Flow evaluation for the Manganui River, Taranaki, downstream of Tariki Road, between the Mangaotea and Mangamawhete Streams

CBER Contract Report 34

Confidential client report prepared for
Kingett Mitchell Ltd,
Christchurch

by

Brendan J. Hicks

Centre for Biodiversity and Ecology Research
Department of Biological Sciences
School of Science and Technology
The University of Waikato
Private Bag 3105
Hamilton, New Zealand

18 August 2004

Email: b.hicks@waikato.ac.nz

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

CBER University of Waikato
Centre for Biodiversity and Ecology Research

Page

Table of contents

List of tables

List of figures

Introduction

A variety of methods have been used to investigate the relationship of fish habitat to river discharge, and in New Zealand the method that has been most widely used, and also the method with the most credibility, is the hydraulic modelling program RHYHABSIM for Windows version 3.20 (Jowett 1999). This method uses depths, velocities, and substrate measurements from the river channel in question to predict changes in hydraulic geometry. These changes can then be matched to known habitat suitability curves to estimate the amount of available habitat for different life stages of fish and invertebrates, and for food production, over a specified range of discharges.

The objective of the flow modelling described in this report was to estimate the impact of the proposed flow reduction in the Mangaotea Stream at its confluence with the Manganui River from 180 to 58 l/s on habitat for brown trout (*Salmo trutta*) in the Manganui River reach between the Mangaotea and the Mangamawhete Streams.

Methods

This evaluation used depth and velocity measurements made at 15-36 points spaced across each of 10 cross sections within a 2.8 km section of the Manganui River, Taranaki, downstream of Tariki Road, between the Mangaotea and Mangamawhete Streams (Figure 1; Table 1). These measurements were made on 12-13 July 2004 at a mean discharge of 1.337 m^3/s.The hydraulic modelling program RHYHABSIM (Jowett 1999) was used to interpolate changes in hydraulic geometry for flows between 0.2 and 1.2 m^3/s. Habitat availability for brown trout was also calculated with RHYHABSIM.

A number of assumptions were made to determine available habitat. The most important of these were:

1. The stage discharge relationship in the surveyed reach of the Manganui River downstream of Tariki Road is the same as Manganui River at Croydon Road.
2. The species of interest is brown trout.
3. Mean channel gradient is adequately represented by the gradient measured from a 1:50,000 scale map.
4. The surveyed reach length is approximately 2.8 km as measured from a 1:50,000 scale map.
5. The cross sections are representative of the reach as a whole.

Channel gradient was measured from the sheet Q19 of the 1:50,000 scale NZMS260 map series between contours 160 and 180 m (Fig. 1), as was the length of the surveyed reach. Velocities were measured with a Pygmy current meter model Oss-PC1 fitted with the appropriate sized bucket wheel for the velocities. Channel width was measured to the nearest 0.1 m, and depth was measured to the nearest 5 mm, which limits the accuracy of widths and depths implied in Tables 2, 6, and 8.

Results

The assumed stage discharge curve used the flow measured in cross-section 1 of the surveyed reach (1.282 m^3/s) and flows of 3.6 and 6.5 m^3/s from the Manganui River at Croydon Road about 3 km upstream (Figure 2). The modelling was relatively insensitive to the stage discharge relationship. Doubling or halving the two higher flows made little difference to the available habitat at ≤ 1.2 m^3/s. Channel gradient measured from the 1:50,000-scale map was 0.0046.

Figure 1. Location of the 2.8 km surveyed reach on the Manganui Stream, Taranaki, showing the measured cross sections.

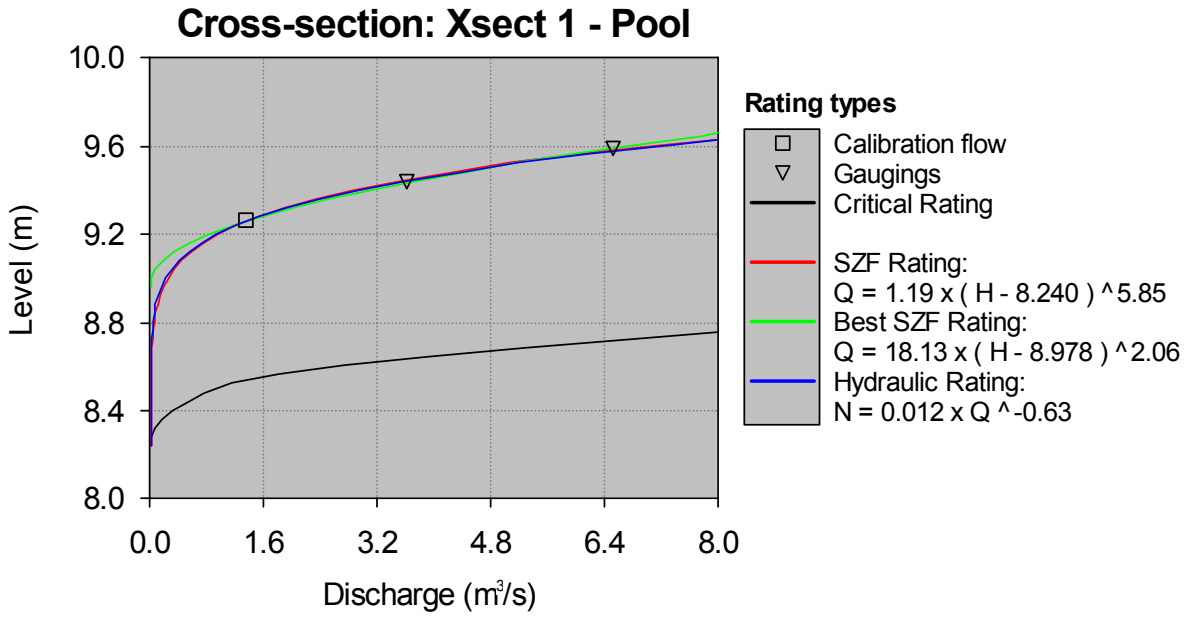

Figure 2. Assumed stage discharge relationship for cross section 1 in the surveyed section of the Manganui River, Taranaki, downstream of Taraiki Road. Points with inverted triangles are from the stage discharge relationship at Croydon Road (NIWA unpublished data).

Cross sections in pools were generally relatively U-shaped, with the exception of cross section 4. Riffles were shallow and flat, whereas the runs had many large boulders that created numerous small pools, or "pocket water" (Figure 3). Habitat in the measured reach was 65% pool, 25% run with boulder-strewn pocket water, and 10% riffle. The 10 cross sections included five pools, two riffles, and three runs. Measured flows ranged between 1.073 and 1.757 m^3/s, and water width was 12.3-27.9 m (Table 2). Depths and velocities had wide ranges. The substrate in the surveyed reach was coarse, and was almost entirely bedrock, boulder, or cobble (Table 3). The reach was dominated by pool habitat, which was reflected in the 78% of measured velocities that were 0-0.2 m/s (Table 4).

