ENVIRONMENTAL MANAGEMENT GROUP

Technical report

INTERNAL

HAWKE'S BAY REGIONAL COUNCIL

SAFEGUARDING YOUR ENVIRONMENT + KAITIAKI TUKU IHO

Ngaruroro River RHYHABSIM modelling update

June 2008
EMI 0816
HBRC Plan Number 4051

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Environmental Management Group
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Environmental Science Section

Ngaruroro River RHYHABSIM modelling updates

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EXECUTIVE SUMMARY

The Hawke's Bay Regional Council manages the region's water resources in accordance with the Regional Resource Management Plan and the Resource Management Act 1991. A critical component of the regional management scheme is the use of minimum flows to regulate abstraction at times of low water availability. Minimum flows must be scientifically robust with regard to environmental impact and must be adaptable to reflect the current state of the environment.

This report documents the review of hydraulic modelling on the Ngaruroro River using RHYHABSIM Version 4.1 (© Jowett 1999). Previous modelling was conducted on IFIM survey data in 1997 and 2001. This was based on habitat estimates expressed as % weighted usable area (WUA), which were derived using rainbow trout habitat suitability curves developed in the United States. New research on rainbow trout in Hawke's Bay rivers indicates their habitat requirements are markedly different than their US counterparts. RHYHABSIM modelling using the Hawke's Bay rainbow trout habitat data produces a minimum flow recommendation of 2600 l/s.

Upon review of previous survey data and analysis methodology, several key issues have been recognized. Since model results and flow records are used conjunctively to arrive at a minimum flow recommendation, a review of the naturalized flow record for the Ngaruroro River is essential. It is also necessary to identify any changes in the ecosystem and river hydrology that may have occurred under the previous minimum flow and abstraction regimes, to assess whether instream management objectives have been achieved. Lastly, the finalisation and peer review of Hawke's Bay rainbow trout habitat suitability curves is necessary to ensure defensible modelling results. The current minimum flow can then be assessed based on an up-to-date and robust understanding of the river environment.

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1.0 INTRODUCTION

The Ngaruroro River has been managed based on a minimum flow system since the 1970s. The Instream Flow Incremental Methodology (IFIM) was subsequently used to assess aquatic habitat in 1997 and the minimum flow was reset in 2000 based on those results. With ever increasing abstraction demand, it is imperative to have a robust, scientifically defensible management plan for surface water allocation. This report documents revisited RHYHABSIM modeling for the Ngaruroro River using updated habitat parameters developed specifically for rainbow trout in Hawke's Bay.

2.0 BACKGROUND

2.1 Previous IFIM Surveys

The Ngaruroro River was the subject of an IFIM study in March 1997 as part of the Hawke's Bay Regional Council Sustainable Low Flow Project assessment of the minimum flow. The survey focused on the reach from upstream of the Maraekakaho stream confluence to the minimum flow site at Fernhill Bridge. The 1997 report, based on the survey results, recommended the minimum flow at Fernhill Bridge could be reduced from 2800 l/s to 2000 l/s and the proposal was incorporated in the proposed regional Water Plan Variation #2, which was notified in November 1999 (Wood et al. 2001).

Additional work for the proposed regional Water Plan Variation #2 indicated that flow loss to the unconfined aquifer was more extensive than measured in the 1997 survey and the minimum flow recommendation could be insufficient to sustain the aquatic ecosystem during low flows. Plan Variation #2 was completed and the proposed Regional Resource Management Plan was publicly notified in April 2000. The minimum flow for the Ngaruroro River was set at 2400 l/s as opposed to the 2000 l/s recommendation, based on uncertainties regarding the results of the 1997 IFIM survey and to account for flow loss downstream of Fernhill Bridge. This led to the initiation of an additional IFIM survey to validate the new minimum flow.

The 2001 survey was carried out on the lower Ngaruroro River from Fernhill Bridge to upstream of the Tutaekuri-Waimate confluence (identified as a critical reach subject to flow loss). A total of 18 cross-sections were surveyed within four representative reaches: Fernhill Bridge, Hill Road, Carrick Road, and Motorway Bridge (Ormond Road). Each cross-section was located where the river flowed within a single, broad-meandering channel. The majority of the lower Ngaruroro is characterised by riffle-run sequences with few pools, with only two pools being identified within the survey reaches.

