow that provided maximum habitat and the flow required to maintain 90% of habitat (WUA) available at the MALF.

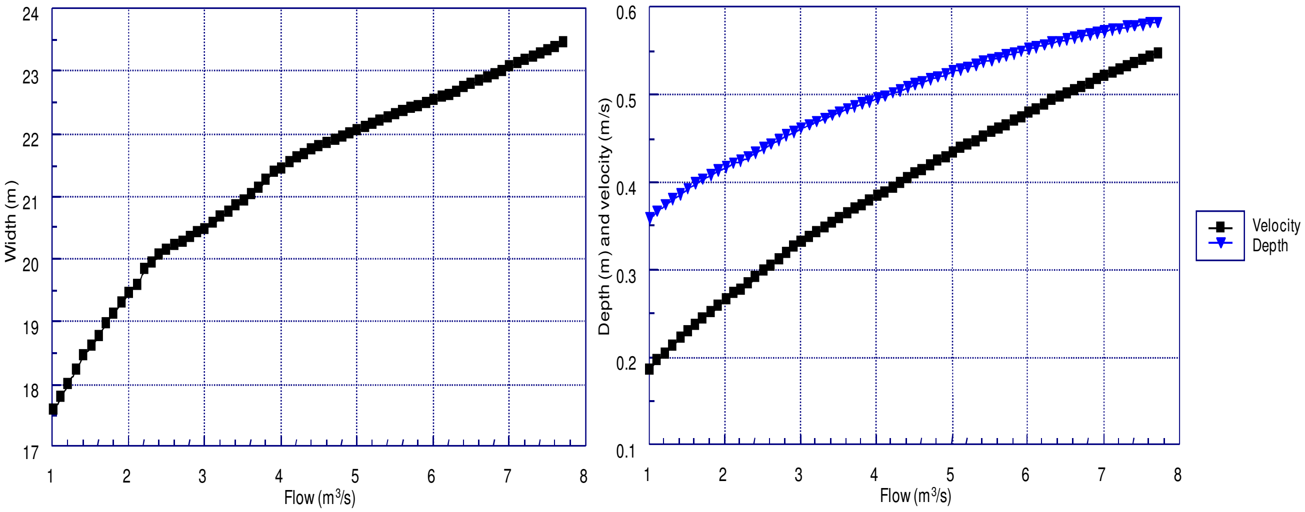

Figure 3: Variation of width (left), depth and velocity (right) with flow in the Inangahua River at Blacks Point.

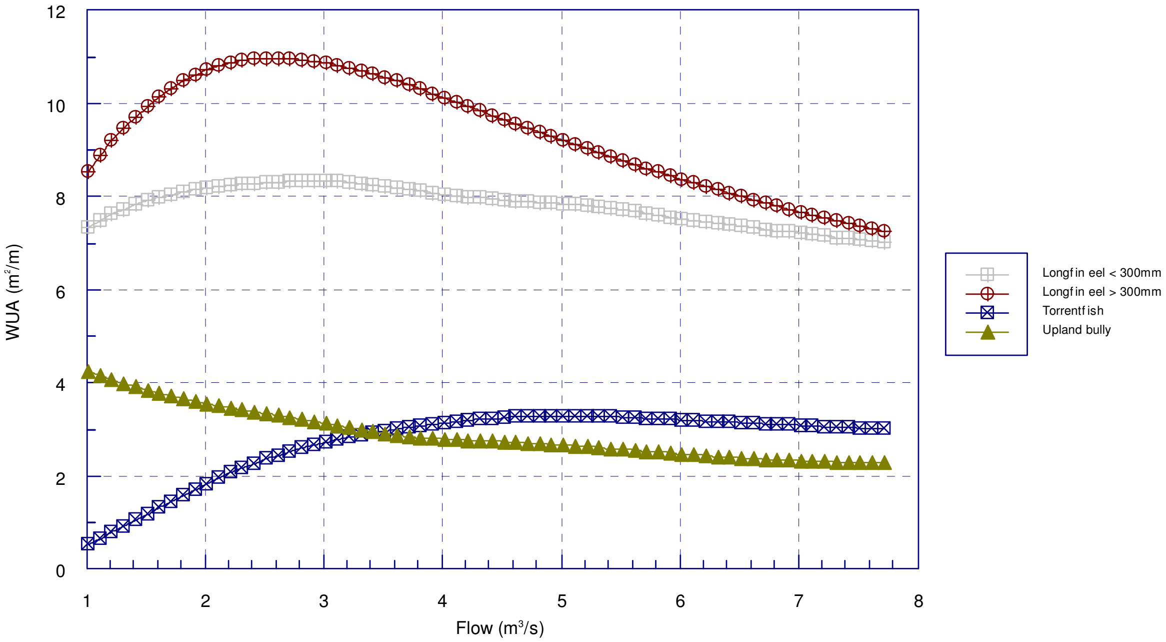

Figure 4: Variation of weighted usable area (WUA m^2/m) with flow for native fish habitat in the Inangahua River at Blacks Point.

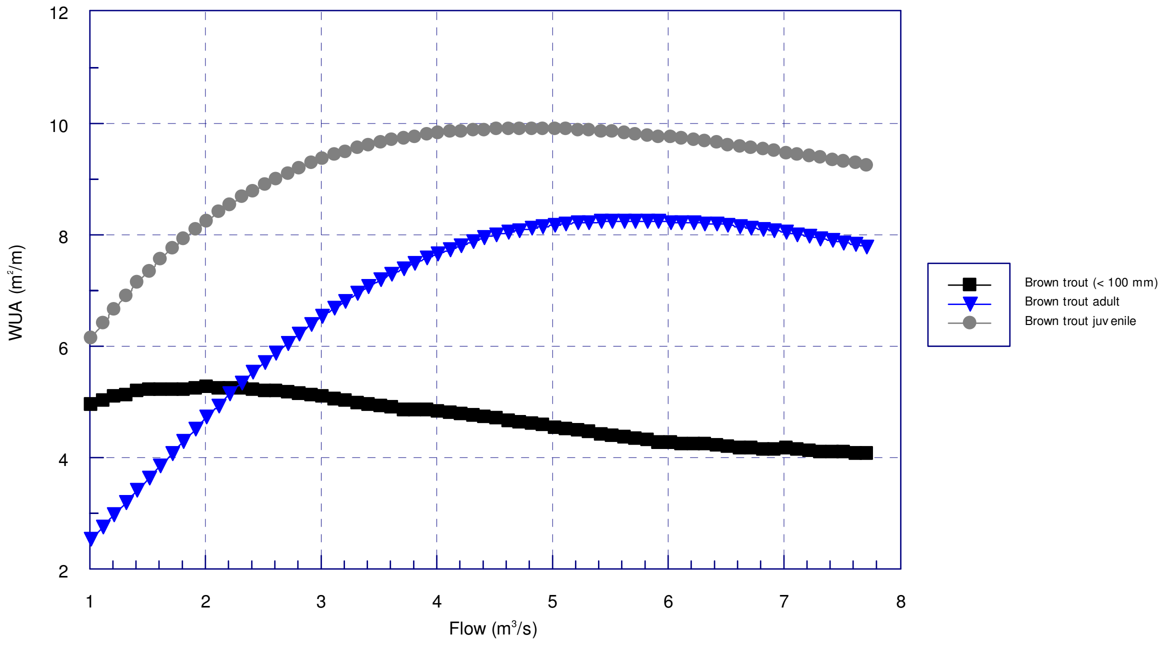

Figure 5: Variation of weighted usable area (WUA m^2/m) with flow for brown trout habitat in the Inangahua River at Blacks Point.

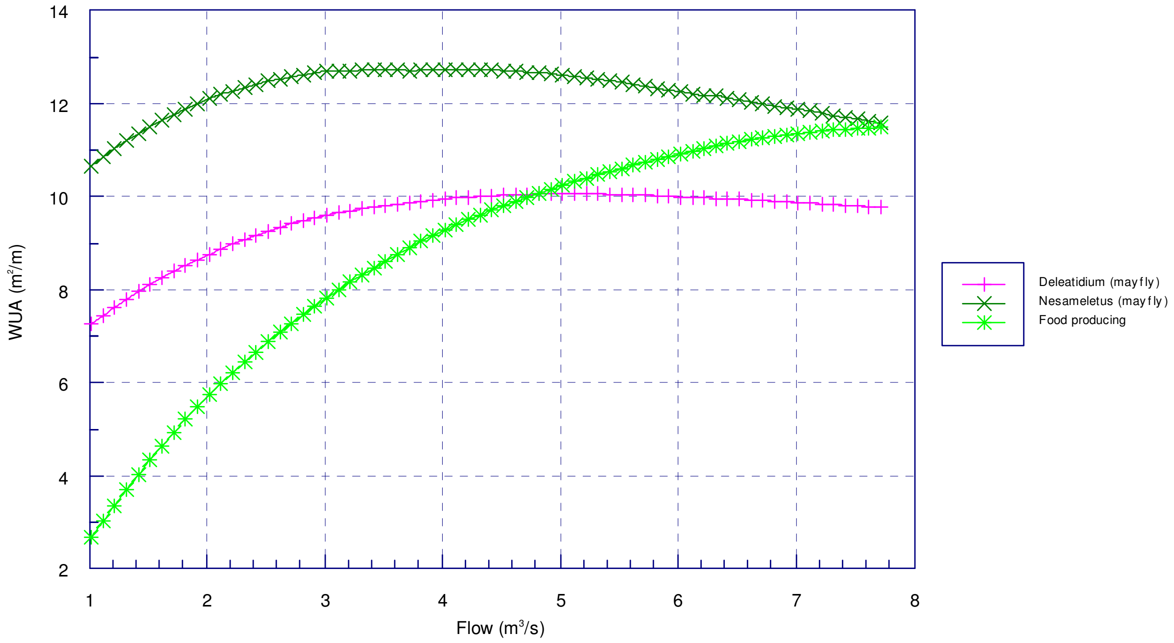

Figure 6: Variation of weighted usable area (WUA m^2/m) with flow for benthic invertebrate and food producing habitat in the Inangahua River at Blacks Point.