Overall, the reach was most suitable for adult and juvenile brown trout, but had little habitat suitable for brown trout fry or food production (Table 5). The relationship of habitat suitability with discharge showed a strongly curvilinear response for brown trout juveniles, and reached a maximum at 1.0 m^3/s (Figure 4). For three out of the five pools, the maximum habitat occurred at < 1.0 m^3/s (Figure 5). The pool at cross section 4 behaved somewhat strangely compared to the other pools, with habitat decreasing linearly with discharge throughout the range. This was probably because of its rather flat bed (Figure 3, X-sect 4).

The relative amounts of pool, riffle, and run habitats changed very little with changing discharge (Table 6). Width increased by < 5 m as flows increased from 0.2 to 1.2 m^3/s, but depths and velocities more than doubled. Habitat for brown trout increased with discharge in response to the increased width and depth (Table 7). Investigating the change in habitat availability over the range of discharges caused by the proposed reduction in the Mangaotea Stream, it is clear that reducing the discharge in the Manganui River from 580 to 458 l/s will have little impact on brown trout (Figure 6). Changes in channel geometry will be negligible (Table 8), and the available habitat for juvenile brown trout will fall from

25.25% to 23.74% (Table 9). There are similar small reductions in habitat for adult brown trout, brown trout fry, and food production, but the reach is fairly unsuitable for these to begin with. The unsuitability of the reach for adult brown trout is shown by small amount of weighted usable area before the proposed flow reduction (12.5%). After the flow reduction 10.1% of the reach remains suitable. This reduction looks dramatic in absolute terms, (1.99 reduced to 1.55 m^2/m, or 22% reduction), but will not be severe considering the limited suitability of the habitat for brown trout in the surveyed section overall.

The temperature effects were also investigated with RHYHABSIM. The heating effect of the flow reduction is unlikely to be measurable.

Conclusions

A reduction in the flow of the Mangaotea Stream so that its flow at the confluence with the Manganui River falls from 180 to 58 l/s will have no observable impact on brown trout in the Manganui River. Of the life stages of brown trout, the surveyed reach is most suitable for juvenile brown trout. The amount of suitable habitat for juvenile brown trout will be reduced from 25.3 to 23.7% of the river, which is a 9% absolute reduction (4.01 m^2/m reduced to 3.65 m^2/m). In the worst-case scenario, habitat for adult trout will be reduced from 12.5 to 10.1% of the reach, or from 1.99 down to 1.55 m^2/m (a 22% reduction), but this is not severe considering the overall unsuitability of the reach for adult brown trout.

The impact of the loss of the water from the Mangaotea Stream will be somewhat offset by contributions from small tributaries and groundwater between the Mangaotea and the Mangamawhete Streams.

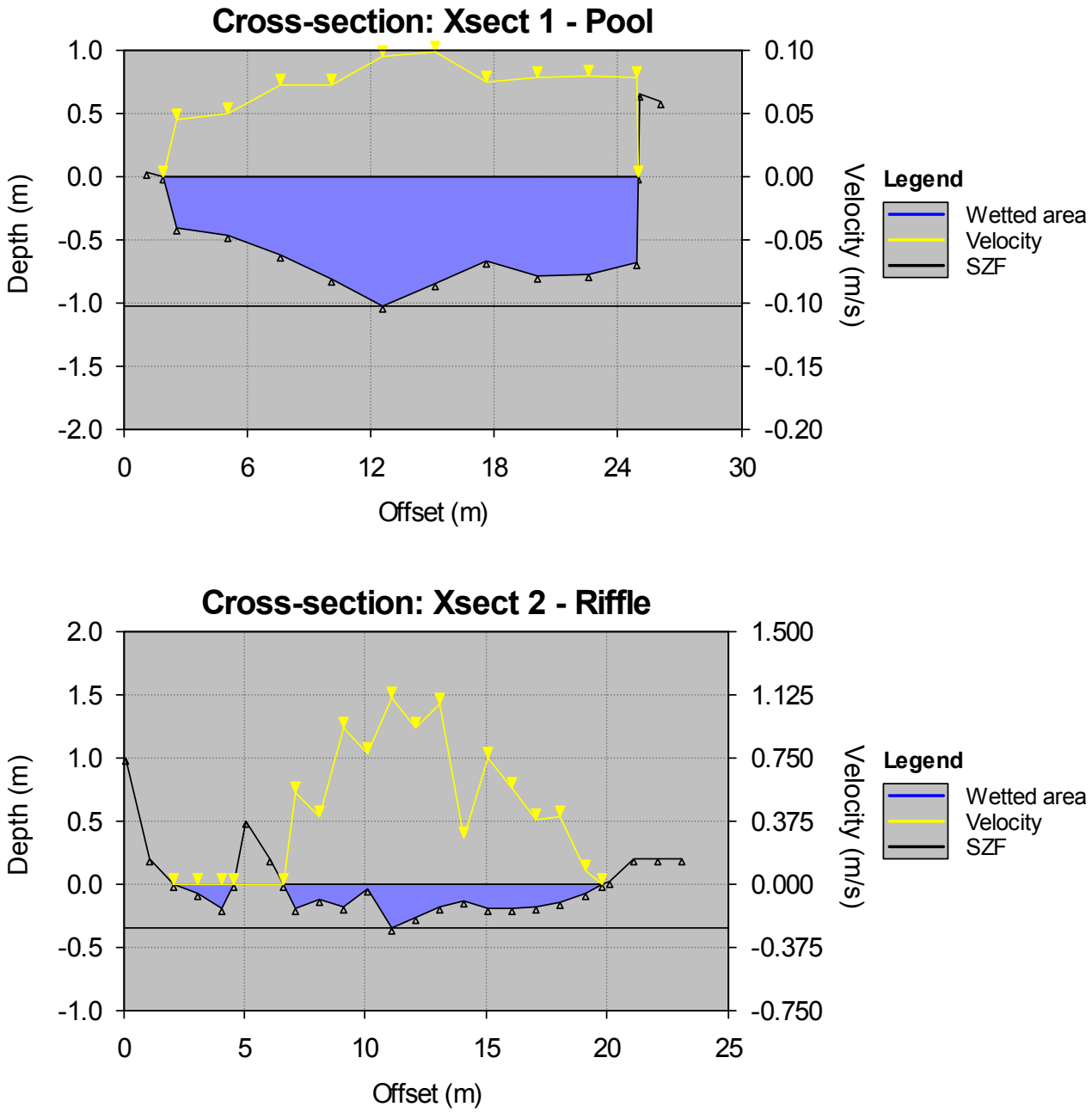

Figure 3. Distribution of depth and velocity at 10 cross sections in a 2.8 km reach of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams measured on 12-13 July 2004. Mean discharge for the surveyed reach was 1.337 m^3/s.