Modeling was completed using the RHYHABSIM programme. Each cross-section was modeled over a range of flows, with accounts made for flow loss between the four reaches. Available habitat was modeled for both native fish and trout species, and the % weighted usable area (%WUA) was used as the appropriate metric to gauge habitat with changes in flow. RHYHABSIM modeling from the 2001 IFIM survey indicated that habitat and stream health would not be negatively affected by a decrease in the minimum flow from 2800 l/s to 2400 l/s (Wood et al. 2001; Appendix C).

2.2 Low-Flow Temperature Modelling

Dr. Kit Rutherford at NIWA was contracted to analyze temperature data from the Ngaruroro River using the NIWA "Streamline" computer model (Rutherford 2001).

This study concluded that the Ngaruroro River is naturally subject to high water temperatures during summer, which is likely to be the predominant stressor to the aquatic environment. Model results suggested that during worst-case meteorology, reductions in flow from 2800 l/s to 2000 l/s would lead to an increase in temperature of 0.2°C. This change would be difficult to measure and would be unlikely to have a significant environmental impact beyond that which occurs at 2800 l/s. It was recommended that a change in the minimum flow to 2400 l/s would not have deleterious effects (Wood et al. 2001).

2.3 Ecological Data

The Ngaruroro River has an oligotrophic designation (low nutrient levels, based on algal concentrations) and algal biomass has been consistently within MfE guidelines for acceptable levels of algae accumulation, and does not pose a risk to macroinvertebrate communities.

Macroinvertebrate communities show variance at low flows and do not correlate to daily mean flow or stage. This variability is also observed at flows greater than 2400 l/s, therefore macroinvertebrate data are inconclusive with regard to supporting the reduced minimum flow.

2.4 Habitat Suitability Criteria

RHYHABSIM modeling in New Zealand has historically used rainbow and brown trout habitat suitability criteria developed in the western United States. It is recognized that the habitat needs of trout in New Zealand are different than those in the United States, and work is being undertaken to quantify those differences. The Cawthron Institute developed a series of habitat suitability curves, based on data collected on rainbow trout in Hawke's Bay. The newly developed habitat criteria show that the depth and velocity needs of rainbow trout in Hawke's Bay are greater than those in the United States, which implies that current minimum flows based on habitat criteria may be insufficient to adequately protect trout habitat. These new habitat suitability criteria are currently being analyzed against new data. Reporting and international peer review is expected soon.

3.0 METHODOLOGY

Modeling was conducted using the 2001 survey data as described in Wood et al. 2001. RHYHABSIM version 4.1 was used along with the default habitat suitability curves for native fish and US rainbow and brown trout. The provisional Hawke's Bay rainbow trout habitat suitability curves were also added to the model suite.

Fish species included:

- Common bully
- Redfin bully
- Inanga
- Shortfin eel
- Longfin eel
- Torrentfish
- Rainbow trout – fry, juvenile, and adult (Bovee 1978; Raleigh et al. 1984; Provisional Hawke's Bay 2008)
- Brown trout – adult (Bovee 1978)

Modeled flow ranged up to 5200 l/s as per Wood et al. 2001, but uses an interval of 200 l/s to increase resolution of the weighted usable area curves.

4.0 2008 RHYHABSIM RESULTS

These model results are based on survey data from 2001, which includes the whole of the lower Ngaruroro between Fernhill Bridge and upstream of the Tuaekuri-Waimate confluence. Data are shown in terms of both the area of the river that provides habitat (WUA m2/m) and the proportion of the river reach that provides habitat (HSI) (Appendix A).

Benthic macroinvertebrate response is modeled using (trout) food producing suitability curves from Waters 1976 (Figures 1 and 3). This response is characterized by a steady increase in habitat with increases in flow. It is accepted that by being dependent for habitat on a wetted surface, they benefit from increases in flow (thus depth and increased wetted area). Furthermore, velocity at the streambed is significantly less than in the water column, and the responses show that these organisms are relatively insensitive to increases in stream velocity.

The native fish responses are typical for current modeling results from across New Zealand (Figures 1 and 3). One response shows a decrease in habitat with increases in flow as indicated by the inanga and redfin bully curves. This reflects a preference for slow-moving water, and indicates that most native species are more responsive to velocity than increasing depth that occurs under higher flow conditions. The second response shows habitat is relatively constant over a range of values until a critical low-flow threshold, below which habitat drops significantly. These fish are believed to benefit from greater depths associated with higher flows and are less sensitive to higher velocities than inanga or redfin bullies. Trout fry and juveniles also exhibit a similar response. It should be noted that there is conjecture over the ability of current modeling to account for all aspects of native fish habitat-flow relationships. It is generally accepted, however, that flow requirements for trout exceed those for native fish, thus focus often shifts to trout habitat when recommending management schemes.