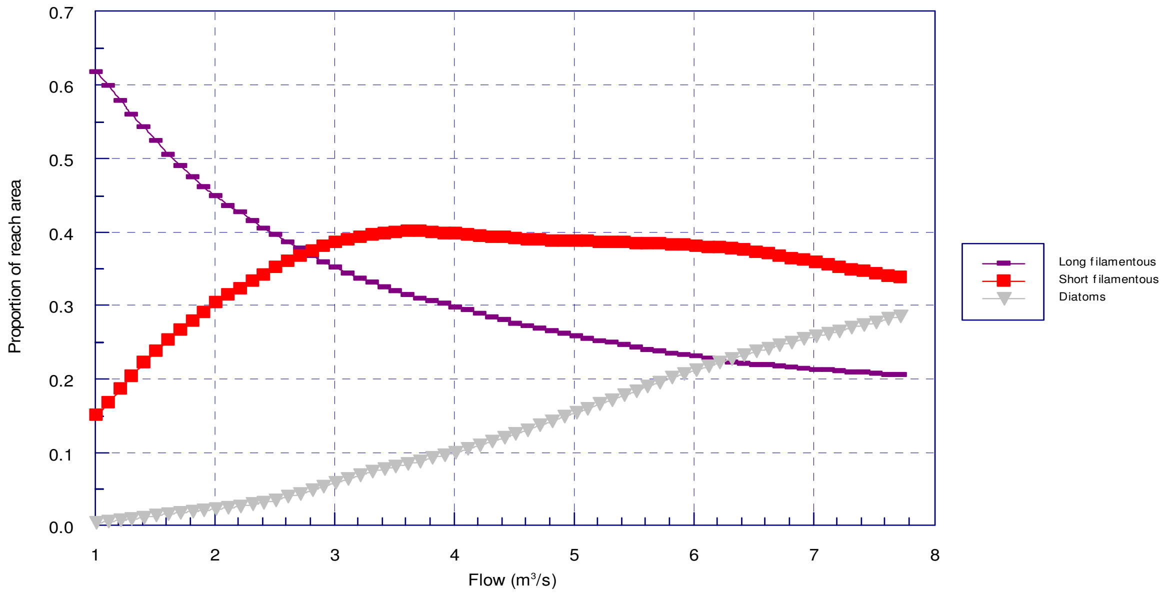

Figure 7: Variation in the percentage of reach area with habitat suitable for the growth of diatoms, short filamentous algae and long filamentous algae.

Brown trout spawning habitat was also assessed using the criteria of Shirvell & Dungey (1983). This showed that there was very little suitable spawning habitat in the survey reach and that a flow of 1.8 m^3/s provided maximum brown trout spawning habitat.

Table 3: Flows that provide maximum habitat and 90% of the amount of habitat at MALF.

	Flow (m^3/s) that provides maximum habitat	Flow (m^3/s) that provides 90% of habitat at MALF
Brown trout (< 100 mm)	2	<1
Brown trout adult	5.7	2
Brown trout juvenile	4.8	1.7
Brown trout spawning	1.8	1.2
Deleatidium (mayfly)	5	1.5
Nesameletus (mayfly)	4.1	1.25
Food producing	>7.7	2
Longfin eel (< 300 mm)	2.9	1.1
Longfin eel (> 300 mm)	2.6	1.45
Torrentfish	5	2.1
Upland bully	<1	NA
Long filamentous	<1	1.95
Short filamentous	3.6	2
Diatoms	>7.7	2.15

3 Hydrology of Inangahua River

3.1 Flow record

A water level recorder has been operated at Blacks Point since 14th May 1965. The water level recorder site is 1.3 km downstream of the proposed hydro intake at Inangahua River and there is about 5 km^2 of catchment (mainly Murray Creek) between the intake and recorder site. However, the flow data from the water level recorder has been assumed to be representative of the expected flows at the intake site. The catchment area at the recorder is 233 km^2 and the mean flow is 16.35 m^3/s (Table 4). The minimum recorded flow is 1.31 m^3/s and flows are less than 2 m^3/s for about 3% of the time.

Table 4: Long-term flow statistics.

Statistic	Flow (m^3/s)
Mean	16.35
Median	7.7
Minimum recorded	1.31
Standard deviation	27.7
Maximum recorded	988
Mean annual 7 day low flow (for complete years only)	2.30

Note: Summary of instantaneous[1] flow record between 15th May 1965 – 8th January 2013.

Table 5: Flow duration statistics for the Inangahua River.

Percent of time flow exceeded	Flow (m^3/s)
0	988.4
5	59.0
10	36.6
15	26.2
20	20.3
25	16.4
30	13.6
35	11.5
40	10.0
45	8.7
50	7.7
55	6.7
60	6.0
65	5.3
70	4.7
75	4.2
80	3.7
85	3.3
90	2.9
95	2.4
100	1.3

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[1] Flow statistics calculated from instantaneous flows differ slightly from those calculated from daily mean flows as in Section 4

Note: Summary of instantaneous flow record between 15th May 1965 – 8th January 2013.

3.2 Annual 7-day minimum flows

Annual minima were calculated using 7-day running means from the Blacks Point flow data (Table 6). There were a number of short (up to 57 days) periods of missing data in the record, but visual inspection of the data indicated that these periods of missing record were unlikely to be at times when annual low flows were expected, except in 1999 when the 7 day low flow was just before the period of missing data. The average of the 7-day annual minima in Table 6 is 2.25 m^3/s. If incomplete years are excluded, the mean annual 7-day low flow is 2.30 m^3/s.

Table 6: Annual 7-day minimum flows at Blacks Point for years beginning 1 September.

Year that water year starts	Minimum 7-day flow (m^3/s)	Start date of annual minima
1966	2.61	14-Jun-66
1967	2.83	1-Sep-66
1968	2.79	22-Feb-68
1969	2.74	8-Feb-69
1970	1.96	14-Feb-70
1971	1.62	15-Feb-71
1972	1.88	27-Feb-72
1973	1.41	24-Feb-73
1974	1.51	9-Jun-74
1975	1.74	2-Jan-75
1976	1.94	20-Apr-76
1977	2.21	25-Aug-77
1978	1.81	12-Mar-78
1979	2.86	21-Mar-79
1980	2.46	21-Apr-80
1981	1.81	22-Jan-81
1982	1.64	1-May-82
1983	3.06	23-Jul-83
1984	2.25	25-Feb-84
1985	1.64	11-Apr-85
1986	3.27	6-Feb-86
1987	2.62	9-Dec-86
1988	2.64	27-Apr-88
1989	1.96	4-Mar-89
1990	2.34	8-Sep-89

Year that water year starts	Minimum 7-day flow (m^3/s)	Start date of annual minima
1991	2.12	20-Mar-91
1992	1.92	7-May-92
1993	2.67	24-Feb-93
1994	2.30	6-Apr-94
1995	2.63	3-Mar-95
1996	2.60	8-Mar-96
1997	2.84	30-Mar-97
1998	2.66	27-Feb-98
1999	1.91	11-Feb-99
2000	1.76	14-Mar-00
2001	1.69	7-Mar-01
2002	2.12	16-Feb-02
2003	1.88	17-Apr-03
2004	3.01	26-Apr-04
2005	2.56	1-Feb-05
2006	2.12	26-Mar-06
2007	2.56	1-Mar-07
2008	2.03	3-Dec-07
2009	2.25	31-Mar-09
2010	2.62	13-Jul-10
2011	2.23	4-Dec-10
2012	1.93	20-Apr-12

3.3 Frequency and duration of high and low flows

The flow data for the Inangahua River at Blacks Point were converted into daily mean values, excluding those days with missing data. The daily mean data were analysed to determine the length of time between high flows of 30 m^3/s (approximately twice the mean flow) and the frequency and duration of low flows of 2.3 m^3/s (MALF), month by month.

A daily mean flow of 30 m^3/s will have a instantaneous peak flow of about 50 m^3/s and can be considered a flushing flow. There will usually be 7 days between events of this magnitude (Table 7).