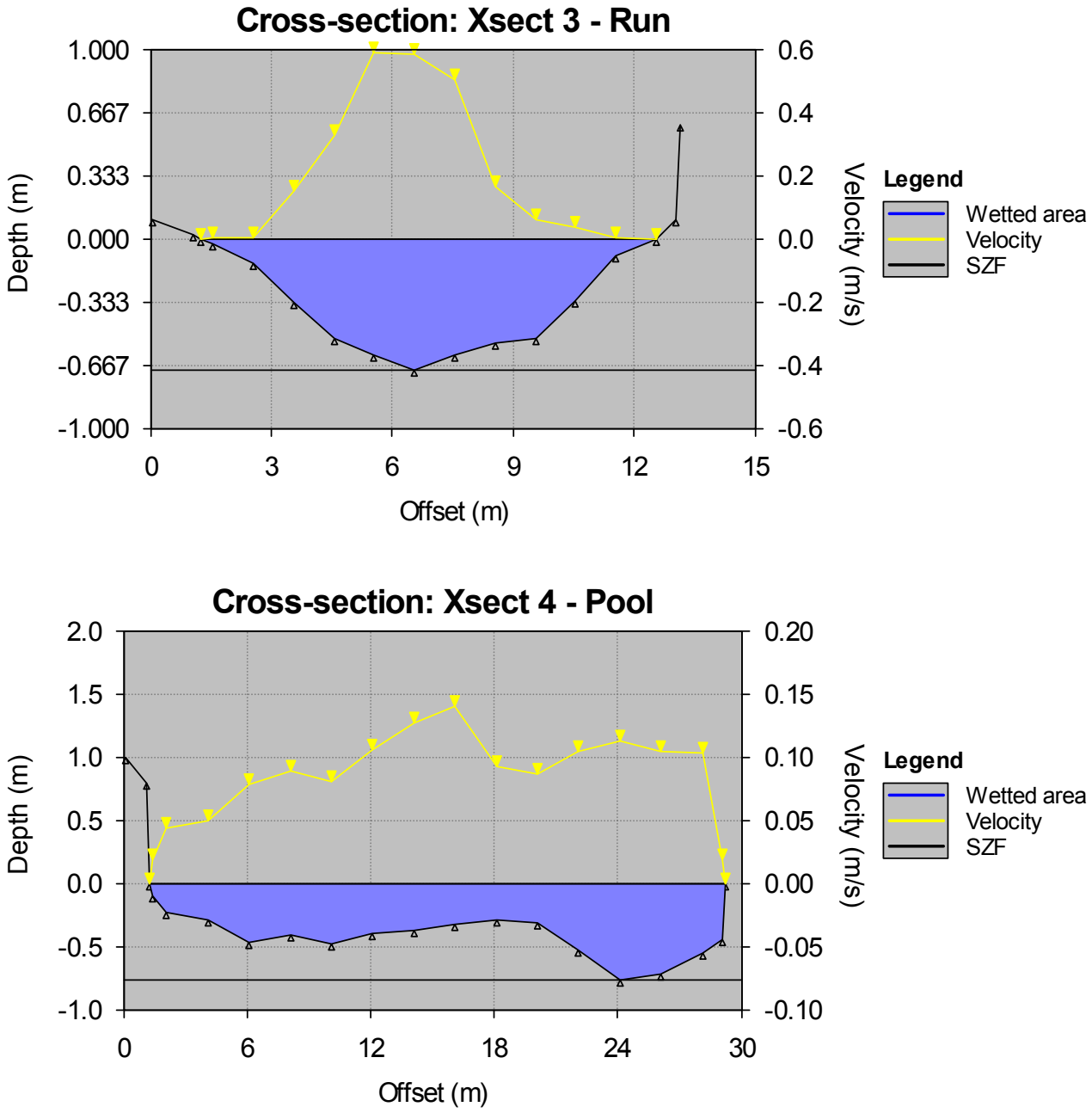

Figure 3 (continued). Distribution of depth and velocity at 10 cross sections in a 2.8 km section of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams measured on 12-13 July 2004. Mean discharge for the surveyed reach was 1.337 m^3/s.

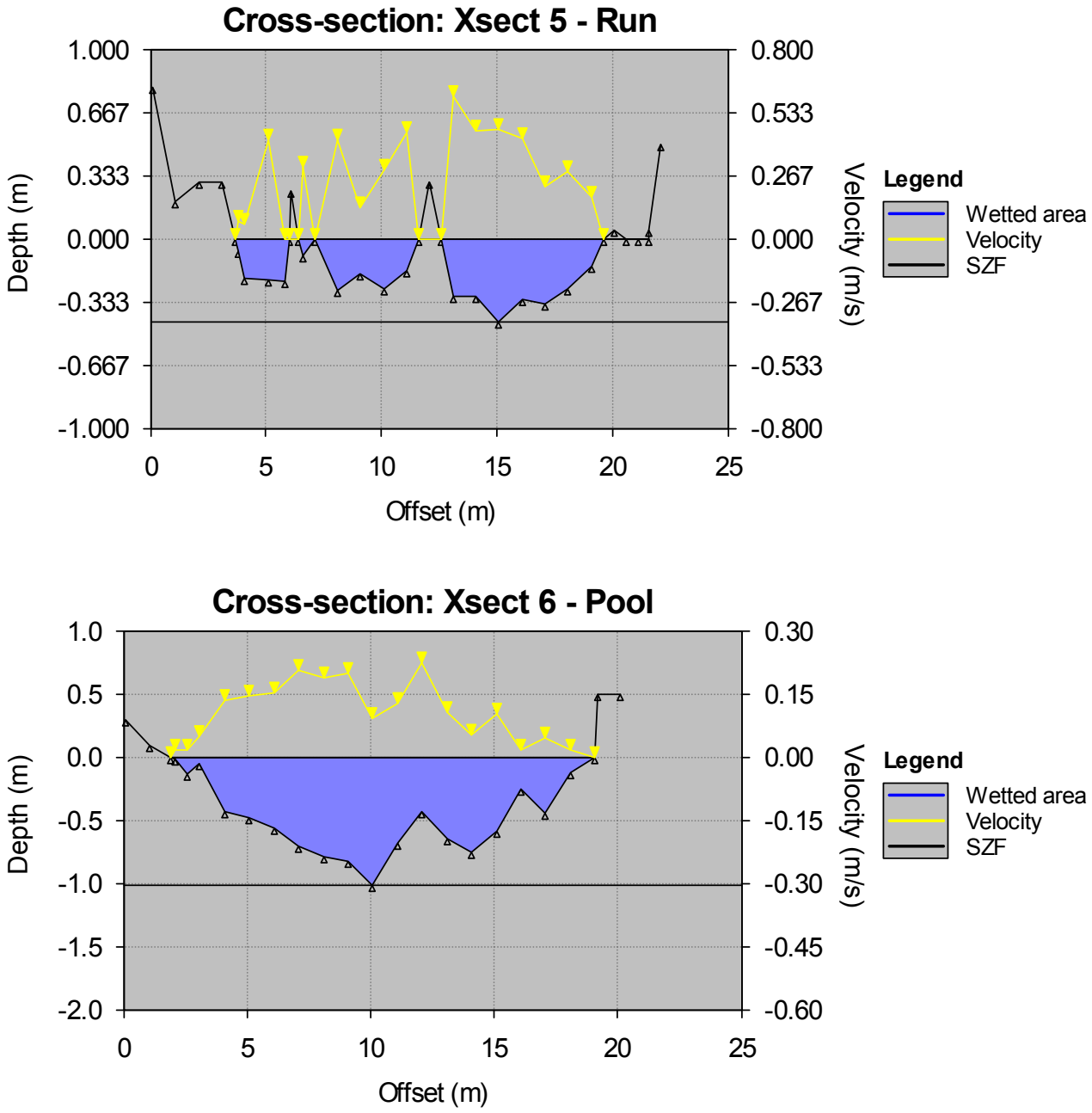

Figure 3 (continued). Distribution of depth and velocity at 10 cross sections in a 2.8 km section of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams measured on 12-13 July 2004. Mean discharge for the surveyed reach was 1.337 m^3/s.