Adult trout response is typical for salmonids, which have high flow requirements (Figures 2 and 4). Optimum flows for trout are greater than those modeled for native species. Adult rainbow trout, as per US-derived habitat criteria, were modeled to have an optimum flow range of 3600 l/s to 3800 l/s. The provisional Hawke's Bay rainbow trout WUA curves indicate that the optimum flow is 8600 l/s (Figure 2).

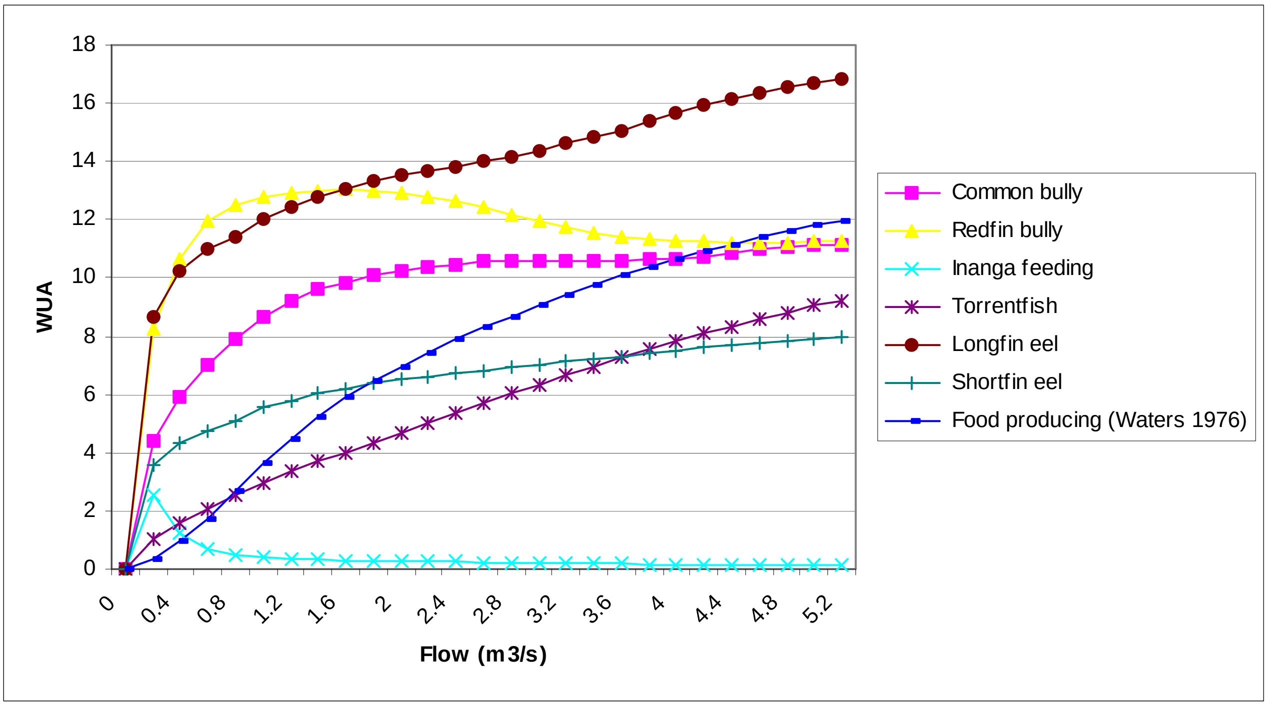

Figure 1 Weighted usable area (WUA) curves for native fish species.