Algal biomass can accumulate to nuisance levels in summer if there is about 40 days without a flushing event. The length of time between flushing events was only greater than 40 days for 5% of the 24 flushing events per year, or about once a year (Table 7). However, there will also be freshes less than a daily mean of 30 m^3/s and these will cause some flushing of algae and fine sediment.

Table 7: Length of time (days duration) between events when the daily mean flow exceeds 30 m^3/s in the Inangahua River at Blacks Point.

	Jan - Dec
Average number of events per year	24.1
Mean duration between flood events	12.3
Maximum duration between flood events	103
Duration between flood events equalled or exceeded by 5% of events	40.0
Duration between flood events equalled or exceeded by 25% of events	16.0
Median duration between flood events	7.0
Duration between flood events equalled or exceeded by 75% of events	3.0
Duration between flood events equalled or exceeded by 95% of events	1.0

Note: Summary of instantaneous flow record between 15th May 1965 – 8th January 2013.

Low flow events between the FRE3 and MALF (23.1-2.3 m^3/s) are more likely to occur in February to April than in other months. On average, these low flows persist for 5-6 days, but have persisted for as long as 60 days (Table 8).

Table 8: Frequency and magnitude of low flow events in the Inangahua River at Blacks Point.

Low flow magnitude (m^3/s)	Average number of days per year	Average number of low flow events per year	Mean duration	Maximum duration	Duration equalled or exceeded by 5% of events	Duration equalled or exceeded by 25% of events	Median duration	Duration equalled or exceeded by 75% of events	Duration equalled or exceeded by 95% of events
<23.1 (natural FRE3)	279	26.4	10.6	75	35	14	6	2.3	1
<10	200	26.8	7.4	61	24	10	5	2	1
<5	107	17	6.3	49	19	8	4	2	1
<2.3 (MALF)	14.4	2.3	6.3	23	15.4	9	5	3	1

Note: Summary of instantaneous flow record between 15th May 1965 – 8th January 2013.

4 Environmental effects of power station operation

Detailed engineering parameters for the proposed scheme were not available at the time of this assessment so the following assumptions were used:

- A head difference of about 8.5 m between the river level at the intake and the river level at the tail race.
- A head loss of about 2.7 m along the intake canal to give an effective head of 5 m at the turbine.
- A single turbine with a maximum output of 154 kw at the maximum generation flow of 3.5 m^3/s.
- A minimum generation flow of 1.4 m^3/s (40% of maximum).
- A minimum flow would be maintained in the 2 km of river between the intake and power station tailrace.
- A fish screen on the intake canal with an appropriate mesh size, approach velocity, and bypass flow back to the river.
- A settling area and gates at the upstream end of the canal to cease diversion and sluice deposited coarse sediment when the instantaneous flow exceeds 50 m^3/s.
- An overflow weir at the downstream end of the canal to allow for the surge created by a sudden shutdown of the turbine.

4.1 Minimum flow

The West Coast Regional Council's Regional Land and Water Plan specifies that the minimum flow is 75% of the 7-Day MALF (Policy 7.3) or 1.73 m^3/s.

A flow of 1.7 m^3/s will provide 99 % of the amount of habitat at MALF for brown trout < 100 mm, 89% of habitat at MALF for juvenile brown trout and 76% of habitat at MALF for adult brown trout (Table 9).

In my opinion, the minimum flow should provide at least 90% of the habitat at MALF in rivers where instream values are high. The Inangahua River is an important trout fishing river on the West Coast and the reach affected by the proposed power development is an important rearing habitat for brown trout, and can hold high numbers of adult trout.

Table 9: Habitat retention for brown trout, benthic invertebrates and food production at flows of 1.7 m^3/s to 2.3 m^3/s compared to habitat at MALF (2.3 m^3/s).

Habitat	Flow (m^3/s)						
	1.7	1.8	1.9	2	2.1	2.2	2.3
Brown trout (< 100 mm)	99.7	99.8	100.3	100.5	100.3	100.2	100
Brown trout adult	76.2	80.4	84.5	88.5	92.4	96.2	100
Brown trout juvenile	89.3	91.4	93.4	95.2	96.9	98.5	100
Deleatidium (mayfly)	92.4	93.9	95.2	96.6	97.8	98.9	100
Nesameletus (mayfly)	95.3	96.3	97.2	98.0	98.7	99.4	100
Food producing	76.5	80.8	85.0	89.0	92.8	96.5	100

A minimum flow of 1.7 m^3/s would retain adequate habitat for trout rearing, but only retains 76% of adult trout and food producing habitat. A reduction in adult trout and food producing habitat is likely to reduce the number of adult trout in this 2 km section of river.

A flow of 2 m^3/s will provide at least 88% of habitat for brown trout (<100mm, juvenile, spawning and adults), as well as at least 90% of benthic invertebrate and food producing habitat (Table 9). A flow of 2 m^3/s provides over 100% of the amount of habitat at the MALF for brown trout < 100 mm and spawning, 95% of the habitat at the MALF for juvenile brown trout, and over 96% of habitat at the MALF for *Deleatidium* and *Nesameletus*.

Jowett (1992) developed a model of adult trout (> 20 cm) abundance based on catchment characteristics, % habitat for adult brown trout at the MALF and % habitat for food production at median flow. The model was based on trout abundance in 71 New Zealand rivers and is essentially a "food and space" model where a change in the space available for adult trout or the food available will result in a change in trout abundance. Data from the Inangahua River were used in the development of this model.

The brown trout model (Jowett 1992) was applied to the Inangahua River to estimate trout abundance in the residual river. With a minimum flow of 1.7 m^3/s, trout drift feeding habitat reduces as the mean annual low flow is reduced from 2.3 m^3/s to 1.7 m^3/s and the food producing capacity reduces as the median daily mean flow reduces from 8.1 m^3/s to 4.6 m^3/s (Table 11), then the number of adult brown trout are predicted to reduce by 35%. With a minimum flow of 2 m^3/s, the predicted reduction in adult brown trout numbers is 28%. Teirney & Jowett (1990) assessed the number of adult brown trout (> 20 cm) in the Inangahua River at Blacks Point as 62, making it the 7th ranked river on the West Coast and the 5th ranked river in terms of popularity. A reduction of 28% would reduce adult trout numbers to about 45 per kilometre similar to those in the Buller River above Hope Junction (Table 10).

The brown trout model was developed from rivers with natural flow regimes and should only be used to predict the effects of changed flow regimes with appropriate caution. In particular, there is an implicit assumption in the model that food production at median flow is indicative of food production over the whole flow regime. In natural rivers, the MALF is typically a third of the median flow so that food production at median flow in the brown trout model represents food production at flows that vary from about a third of median (i.e., MALF) to more the mean flow. In the residual river, the median flow is almost halved (8.1 m^3/s to 4.6 m^3/s) and the low flows (MALF) reduce from 2.3 m^3/s to 1.9 m^3/s. Thus, the low flows are about 40% of the median flow rather than 28% as in the natural river. This means that food production in the residual river would be slightly higher than assumed in the model and the predicted reduction in trout numbers should be regarded as an upper limit.

Table 10: Adult brown trout numbers (Teirney & Jowett 1990) and angler usage (Unwin & Brown 1998, Unwin & Image 2003, Unwin 2009) in West Coast rivers.

River and access	Large and medium brown trout per km	Average angler days
Arnold River at Kokiri	206	1,589
Grey River at Waipuna	195	4,733
Haupiri River d/s of Lake	168	304
Mangles River at Gorge	89	353
Karamea River above bend	85	717
Mokihinui River (North Branch)	66	711
Inangahua River at Blacks Point	62	1,018
Buller River above Hope Junction	46	4,289
Ahaura River above Haupiri confluence	40	622
Taramakau River at Kumara	37	2,010

4.2 Flow regime with hydro generation

As well as an adequate minimum flow, a river also needs flushing flows and channel maintenance flows to maintain the habitat. Flushing flows are necessary to maintain a degree of flow variability and remove accumulations of fine sediment and filamentous algae. Channel maintenance flows are required every year or two to maintain channel morphology by scouring pools, creating instream cover, and removing bankside vegetation.

The flow record for the Inangahua River at Blacks Point was used to model the effect of power station operation on the flow regime in the 2 km of river that would be affected by power station operation.

The minimum flow requirements for the river and turbine mean that the flow in the river must exceed 3.4 m^3/s before the power station operates.

The flow modelling in this report differs from that in the URS report (URS 2012) in the following respects:

- URS assumed a minimum flow of 1.7 m^3/s, but did consider the effect of minimum flows that were higher. This report uses a minimum flow of 2 m^3/s.
- URS assumed that all water above the minimum flow could be diverted. This report assumes that the turbine cannot operate on very low flow (20-40% of maximum turbine rating) and that the intake will shut down during floods so that coarse sediment is not carried into the diversion canal.
- URS used data to 13 November 2012. This report uses data to 8 January 2013.