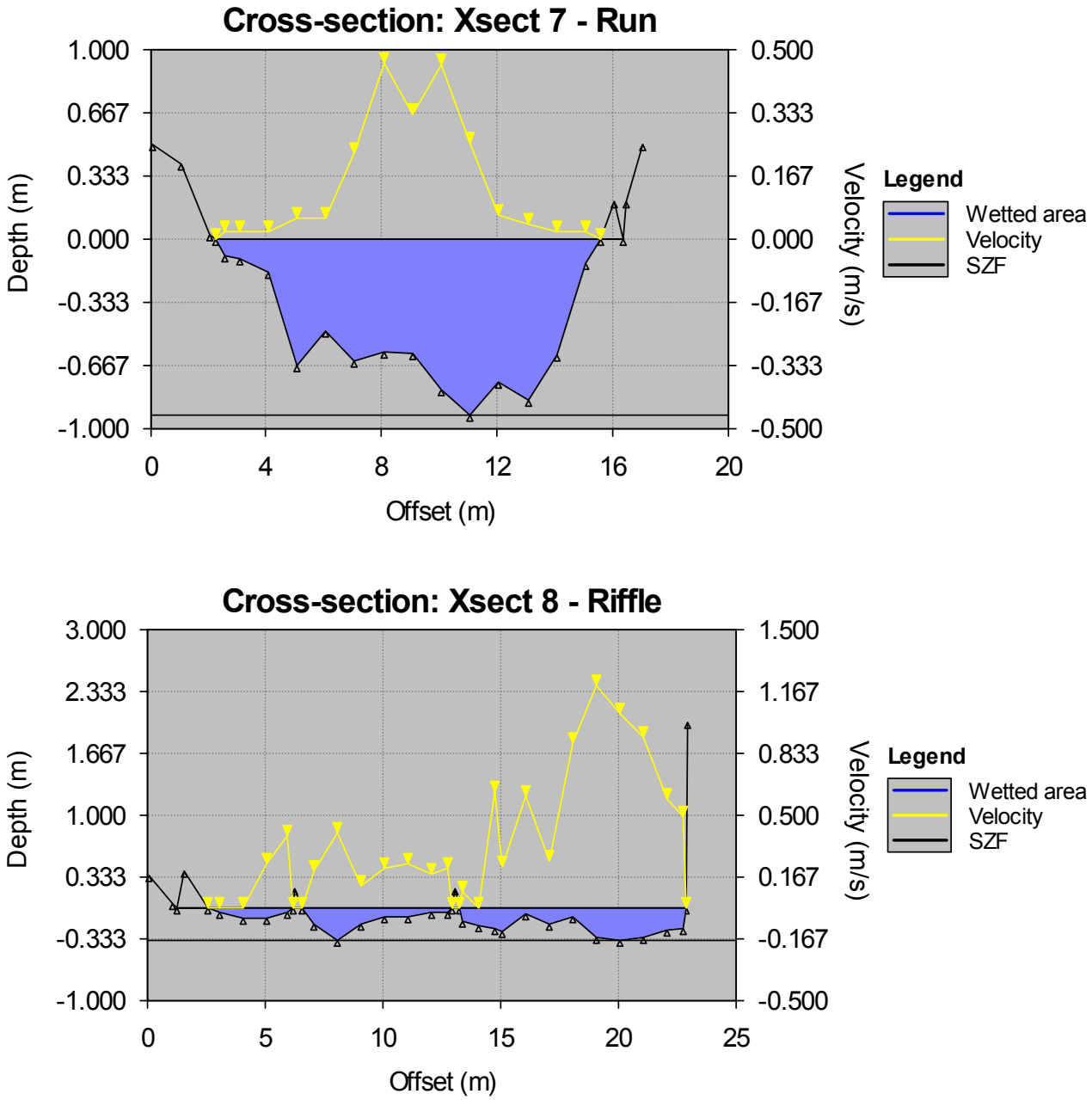

Figure 3 (continued). Distribution of depth and velocity at 10 cross sections in a 2.8 km section of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams measured on 12-13 July 2004. Mean discharge for the surveyed reach was 1.337 m^3/s.