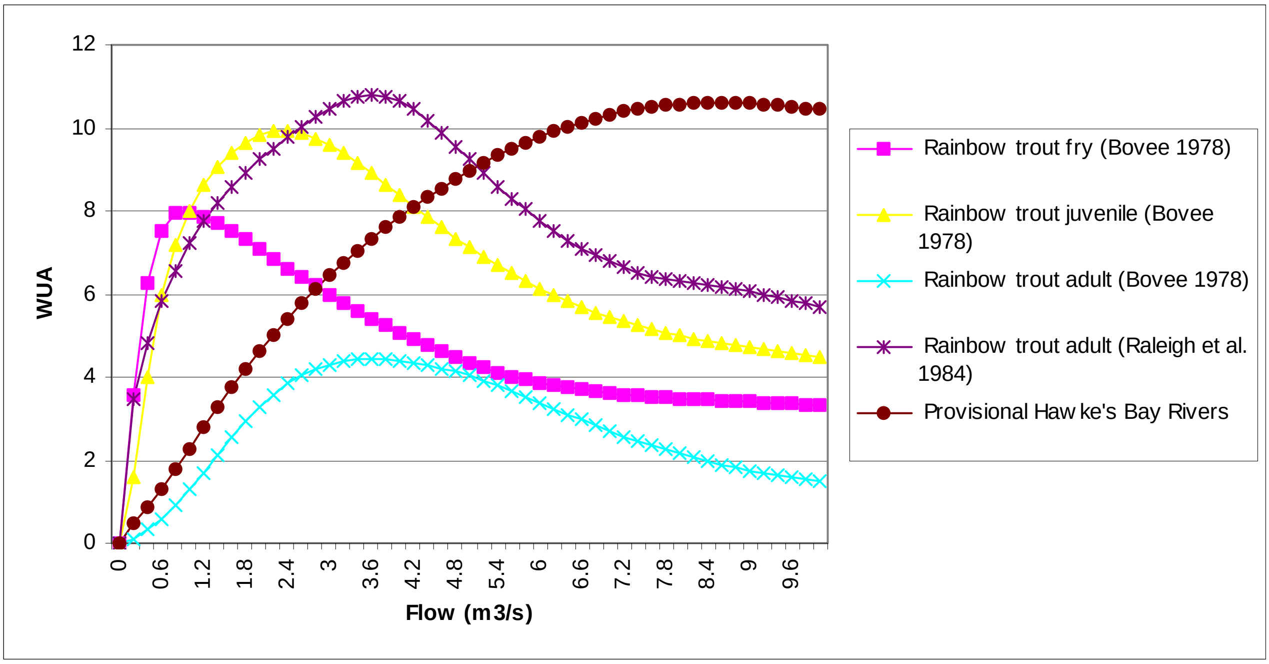

Figure 2 Weighted usable area (WUA) curves for rainbow and brown trout.

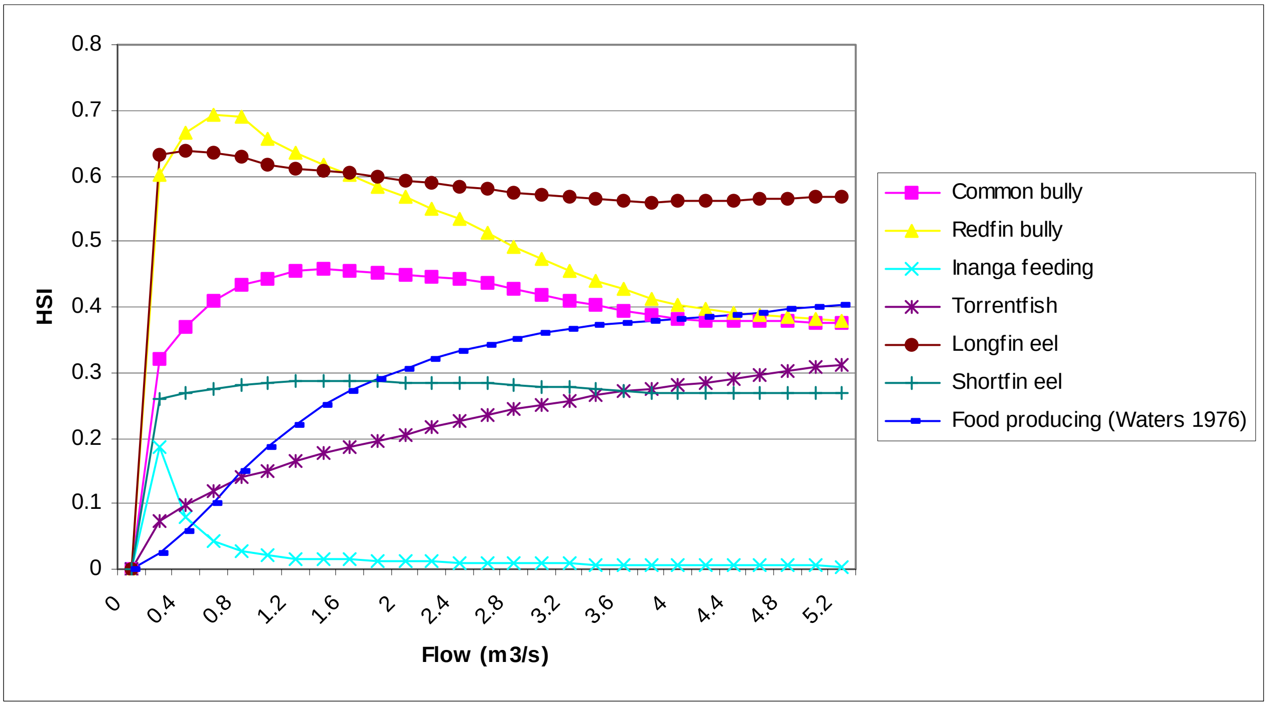

Figure 3 Habitat suitability index (HSI) for native fish species.