The mean flow diverted for generation would be 2.24 m^3/s (Table 11). With a minimum generation flow of 1.4 m^3/s and a minimum flow in the river, the power station will operate for 70% of the time and the flow in the residual river will be at or less than the minimum flow of 2 m^3/s for about 22% of the time compared to 98% of the time without the scheme (Fig. 8). The frequency of freshes would be substantially unchanged. Both generation flows and residual flows would be higher in the winter than summer - a seasonal pattern similar to that in the natural river flows (Table 12). If the minimum turbine discharge is 0.55 m^3/s rather the 1.4 m^3/s, the mean generation increases from 2.24 m^3/s to 2.33 m^3/s (4%) and the residual river mean flow decreases from 14.09 m^3/s to 14.00 m^3/s (0.6%). Thus, the minimum turbine flow only has a small effect on the residual river flow regime, and does not affect the assessment of flow regime effects, significantly.

Table 11: Long-term flow statistics based on simulated daily mean flows.

	Natural	1.4 $m^{3/}$s minimum turbine flow		0.55 $m^{3/}$s minimum turbine flow	
		Generation	Residual river	Generation	Residual river
Mean	16.33	2.24	14.09	2.33	14.00
Median	8.09	3.50	4.59	3.50	4.59
Minimum	1.36	0	1.36	0	1.36
Standard deviation	22.85	1.54	23.41	1.44	23.45

Maximum	278.54	3.50	278.54	3.50	278.54
Mean annual 7 day low flow	2.30	0.01	1.94	0.15	1.93
Frequency of freshes > 3 times median (FRE3)	16.67	-	17.01	-	17.01

Note: Uses daily mean flow record between 15th May 1965 – 8th January 2013.

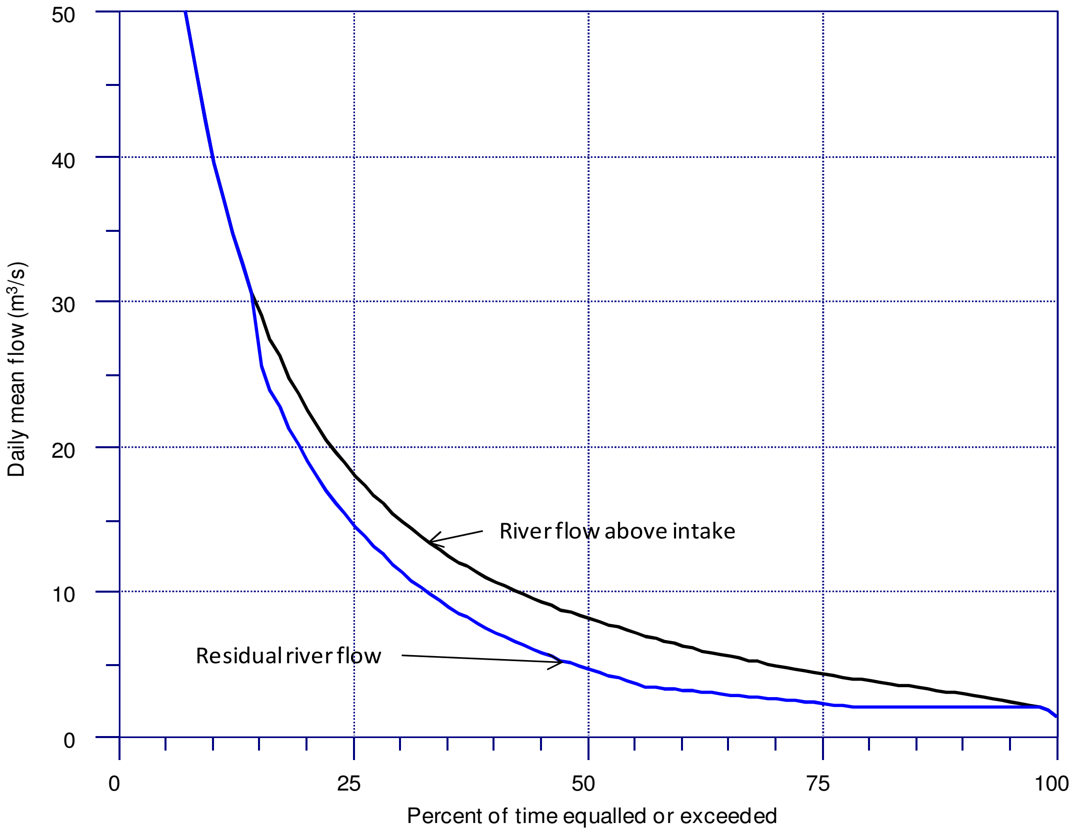

Figure 8: Flow duration curves for residual river and natural river flow. Daily mean flow record between 15th May 1965 – 8th January 2013.

Table 12: Monthly generation and residual river flow (m^3/s)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Generation	2.06	1.61	1.69	1.91	2.19	2.39	2.46	2.59	2.51	2.56	2.43	2.31
Residual River	10.75	7.83	8.18	12.07	15.16	16.66	14.03	14.20	17.96	20.20	16.60	14.37
Natural river	12.81	9.43	9.86	13.98	17.35	19.04	16.49	16.79	20.46	22.76	19.02	16.68

Note: Uses daily mean flow record between 15th May 1965 – 8th January 2013.

Flushing flows should occur every 4-6 weeks to prevent accumulation of filamentous algae and fine sediment. Floods and freshes occur frequently on the West Coast. The median length of time between events with a daily mean flow greater than 30 m^3/s is 7 days and the duration of 95% of events is less than 40 days. As the flow will not be at the minimum flow or less for long periods of time, the river will be flushed by naturally occurring floods. To ensure flushing is as effective as possible, the intake would be closed for 24 hours when the instantaneous flow exceeds 50 m^3/s[2]. At this time, a sluice gate would be opened to remove any coarse sediment that had accumulated in the 320 m concrete section of the intake channel, and this would help remove any accumulation of periphyton. The discharge of the additional sediment load would not be noticeable during a flood and would have no effect on river morphology or bed sediments. The closure of the intake at flows of greater than 50 m^3/s will also prevent coarse sediment from being carried into the diversion canal.

The duration of low flow events will usually be short, but once every 50 years or so there could be periods of up to 60 days without a fresh (Table 13).

Table 13: Duration (days) of low flow events in the residual river.

Low flow magnitude (m^3/s)	Average number of days per year	Average number of low flow events per year	Mean duration	Maximum duration	Duration equalled or exceeded by 5% of events	Duration equalled or exceeded by 25% of events	Median duration	Duration equalled or exceeded by 75% of events	Duration equalled or exceeded by 95% of events
<23.1 (natural FRE3)	288	25.1	11.5	103	38	15	7	3	1
<10	233	28.1	8.3	66	27	11	5	2	1
<5	179	25.3	7.1	61	22	9	5	2	1
<2.3 (MALF)	88	25.8	3.4	23	9	5	3	1	1

Note: Uses daily mean flow record between 15th May 1965 – 8th January 2013.

4.3 Changes to flow regime

The changes to the flow regime in the 2 km of river affected by the power scheme are minor, with slightly prolonged periods of minimum flow. The median daily flow is reduced from 8.1 m^3/s to 4.6 m^3/s (Table 11), but extreme low flows are not affected, although the amount of time that flows are at or below the minimum flow of 2 m^3/s will increase from 3% to 22%. The average time between flow events of FRE3 in the residual river (11.5 days Table 13) is only about 1 day longer than that in the natural river (10.6 days Table 8). This is a relatively high frequency of floods and freshes and will remove

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[2] An instantaneous flow of 50 m^3/s will result in a daily mean flow of 30 m^3/s or greater.

accumulations of fine sediment and filamentous algae. Large floods will be substantially unchanged and these will maintain the present channel morphology.

4.4 Fish Screening

Brown trout spawn upstream of Blacks Point and the young fish gradually move downstream and populate the reach between Blacks Point and Reefton. Larinier & Travade (2002) have summarized the data available on fish passage through turbines. The increased mortality caused by turbine passage varies greatly, depending on the type of turbine, the head of water and several other factors, (Ruggles 1980). Numerous studies have been carried out, mainly on juvenile salmonids, to determine their mortality rate when passing through the main types of turbines (EPRI, 1992).

The mortality of fish passing through turbines depends on the fish length and turbine characteristics, especially the head on the turbine. The mortality of large fish such as adult trout and eels can be high, but small trout can pass through low head turbines with low mortality. The proposed turbine is an axial flow turbine, and this type of turbine usually has a large diameter and low rotational speed, both resulting in low fish mortality.

Trout fry have been observed in the affected reach and this would require relatively fine mesh screens with low approach velocities to prevent trout fry from mortality as they pass through the turbine. The recommended aperture size for trout fry is 3 mm with an approach velocity of 0.12 m/s which would require a screen area of over 30 m^2, and this may be impractical and in my opinion unnecessary. This is because trout up to 1+ (about 100 mm) are likely to pass through the turbine with at least 85% survival (Bell 1986). A mesh size or bar gap of about 10 mm and approach velocity of 0.3 m/s would be required to exclude trout larger than 1+ (Bell 1986). Adult eels also require downstream passage to complete their life cycles, and screening to prevent the ingress of trout will also prevent adult eels from reaching the headrace. If the screen is placed at the intake, there may be no need for a fish bypass back to the river, but this will only be known when a detailed design is prepared. However if the screen is some distance along the headrace, a fish bypass will be required and the flow through this bypass would be about 5% of the flow in the headrace (NMFS 2008). The section of headrace between the intake and screen would provide some trout rearing habitat and help compensate for the habitat loss in the residual river.