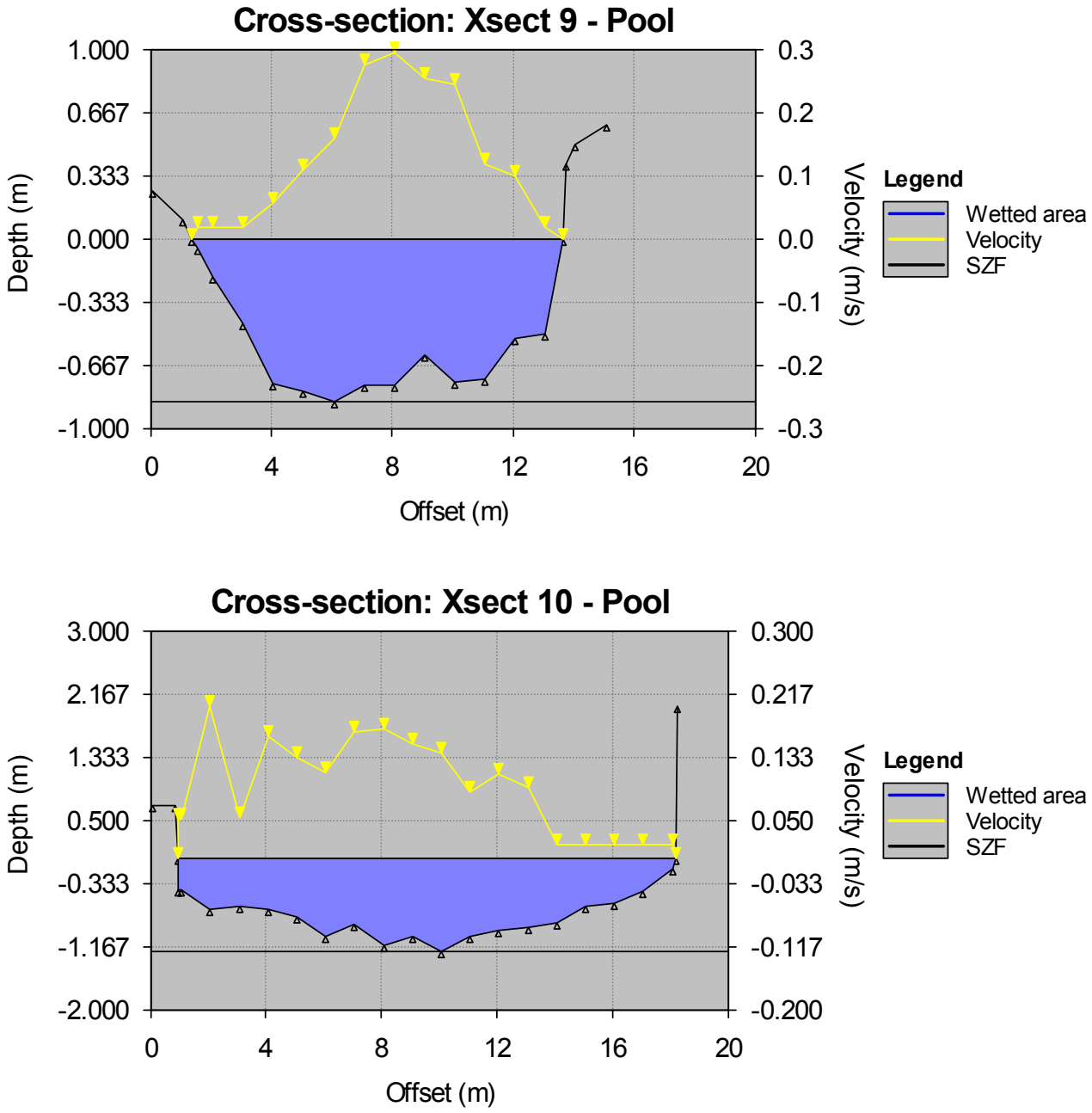

Figure 3 (continued). Distribution of depth and velocity at 10 cross sections in a 2.8 km section of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams measured on 12-13 July 2004. Mean discharge for the surveyed reach was 1.337 m^3/s.

Table 1. Flow and hydraulic geometry and discharges calculated with RHYHABSIM in a 2.8 km section of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams on 12-13 July 2004.

Section	Distance (m)	Water Level (m)	Discharge (m^3/s)	Area (m^2)	Mean Velocity (m/s)	Width (m)	Energy Coefficient
1 Xsect 1 - Pool	0.00	9.260	1.2817	16.370	0.078	23.10	1.08
1 Channel 1	**0.00**		**1.28**	**16.37**	**0.078**	**23.10**	
2 Xsect 2 - Riffle	549.00	6.740	1.4834	2.374	0.625	15.70	1.72
2 Channel 2	**549.00**		**1.48**	**2.37**	**0.625**	**15.70**	
3 Xsect 3 - Run	732.00	5.890	1.4013	4.403	0.318	11.30	2.27
3 Channel 3	**732.00**		**1.40**	**4.40**	**0.318**	**11.30**	
4 Xsect 4 - Pool	1189.00	3.790	1.1554	12.056	0.096	27.90	1.14
4 Channel 4	**1189.00**		**1.16**	**12.06**	**0.096**	**27.90**	
5 Xsect 5 - Run	1555.00	2.110	1.0728	3.293	0.326	14.50	1.40
5 Channel 5	**1555.00**		**1.07**	**3.29**	**0.326**	**14.50**	
6 Xsect 6 - Pool	1829.00	0.850	1.1564	8.798	0.131	17.20	1.45
6 Channel 6	**1829.00**		**1.16**	**8.80**	**0.131**	**17.20**	
7 Xsect 7 - Run	1902.00	0.510	1.3669	7.315	0.187	13.30	3.13
7 Channel 7	**1902.00**		**1.37**	**7.32**	**0.187**	**13.30**	
8 Xsect 8 - Riffle	2451.00	-2.010	1.7572	3.283	0.535	19.60	2.48
8 Channel 8	**2451.00**		**1.76**	**3.28**	**0.535**	**19.60**	
9 Xsect 9 - Pool	2542.00	-2.430	1.2024	7.604	0.158	12.30	1.97
9 Channel 9	**2542.00**		**1.20**	**7.60**	**0.158**	**12.30**	
10 Xsect 10 - Pool	2817.00	-3.700	1.4953	13.732	0.109	17.20	1.50
10 Channel 10	**2817.00**		**1.50**	**13.73**	**0.109**	**17.20**	

Table 2. Channel characteristics and discharges calculated with RHYHABSIM in a 2.8 km section of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams on 12-13 July 2004.

Section	Flow (m^3/s)	Width (m)	Depth (m)	Velocity (m/s)	Area (m^2)	Pool (%)	Run (%)	Riffle (%)	Habitat type
Xsect 1 - Pool	1.282	23.100	0.709	0.074	16.37	100.00	0.00	0.00	pool
Xsect 2 - Riffle	1.483	15.700	0.151	0.515	2.37	25.16	30.25	44.59	riffle
Xsect 3 - Run	1.401	11.300	0.390	0.215	4.40	73.45	26.55	0.00	pool
Xsect 4 - Pool	1.155	27.900	0.432	0.093	12.06	100.00	0.00	0.00	pool
Xsect 5 - Run	1.073	14.500	0.227	0.286	3.29	46.90	53.10	0.00	run
Xsect 6 - Pool	1.156	17.200	0.512	0.110	8.80	100.00	0.00	0.00	pool
Xsect 7 - Run	1.367	13.300	0.550	0.152	7.32	92.48	7.52	0.00	pool
Xsect 8 - Riffle	1.757	19.600	0.167	0.405	3.28	30.87	38.27	30.87	run
Xsect 9 - Pool	1.202	12.300	0.618	0.136	7.60	100.00	0.00	0.00	pool
Xsect 10 - Pool	1.495	17.200	0.798	0.099	13.73	100.00	0.00	0.00	pool
Reach	**1.337**	**17.725**	**0.516**	**0.156**	**9.15**	**87.36**	**8.96**	**3.68**	

Table 3. Substrate characteristics and discharges calculated with RHYHABSIM at a mean flow of 1.337 m^3/s in a 2.8 km reach of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams on 12-13 July 2004.