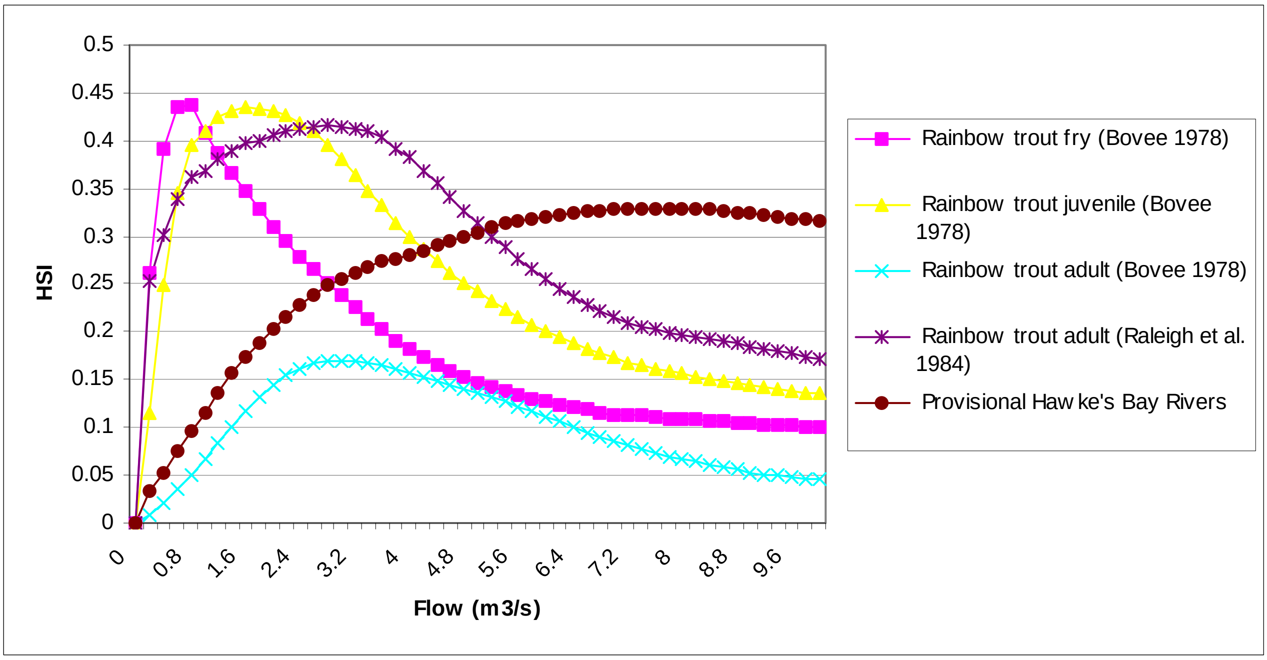

Figure 4 Habitat suitability index (HSI) for rainbow and brown trout.

5.0 DISCUSSION

5.1 Model Results

The Hawke's Bay Regional Council Sustainable Low Flow Project describes the methods used to determine appropriate minimum flows based on RHYHABSIM model outputs (Wood 2007). It states that where maximum habitat is greater than the mean annual low flow (MALF), it is acceptable to set the recommended minimum flow at 80% of the habitat available at the MALF (Figure 5). This situation often exists in Hawke's Bay, where annual summer low flows cannot provide optimum conditions; therefore setting minimum flows at the habitat optimum is unrealistic. The approach described in the Sustainable Low Flow Project recognises this and uses both habitat data and historical flow data to arrive at minimum flow recommendations that are realistic, conservative, and attainable.

It is important to consider natural flow conditions without the influence of abstraction when setting minimum flows. Naturalized flow data have been compiled for the Fernhill Bridge site (Lew 1997). The naturalized MALF for Fernhill Bridge is approximately 3400 l/s (Appendix B), thus optimum habitat values for rainbow trout fall above this flow for all modeled adult trout curves.