4.5 Water temperature

The magnitude and rate of change in water temperature will depend on meteorological conditions such as radiation, air temperature, shade and flow. The temperature of water in a river is influenced more by climate than by river flow. Flow does not have a large effect on daily mean water temperature, but a reduction in flow will increase diurnal variation by increasing temperatures in the afternoon and decreasing them in early morning. After studying the lethal effects of diurnally varying water temperature on aquatic invertebrates, Cox & Rutherford (2000) concluded that water temperature limits should be applied to a temperature midway between the daily average and the daily maximum of a diurnal profile.

In general terms, heat is gained or lost from water as it travels downstream. This heat loss includes convection, conduction, evaporation, as well as heat to or from the air (long wave radiation), direct solar radiation (short wave), and radiation back from the water. Water flowing downstream will increase or decrease in temperature until a dynamic equilibrium is established between the diurnal pattern of incoming radiation and the diurnal heat losses from the river through radiation and evaporation. This final state, when there is no further change in the diurnal variation of water temperature with distance downstream, is known as the equilibrium condition.

When the flow of a river is reduced, it becomes more responsive to solar radiation because it is shallower. Thus as a result of day heating and night cooling, daily fluctuations in water temperature increase, but there is little change in the daily mean temperature.

Maximum water temperatures in the Inangahua River will occur during the extended periods of summer low flow (e.g., January 2009). Because the river has changed from an open farmed valley to a more confined valley at and below Blacks Point, it is likely water temperatures will be reducing through the affected reach and that power station operation will have no significant effect on water temperatures.

5 Conclusion

The Inangahua River is a popular brown trout angling river and the affected reach contains high numbers of young trout and variable numbers of adult trout. Brown trout, torrentfish, longfin eels and upland bullies have been found in the main stem of the river between Reefton and Blacks Point.

The quality of the macroinvertebrate community is high with stoneflies, mayflies and caddisflies (EPT taxa) comprising an average of 83% of the total number of macroinvertebrates collected and an average Macroinvertebrate Community Index (MCI) score of about 120.

Because of the numbers of trout in the affected reach and the popularity of the Inangahua River as an angling river, the suggested minimum flow is the flow that retains about 90% of the habitat available at the MALF.

A minimum flow of 2 m^3/s will provide at least 88% of habitat for brown trout (<100 mm, juvenile and adults), as well as at least 90% of benthic invertebrate and food producing habitat. A flow of 2 m^3/s provides over 100% of the amount of habitat at the MALF for brown trout < 100 mm, 95% of the habitat at the MALF for juvenile brown trout, and over 96% of habitat at the MALF for *Deleatidium* and *Nesameletus*. A 10% reduction in habitat for native fish is unlikely to affect their numbers.

Although a flow of 2 m^3/s retain 88% of trout habitat, the reduction in median flow will reduce the food producing capacity of the affected section of river and this is likely to reduce the number of adult trout. The brown trout model (Jowett 1992) predicts the number of adult trout using river and catchment characteristics including adult brown trout habitat at MALF and food producing habitat at median flow. With a minimum flow of 2 m^3/s, the number of adult trout could be reduced by up to 28%.

The survival rate of adult trout and eels passing through turbines would be low, so that it would be necessary to screen the intake to avoid entrainment. The suggested bar spacing is 10 mm with an approach velocity of less than 0.3 m/s. This should prevent the entrainment of adult eels and trout > 100mm. Because the head on the turbine is low (5 m), smaller fish should pass through the turbine with at least 85% survival. Given the high natural mortality of juvenile trout, this mortality is not expected to affect adult trout numbers in the remainder of the Inangahua River.

The key points of this proposal are that it only affects a short section (2 km) of the Inangahua River. The main effect will be on adult trout where the number of adult trout could be reduced by up to 28%, mainly as a result of the reduction in food (benthic invertebrate) production.

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7 Appendix

7.1 Flow regime assessment methodology

Long-term solutions to river flow management need to take a holistic view of the river system, including geology, fluvial morphology, sediment transport, riparian conditions, biological habitat and interactions, and water quality, both in a temporal and spatial sense.

The instream flow incremental methodology (IFIM; Bovee 1982) is an example of an interdisciplinary framework that can be used in a holistic way to determine an appropriate flow regime by considering the effects of flow changes on instream values, such as river morphology, physical habitat, water temperature, water quality, and sediment processes (Figure A1.1). Its use requires a high degree of knowledge about seasonal and life-stage requirements of species and inter-relationships of the various instream values or uses.

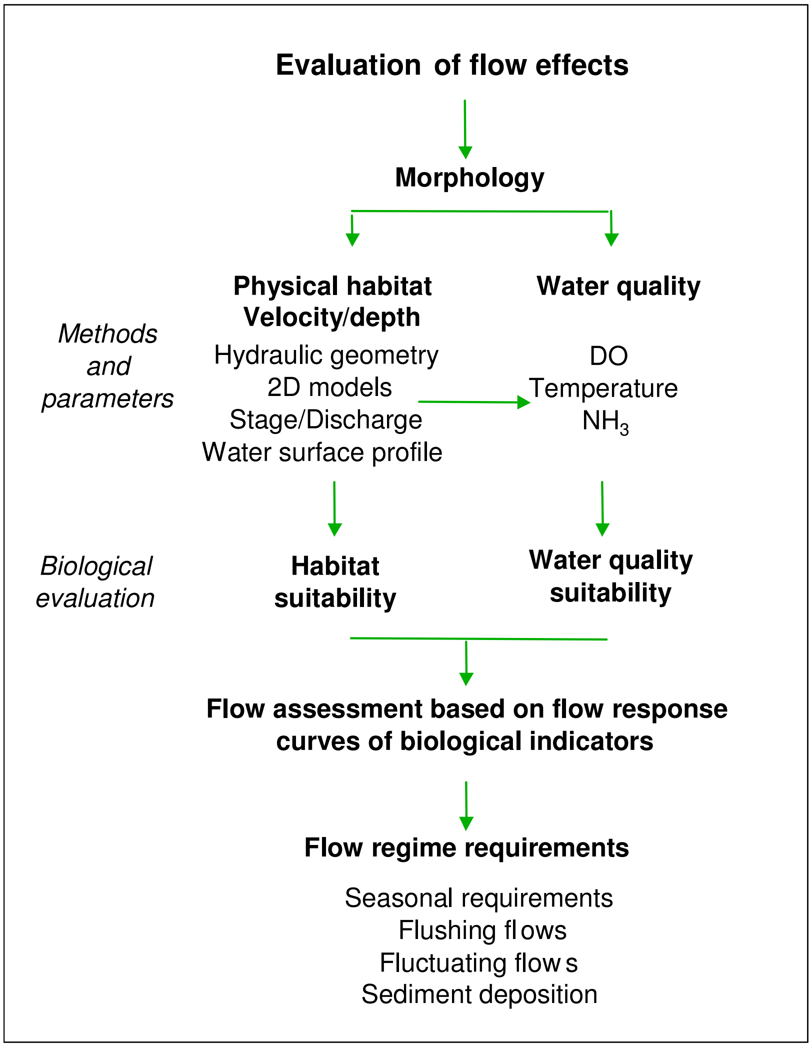

Figure A1.1: A framework for the consideration of flow requirements.

Other flow assessment frameworks are more closely aligned with the "natural flow paradigm" (Poff et al. 1997). The range of variability approach (RVA) and the associated indicators of hydrologic alteration (IHA) allow an appropriate range of variation, usually one standard deviation, in a set of 32 hydrologic parameters derived from the 'natural' flow record (Richter et al. 1997). The implicit assumption in this method is that the natural flow regime has intrinsic values or important ecological functions that will be maintained by retaining the key elements of the natural flow regime. Arthington et al. (1992) described a holistic method that considers not only the magnitude of low flows, but also the timing, duration and frequency of high flows. This concept was extended to the building block methodology (BBM), which "is essentially a prescriptive approach, designed to construct a flow regime for maintaining a river in a predetermined condition" (King et al. 2000). It is based on the concept that some flows within the complete hydrological regime are more important than others for the maintenance of the river ecosystem, and that these flows can be identified and described in terms of their magnitude, duration, timing, and frequency.

A holistic consideration of every aspect of flow and sediment regime, river and riparian morphology, and their associations with the life cycles of the aquatic biota requires a degree of knowledge about individual rivers that is rarely available. Fortunately, the large proportion of consents considered by regional councils in New Zealand involves changes to the low flows rather than the high flows, and thus there is no significant effect on the sediment transport regime and river morphology. The aim of the minimum flow is to retain adequate water depths and velocities in the stream or river for the maintenance of the critical values. The flow assessment considers physical habitat at a meso- to macro-habitat level rather than microhabitat. In this way, suitable average depths and velocities can be maintained in the main habitats, with a degree of habitat diversity that is generated by the morphology of the river, and is largely independent of flow. Although the geomorphological and flow related ecological processes that are associated with low to median flows are generally taken into consideration in instream flow methods, special issues, such as fish passage or seasonal flow requirements, may need to be investigated in some situations. Consideration should also be given to downstream effects. The effect of an abstraction is usually greatest immediately below the abstraction site, but diminishes as the river flow is supplemented by contributions from tributaries and the proportional change in flow reduces. However, there may be situations where the critical effect is well downstream. This is most likely where the cumulative effect of abstractions from tributaries may result in unacceptably low flows in downstream reaches.