Cross section	Bedrock %	Boulder %	Cobble %	Gravel %	Fine Gravel %	Sand %	Mud %	Vegetation %
Xsect 1 - Pool	16.0	43.1	4.2	2.2	30.3	4.2	0.0	0.0
Xsect 2 - Riffle	45.1	46.6	7.7	0.6	0.0	0.0	0.0	0.0
Xsect 3 - Run	29.4	38.9	11.1	0.0	16.2	4.4	0.0	0.0
Xsect 4 - Pool	20.6	33.0	8.6	1.8	35.7	0.0	0.4	0.0
Xsect 5 - Run	41.4	37.1	19.8	0.0	1.7	0.0	0.0	0.0
Xsect 6 - Pool	78.9	13.8	6.0	0.0	1.3	0.0	0.0	0.0
Xsect 7 - Run	63.9	23.7	8.5	3.0	0.9	0.0	0.0	0.0
Xsect 8 - Riffle	51.3	35.5	12.9	0.0	0.0	0.0	0.3	0.0
Xsect 9 - Pool	25.2	28.5	22.8	10.0	1.6	12.0	0.0	0.0
Xsect 10 - Pool	6.4	43.7	11.3	3.3	2.9	32.3	0.0	0.0
Reach	**33.2**	**34.0**	**10.2**	**2.3**	**14.1**	**6.1**	**0.1**	**0.0**

Table 4. Reach depth and velocity distribution calculated with RHYHABSIM at a mean flow of 1.337 m^3/s for a 2.8 km reach of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams on 12-13 July 2004.

Depth (m)	Velocity (m/s) 0-0.2	Velocity (m/s) 0.2-0.4	Velocity (m/s) 0.4-0.6	Velocity (m/s) 0.6-0.8	Velocity (m/s) 0.8-1.0	Velocity (m/s) 1.0-1.2	Velocity (m/s) 1.2-1.4	Velocity (m/s) >1.4	Sum (%)
0-0.2	12.05	2.34	1.69	0.56	0.56	0.28	0.00	0.00	17.49
0.2-0.4	11.98	1.59	2.44	0.49	0.56	0.56	0.28	0.00	17.92
0.4-0.6	19.42	1.20	0.94	0.00	0.00	0.00	0.00	0.00	21.56
0.6-0.8	19.82	5.34	1.88	0.00	0.00	0.00	0.00	0.00	27.04
0.8-1.0	9.27	0.47	0.00	0.00	0.00	0.00	0.00	0.00	9.74
1.0-1.2	5.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.50
1.2-1.4	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73
>1.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**78.78**	**10.94**	**6.96**	**1.06**	**1.13**	**0.85**	**0.28**	**0.00**	

Table 5. Reach in-stream habitat calculated with RHYHABSIM at a mean flow of 1.337 m^3/s for a 2.8 km reach of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams on 12-13 July 2004.

1:- Brown trout juvenile (I.G. Jowett, pers. comm.)
2:- Brown trout fry to 15cm (Raleigh et al 1984)
3:- Brown trout adult (Hayes & Jowett 1994)
4:- Food producing (Waters 1976)

Section	1 (m)	1 (%)	2 (m)	2 (%)	3 (m)	3 (%)	4 (m)	4 (%)
Xsect 1 - Pool	6.27	27.13	3.06	13.26	6.57	28.42	0.00	0.00
Xsect 2 - Riffle	1.21	7.74	0.04	0.26	0.00	0.01	6.01	38.27
Xsect 3 - Run	4.34	38.41	1.07	9.44	3.76	33.32	2.49	22.06
Xsect 4 - Pool	9.79	35.08	4.81	17.25	4.18	14.98	0.00	0.00
Xsect 5 - Run	2.86	19.71	0.45	3.11	0.93	6.41	4.53	31.27
Xsect 6 - Pool	2.32	13.49	0.59	3.45	5.38	31.28	0.47	2.72
Xsect 7 - Run	2.61	19.62	0.31	2.35	6.17	46.36	1.97	14.84
Xsect 8 - Riffle	1.79	9.12	0.14	0.72	0.22	1.11	5.36	27.32
Xsect 9 - Pool	3.83	31.17	1.35	10.99	5.23	42.50	1.50	12.20
Xsect 10 - Pool	4.28	24.87	2.38	13.82	4.51	26.24	0.10	0.61
Reach	**4.41**	**24.89**	**1.75**	**9.86**	**4.28**	**24.14**	**1.59**	**8.96**

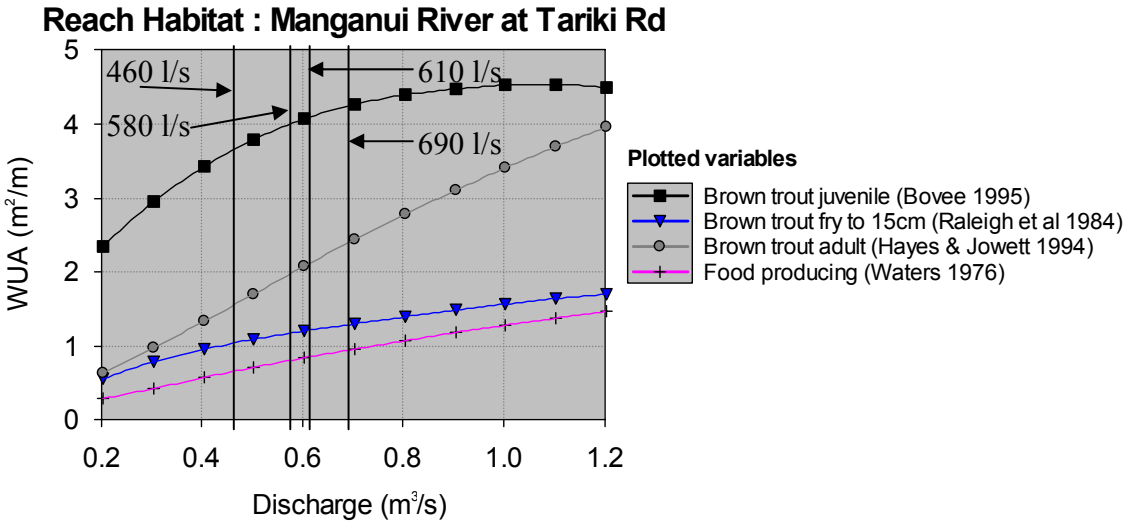

Figure 4. Relationship of weighted usable area (WUA) for brown trout and their food modelled for discharges between 0.2 and 1.2 m^3/s with RHYHABSIM in a 2.8 km section of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams.

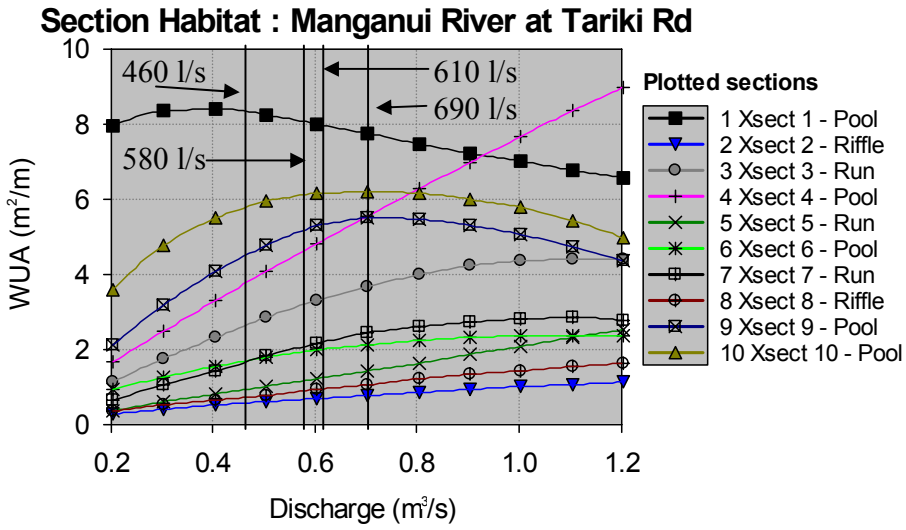

Figure 5. Relationship of weighted usable area (WUA) for brown trout and their food modelled for discharges between 0.2 and 1.2 m^3/s with RHYHABSIM for each of 10 cross sections in a 2.8 km section of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams.

Table 6. Channel geometry modelled with RHYHABSIM for discharges between 0.2 and 1.2 m^3/s in a 2.8 km reach of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams.

Flow (m^3/s)	Width (m)	Depth (m)	Velocity (m/s)	Area (m^2)	Wetted perimeter (m)	Pool %	Run %	Riffle %
0.200	12.779	0.243	0.070	3.104	12.942	92.494	5.500	2.006
0.300	14.268	0.275	0.083	3.919	14.466	91.617	5.463	2.920
0.400	15.046	0.307	0.093	4.621	15.272	91.066	6.120	2.814
0.500	15.566	0.337	0.101	5.246	15.817	90.647	6.862	2.491
0.600	15.941	0.365	0.111	5.815	16.214	90.145	7.080	2.775
0.700	16.191	0.392	0.118	6.343	16.482	89.232	8.017	2.751
0.800	16.422	0.416	0.126	6.836	16.730	88.923	8.044	3.033
0.900	16.699	0.437	0.134	7.303	17.023	87.617	8.951	3.432
1.000	16.975	0.457	0.139	7.750	17.314	87.818	8.799	3.383
1.100	17.244	0.474	0.144	8.181	17.599	87.648	8.871	3.481
1.200	17.450	0.493	0.149	8.597	17.821	87.728	8.540	3.732

Table 7. Relationship of weighted usable area (WUA) for brown trout and their food modelled with RHYHABSIM for discharges between 0.2 and 1.2 m^3/s in a 2.8 km reach of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams.

1:- Brown trout juvenile (I.G. Jowett, pers. comm.)
2:- Brown trout fry to 15cm (Raleigh et al 1984)
3:- Brown trout adult (Hayes & Jowett 1994)
4:- Food producing (Waters 1976)

Flow (m^3/s)	1 (m^2/m)	1 (%)	2 (m^2/m)	2 (%)	3 (m^2/m)	3 (%)	4 (m^2/m)	4 (%)
0.200	2.332	18.25	0.550	4.31	0.625	4.89	0.277	2.17
0.300	2.948	20.66	0.776	5.44	0.968	6.78	0.427	2.99
0.400	3.418	22.72	0.946	6.29	1.328	8.82	0.568	3.78
0.500	3.781	24.29	1.076	6.91	1.695	10.89	0.703	4.52
0.600	4.060	25.47	1.191	7.47	2.066	12.96	0.835	5.24
0.700	4.254	26.27	1.299	8.02	2.433	15.03	0.955	5.90
0.800	4.387	26.71	1.394	8.49	2.780	16.93	1.073	6.53
0.900	4.471	26.77	1.478	8.85	3.106	18.60	1.180	7.07
1.000	4.518	26.62	1.559	9.18	3.408	20.08	1.277	7.52
1.100	4.525	26.24	1.629	9.44	3.693	21.41	1.369	7.94
1.200	4.491	25.74	1.686	9.66	3.958	22.68	1.459	8.36

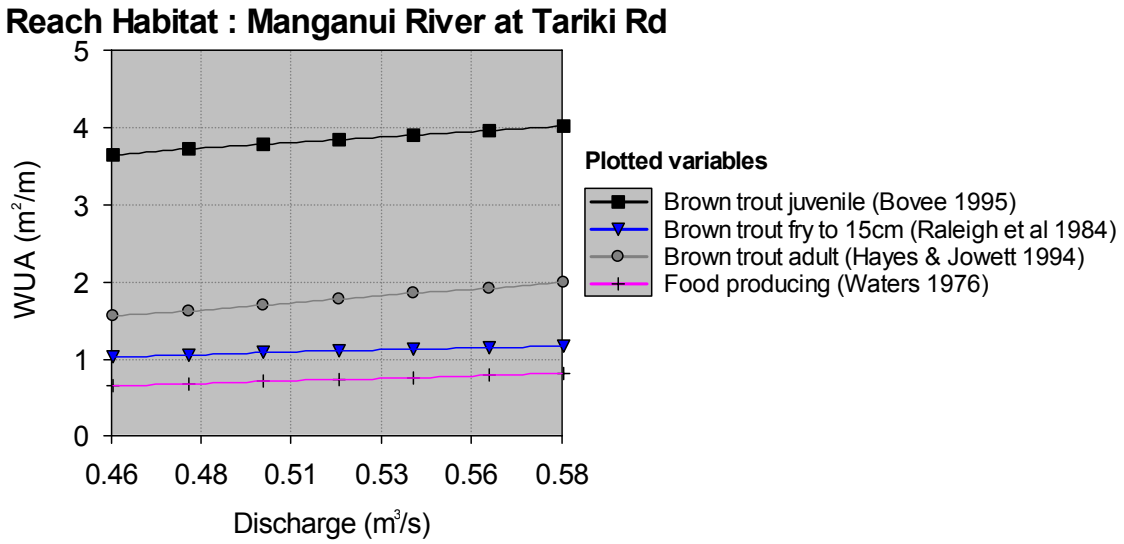

Figure 6. Relationship of weighted usable area (WUA) for brown trout and their food modelled with RHYHABSIM for discharges between 460 and 580 l/s in a 2.8 km section of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams.

Table 8. Channel geometry modelled with RHYHABSIM for discharges between 460 and 580 l/s in a 2.8 km reach of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams.

Flow (m^3/s)	Width (m)	Depth (m)	Velocity (m/s)	Area (m^2)	Wetted perimeter (m)	Pool %	Run %	Riffle %
0.460	15.361	0.326	0.098	5.003	15.603	90.615	6.876	2.509
0.480	15.446	0.332	0.100	5.125	15.693	90.314	7.184	2.503
0.500	15.566	0.337	0.101	5.246	15.817	90.647	6.862	2.491
0.520	15.686	0.342	0.103	5.363	15.942	90.376	7.145	2.479
0.540	15.756	0.348	0.104	5.479	16.016	90.396	7.129	2.474
0.560	15.824	0.354	0.106	5.594	16.089	90.258	7.114	2.628
0.580	15.888	0.359	0.109	5.705	16.157	90.126	7.094	2.780

Table 9. Relationship of weighted usable area for brown trout and their food modelled with RHYHABSIM for discharges between 460 and 580 l/s in a 2.8 km reach of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams.