Instream flow methods can be classified into three basic types; historic flow, hydraulic and habitat based methods. Historic flow methods are coarse and largely arbitrary. An ecological justification can be argued for the mean annual low flow (MALF) and retention of the natural flow regime, and the concept of a low flow habitat bottleneck for large brown trout has been partly justified by research (e.g., Jowett 1992), but setting flows at lower levels (e.g., the 5 year 7 day low flow — $Q_{7,5}$ etc.) is rather arbitrary. Hydraulic methods do not have a direct link with instream habitat and interpretation of ecological thresholds based on breakpoints or other characteristics of hydraulic parameters, such as wetted perimeter and mean velocity, are arbitrary and depend on rules of thumb and expert experience. On the other hand, habitat-based methods have a direct link to habitat use by aquatic species. They predict how physical habitat (as defined by various habitat suitability models) varies with flow and the shapes of these characteristic curves provide the information that is used to assess flow requirements. Habitat based methods allow more flexibility than historic flow methods, offering the possibility of allocating more flow to out-of-stream uses while still maintaining instream habitat at levels acceptable to other stakeholders (i.e., the method provides the necessary information for instream flow analysis and negotiation).

The ecological goal of habitat methods is to provide or retain a suitable physical environment for aquatic organisms that live in a river. The consequences of loss of physical habitat are well known; the environmental bottom line is that if there is no suitable habitat for a species it will cease to exist. Habitat methods tailor the flow assessment to the resource needs and can potentially result in improved allocation of resources. Although it is essential to consider all aspects such as food, shelter, and living space (Orth 1987; Jowett 1995), appropriate habitat suitability curves are the key to the successful application of habitat based methods.

The procedure in an instream habitat analysis is to select appropriate habitat suitability curves or criteria (e.g., Figure A1.2), and then to model the effects of a range of flows on the selected habitat variables in relation to these criteria. The habitat suitability index (HSI) at each point was calculated as a joint function of depth, velocity and substrate type using the method shown in Figure A2. The area of suitable physical habitat, or weighted usable area (WUA), was calculated by multiplying the area represented by each point by its joint habitat suitability. So, for example in Figure A2, at a given point in the river (it is really an area of reasonably uniform depth and velocity) where the depth is 0.1 m, depth suitability is only 65% optimal, according to knowledge of the depth requirements of the fish. Similarly, the velocity recorded at the point is 0.25 m/s, which is optimal (suitability weighting of 1), and the substrate is fine gravel (sub-optimal with a weighting of 0.4) and cobbles (optimal with a weighting of 1). Multiplying these weighting factors together we get a joint habitat suitability weighting of 0.455 for that point in the river for the selected fish species. If the depth had been 0.2 m and there had been no fine gravel, then that point in the river would have been optimal (i.e., 1 for depth × 1 for velocity × 1 for substrates = 1). This exercise was repeated within the habitat assessment model for the depth/velocity/substrate types in every grid square across the river and the area covered by each square was multiplied by the point suitability. These areas which have been weighted by their respective point suitability values were then summed to get a measure of total area of suitable physical habitat for the given species at the given flow. This process was then repeated for a series of other flows with the depths, velocities, and habitat suitability being modelled for the new flows as described above. The total area of suitable physical habitat was then plotted as a function of flow to show how the area of suitable physical habitat for a given species changes with flow. Variations in the amount of suitable habitat with flow are then used to assess the effect of different flows for target organisms. Flows can then be set so that they achieve a particular management goal.

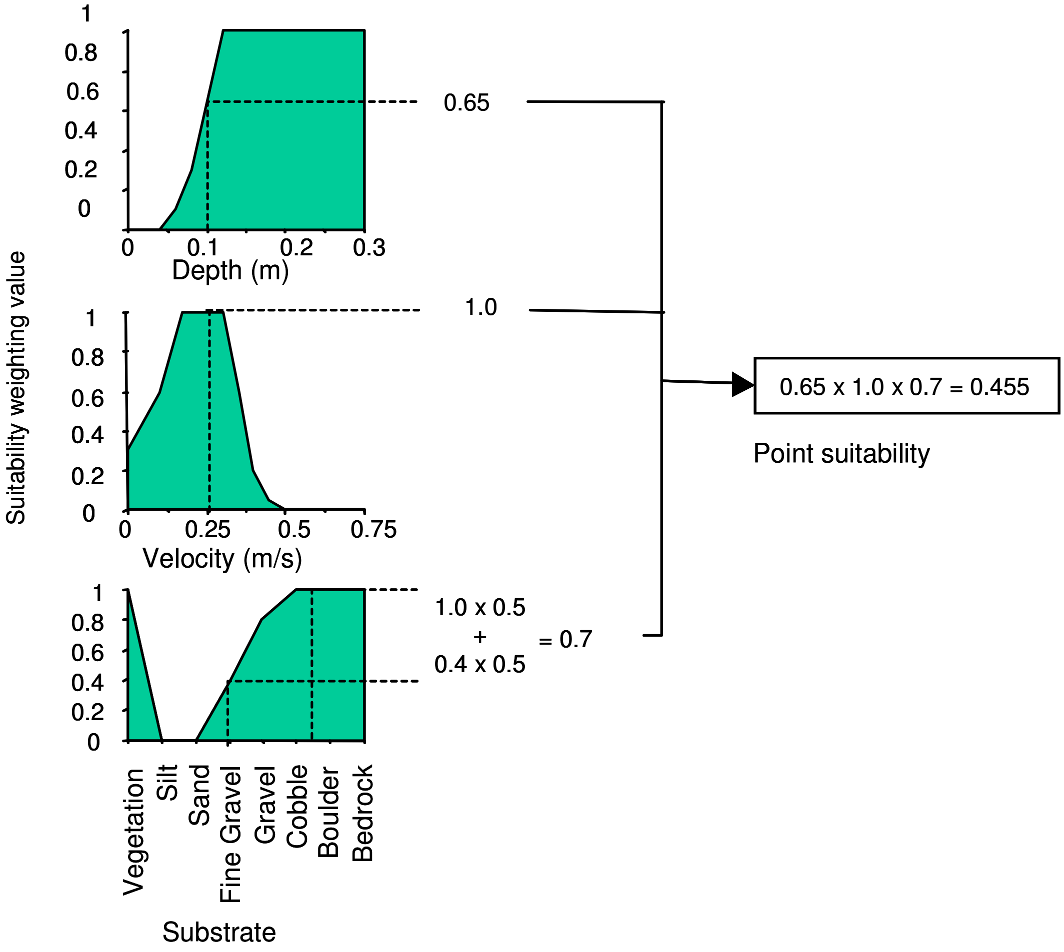

Figure A1.2: **Calculation of habitat suitability for a fish species at a point with a depth of 0.1 m, velocity of 0.25 m/s, and substrate comprising 50% fine gravel and 50% cobble. The individual suitability weighting values for depth (0.65), velocity (1.0), and substrate (0.7) are multiplied together to give a combined point suitability of 0.455.**

The flow related habitat metrics used to quantify instream habitat are weighted useable area (WUA m^2/m) and the average habitat suitability index (HSI) (Bovee 1982; Stalnaker et al. 1995). HSI is numerically equivalent to WUA divided by the wetted river width.

Various approaches to setting levels of protection have been used, from maintaining a maximum amount of habitat, a percentage of habitat at median flow, or using an “inflection point” of the habitat/flow relationship (Jowett 1997). The latter is possibly the most common procedure used for assessing minimum flow requirements using habitat methods. While there is no percentage or absolute value associated with an inflection point, it is a point of diminishing return, where proportionately more habitat is lost with decreasing the flow than is gained by increasing the flow.

Habitat methods can also incorporate flow regime requirements, in terms of both seasonal variation and flow fluctuations. Flow fluctuations are an important component of the habitat of most naturally flowing streams. Such fluctuations remove excess accumulations of silt and accumulated organic matter (e.g., from algal slimes) and rejuvenate stream habitats. Extended periods without a flow disturbance usually result in a shift in benthic community composition such as a reduction in diversity, and an increase in biomass of a few species within plant and animal communities.