1:- Brown trout juvenile (I.G. Jowett, pers. comm.)
2:- Brown trout fry to 15cm (Raleigh et al 1984)
3:- Brown trout adult (Hayes & Jowett 1994)
4:- Food producing (Waters 1976)

Flow (m^3/s)	1 (m^2/m)	1 (%)	2 (m^2/m)	2 (%)	3 (m^2/m)	3 (%)	4 (m^2/m)	4 (%)
0.460	3.646	23.74	1.027	6.68	1.548	10.08	0.649	4.23
0.480	3.715	24.05	1.052	6.81	1.621	10.49	0.676	4.38
0.500	3.781	24.29	1.076	6.91	1.695	10.89	0.703	4.52
0.520	3.844	24.51	1.100	7.01	1.769	11.28	0.730	4.65
0.540	3.904	24.78	1.124	7.13	1.843	11.70	0.756	4.80
0.560	3.960	25.02	1.147	7.25	1.918	12.12	0.781	4.94
0.580	4.011	25.25	1.169	7.36	1.992	12.54	0.810	5.10

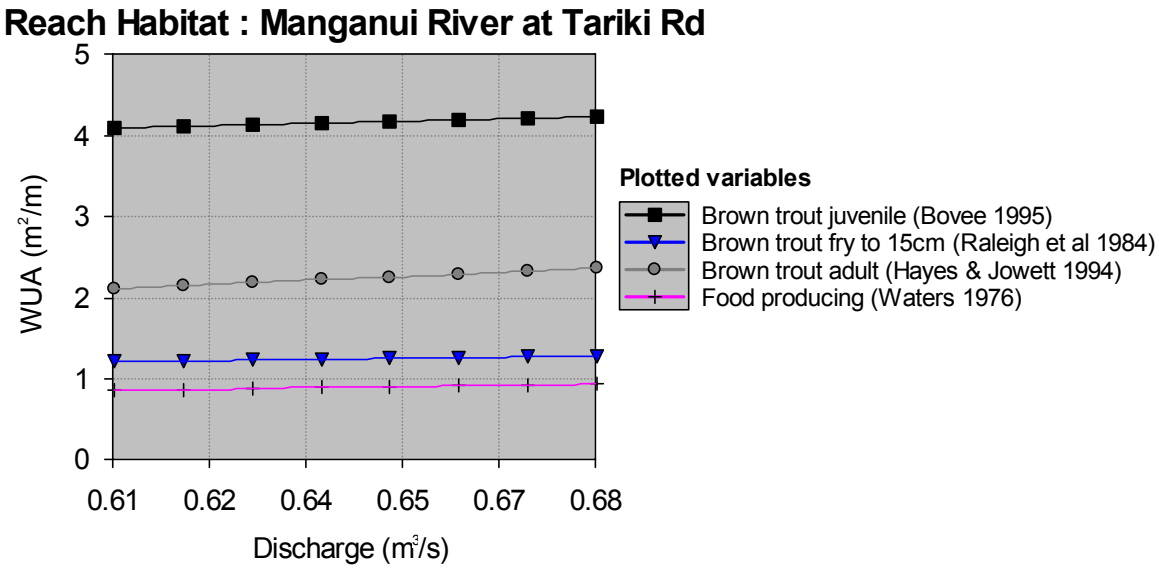

Figure 7. Relationship of weighted usable area (WUA) for brown trout and their food modelled with RHYHABSIM for discharges between 610 and 680 l/s in a 2.8 km section of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams.

Table 10. Channel geometry modelled with RHYHABSIM for discharges between 610 and 680 l/s in a 2.8 km reach of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams.

Flow (m^3/s)	Width (m)	Depth (m)	Velocity (m/s)	Area (m^2)	Wetted perimeter (m)	Pool %	Run %	Riffle %
0.610	15.967	0.368	0.111	5.870	16.242	90.155	7.073	2.772
0.620	15.993	0.370	0.112	5.924	16.270	90.164	7.066	2.770
0.630	16.018	0.373	0.113	5.978	16.297	90.174	7.059	2.767
0.640	16.043	0.376	0.114	6.031	16.324	90.183	7.052	2.765
0.650	16.068	0.379	0.114	6.083	16.350	90.192	7.046	2.762
0.660	16.093	0.381	0.115	6.136	16.377	90.201	7.039	2.760
0.670	16.118	0.384	0.116	6.188	16.403	89.976	7.267	2.758
0.680	16.142	0.387	0.117	6.240	16.430	89.744	7.500	2.755
0.690	16.167	0.389	0.117	6.291	16.456	89.745	7.502	2.753

Table 11. Relationship of weighted usable area for brown trout and their food modelled with RHYHABSIM for discharges between 610 and 680 l/s in a 2.8 km reach of the Manganui River, Taranaki, between the Mangaotea and Mangamawhete Streams.

1:- Brown trout juvenile (I.G. Jowett, pers. comm.)
2:- Brown trout fry to 15cm (Raleigh et al 1984)
3:- Brown trout adult (Hayes & Jowett 1994)
4:- Food producing (Waters 1976)

Flow (m^3/s)	1 (m^2/m)	1 (%)	2 (m^2/m)	2 (%)	3 (m^2/m)	3 (%)	4 (m^2/m)	4 (%)
0.610	4.083	25.57	1.203	7.53	2.104	13.17	0.847	5.31
0.620	4.104	25.66	1.214	7.59	2.141	13.39	0.860	5.38
0.630	4.126	25.76	1.225	7.64	2.178	13.60	0.872	5.44
0.640	4.146	25.84	1.235	7.70	2.215	13.81	0.884	5.51
0.650	4.165	25.92	1.246	7.76	2.252	14.01	0.896	5.58
0.660	4.184	26.00	1.257	7.81	2.288	14.22	0.908	5.64
0.670	4.203	26.07	1.267	7.86	2.324	14.42	0.920	5.71
0.680	4.220	26.15	1.278	7.92	2.361	14.62	0.932	5.77
0.690	4.237	26.21	1.288	7.97	2.397	14.83	0.944	5.84

Acknowledgments

Richard Montgomerie of Kingett Mitchell Ltd, Christchurch, collected the cross-sectional data for the analysis. I thank Ian Jowett for his advice on the operation of RHYHABSIM, for creating the computer modelling program, and for the stage discharge data for Croydon Road.

References

Jowett, I. G. 1999. RHYHABSIM: river hydraulics and habitat simulation. Unpublished report.

Raleigh, R. F., L. D. Zuckerman, and P. C. Nelson. 1984. Habitat suitability index models and instream flow suitability curves: brown trout. U.S. Fish and Wildlife Service, FWS/OBS-82/10.71.

Hayes, J. W., and I. J. Jowett. 1994. Microhabitat models of large drift-feeding brown trout in three New Zealand rivers. North American Journal of Fisheries Management 14:710-725.

Waters, B. F. 1976. A methodology for evaluating the effects of different streamflows on salmonid habitat. Pages 254-266 in Orsborn, J. F. and Allman, C. H. (eds), Proceedings of the Symposium and Speciality Conference on Instream Flow Needs II. American Fisheries Society, Bethesda, Maryland. pp. 224-234.