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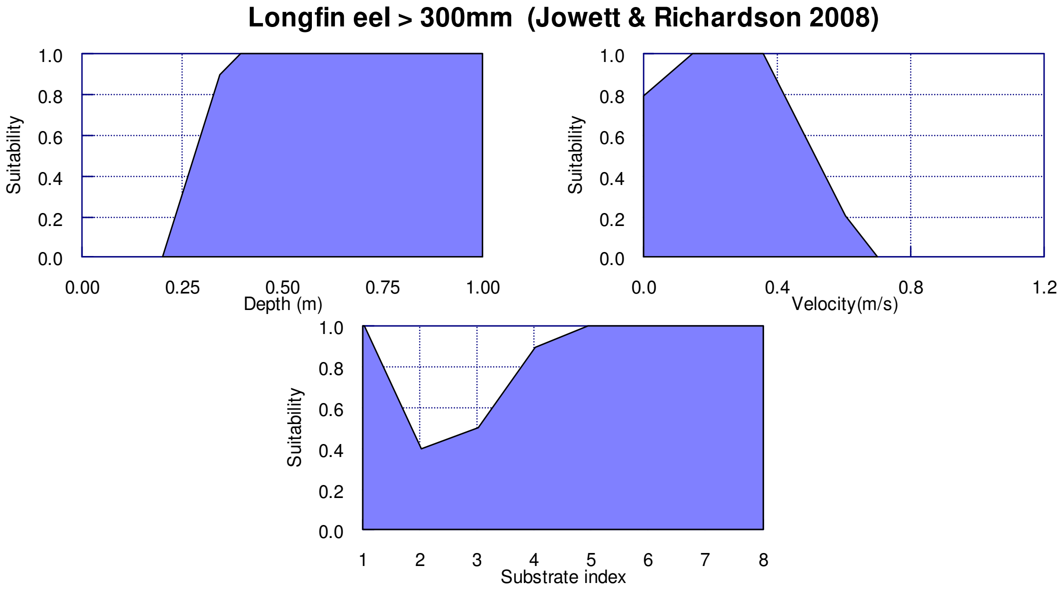
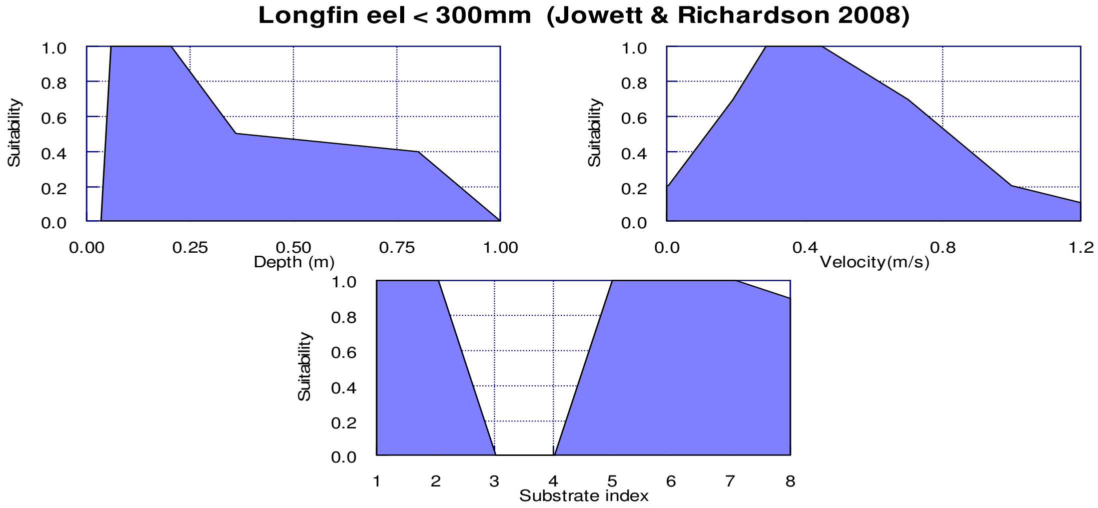
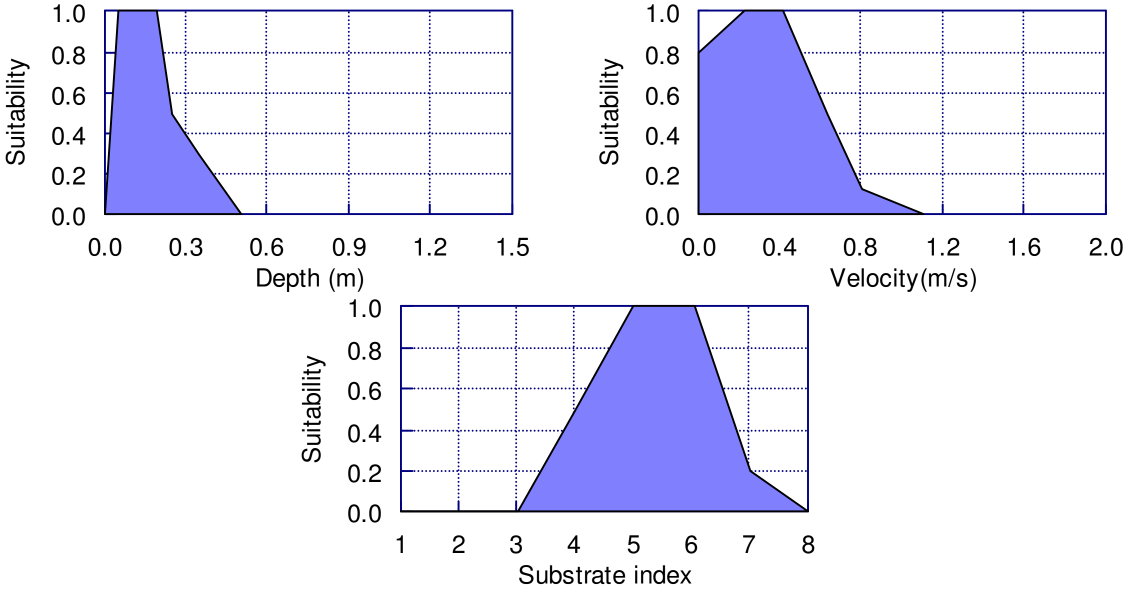
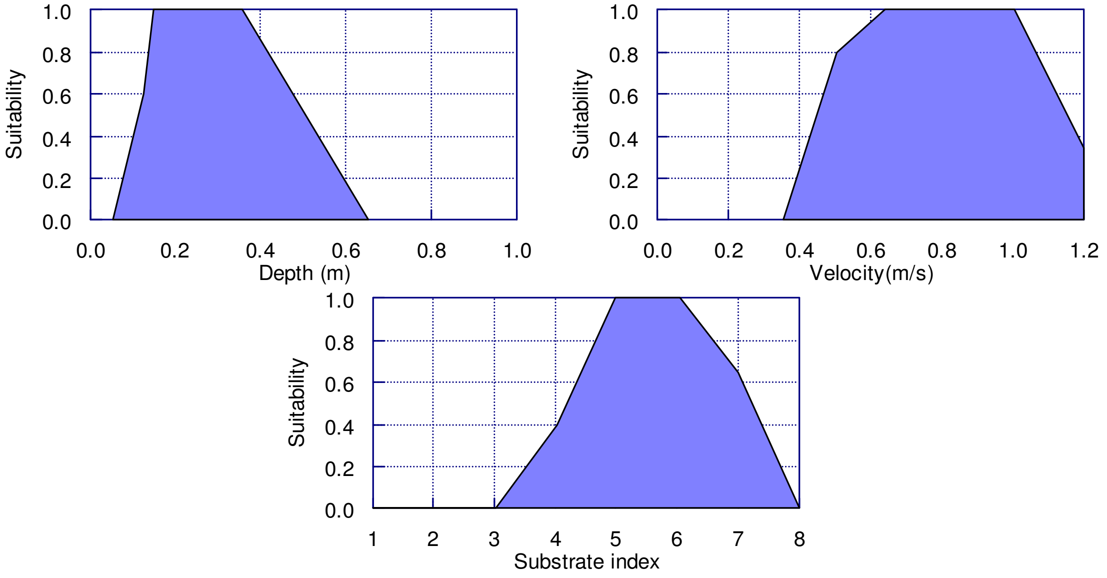
7.2 Habitat suitability curves used in this study





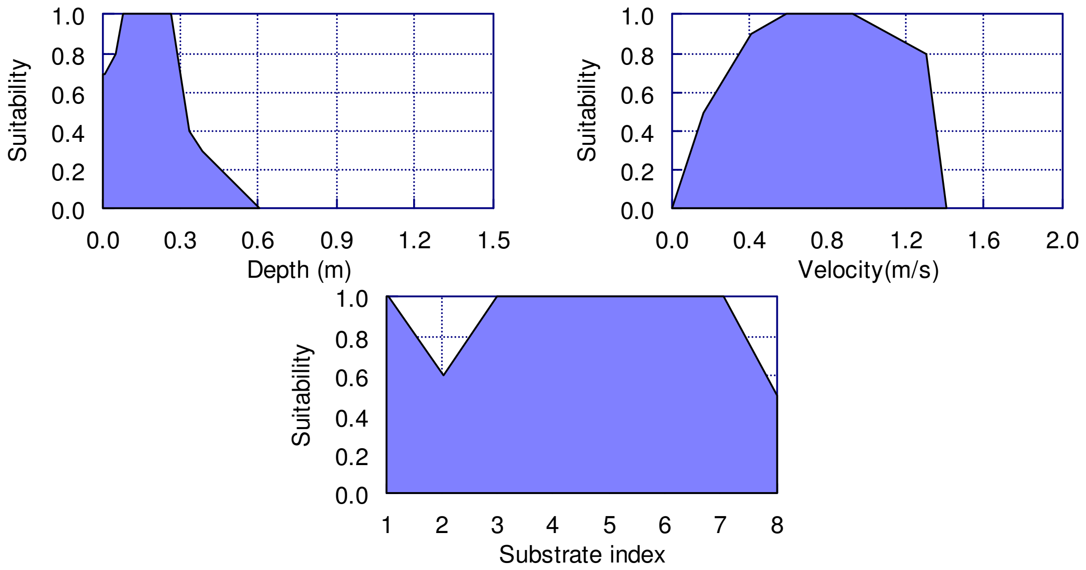


Upland bully (Jowett & Richardson 2008)

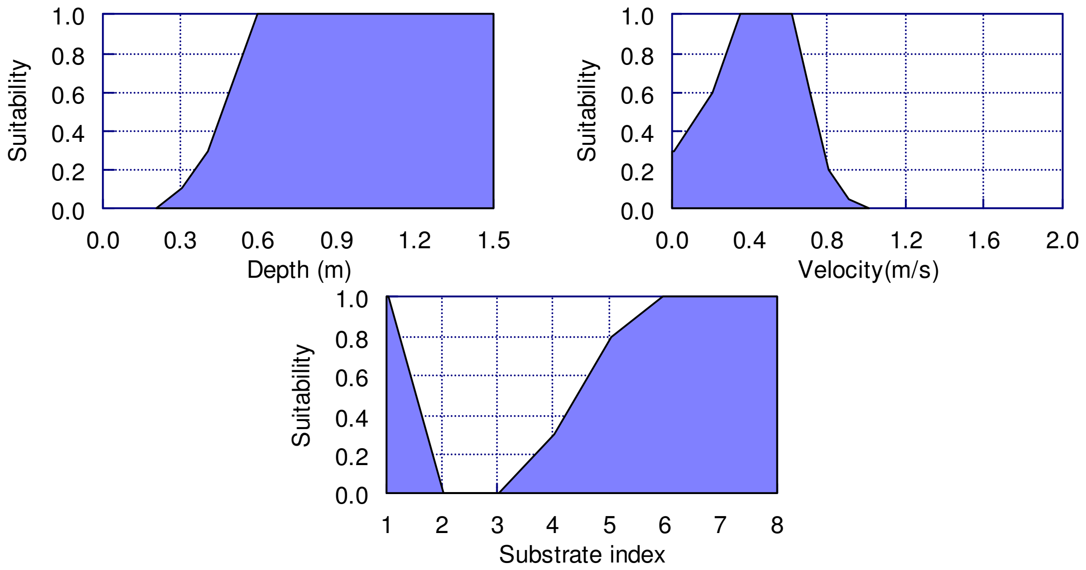


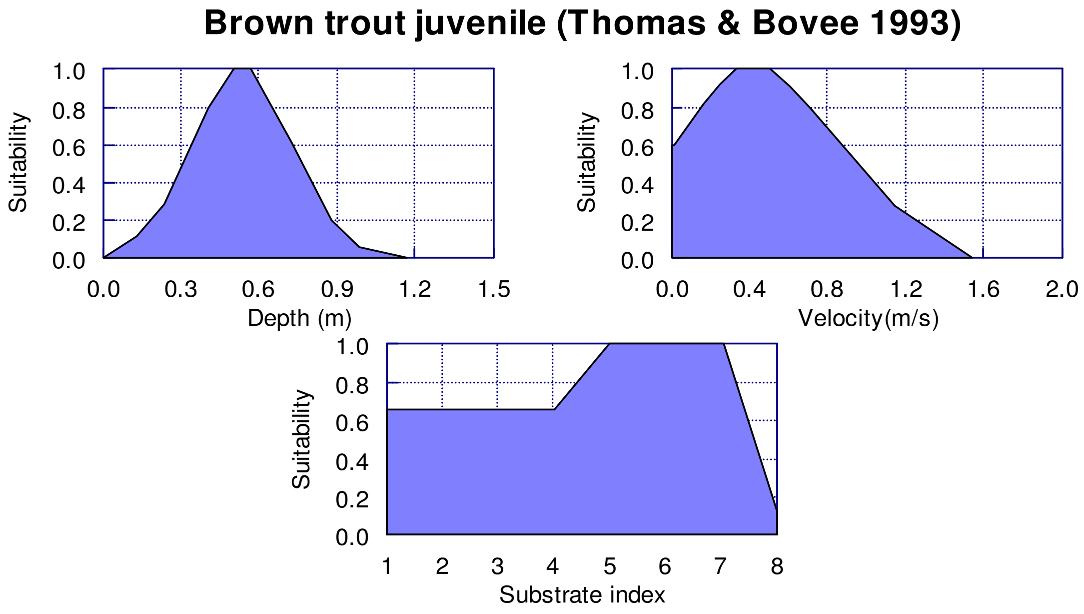
Torrentfish (Jowett & Richardson 2008)

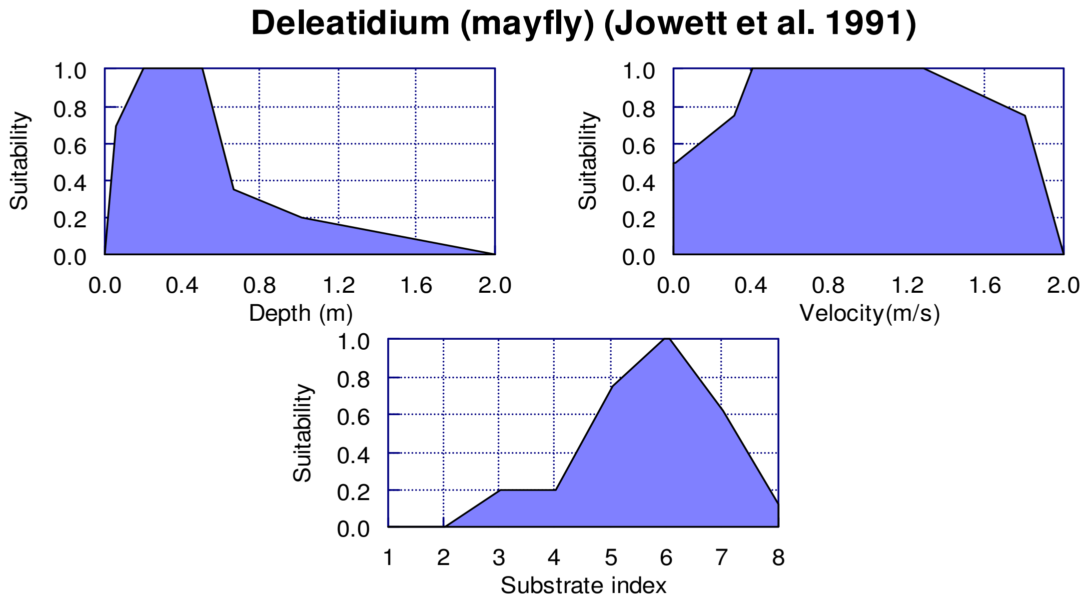
Brown trout (< 100 mm) (Jowett & Richardson 2008)



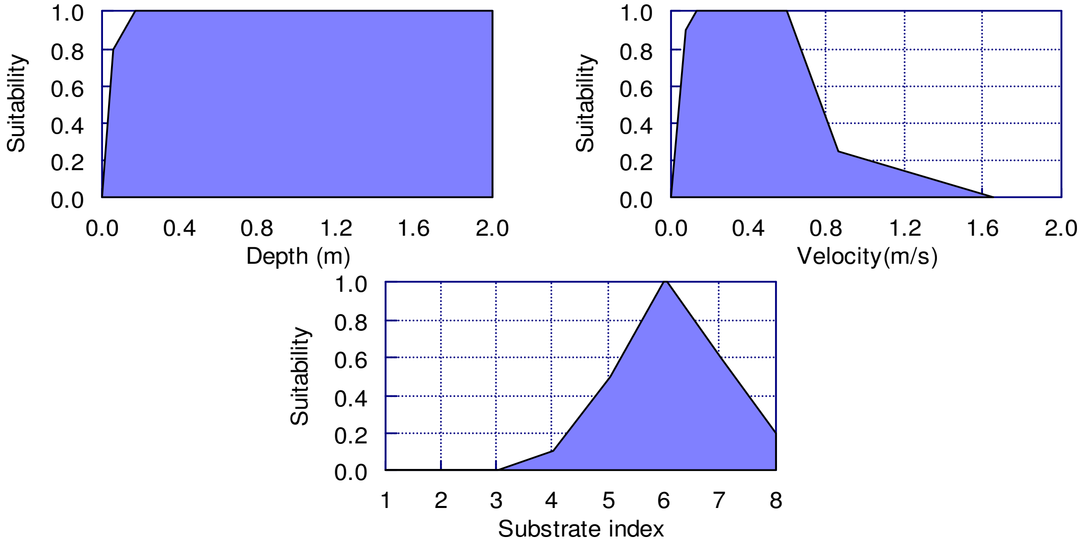
Brown trout adult (Hayes and Jowett 1994)




Brown trout juvenile (Thomas & Bovee 1993)


Deleatidium (mayfly) (Jowett et al. 1991)

Nesameletus (mayfly) (Jowett et al. 1991)



Food producing (Waters 1976)