Using the SLFP methodology, the resulting minimum flows based on modeling results for rainbow trout are presented in Table 1.

HSI graphs indicate that the optimum quality of fish habitat occurs at lower flows than optimum habitat quantity (WUA). It is recommended by the Cawthron Institute that WUA be the primary consideration when addressing minimum flows. WUA combines habitat quality with area (quantity), and is considered to be more conservative. From a fisheries management perspective, a greater supply of suitable habitat is more important for fish productivity than a small supply of high quality habitat (Joe Hay, personal communication), thus WUA was used to arrive at a minimum flow figure.

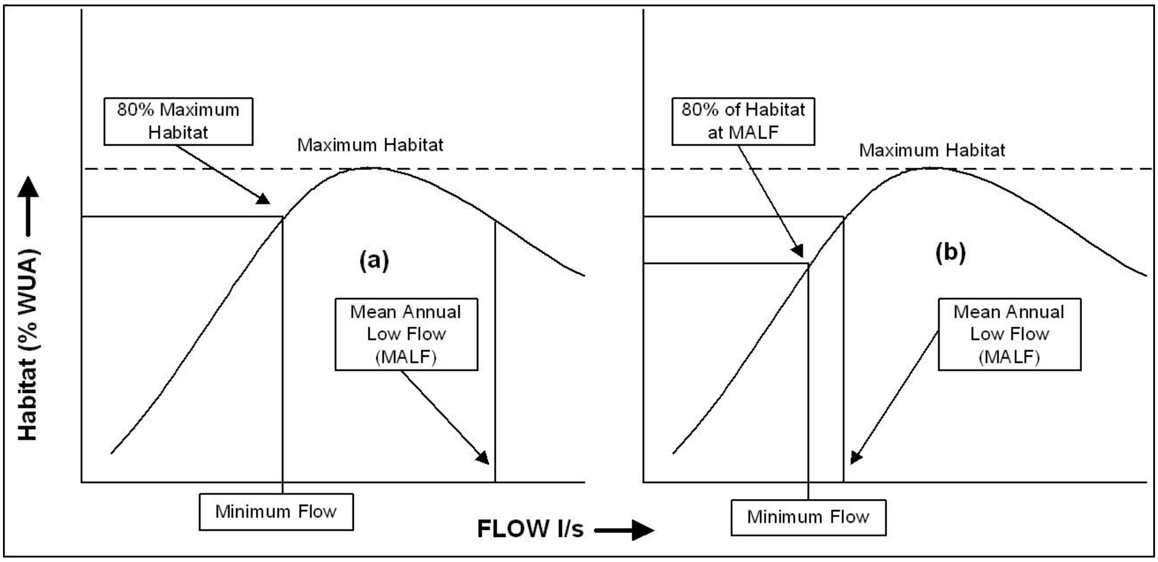

Figure 5 Decision schematic for determining minimum flow recommendations based on RHYHABSIM model results and flow statistics.

Table 1 Recommended minimum flows based on various rainbow trout models, using methodologies outlined in the HBRC Sustainable Low-Flow Project. MALF is calculated using a naturalized flow series for Fernhill Bridge (Lew 1997).

Trout HSC	WUA (m2/m) @ MALF	WUA (m2/m) – 20%	Corresponding Minimum Flow l/s (approximate)
Raleigh et al. 1984	10.8	8.64	1700
Bovee 1978	4.43	3.54	2200
Provisional Hawke's Bay 2008	7.34	5.87	2600

5.2 Methodologies

The HBRC Sustainable Low Flow Project methodology was used to calculate a minimum flow for the Ngaruroro River based on rainbow trout habitat criteria. This methodology describes setting the minimum flow at flow that provides 80% of the habitat available at the mean annual low flow (MALF). The justification behind the 80% habitat at the MALF figure is poorly documented, although variations of this method are prevalent in New Zealand. The HBRC Sustainable Low Flow Project describes this approach to be advantageous because it links available habitat to the hydrologic regime. The SLFP also states that the 80% level is within the natural variation that occurs in Hawke's Bay and is thus conservative.

The use of this method in other Regions is also usually expressed as a change in the percent habitat retention from an optimum value or habitat at the MALF. The percent habitat retention commonly varies from 90% to 70%. It is apparent that these figures arise primarily from discussions with stakeholders, but are also based on trends in low-flow hydrology and IFIM results. Horizons Regional Council uses 90% habitat at the MALF as the minimum flow value in the event that the optimum habitat value is at flows greater than the MALF (Hurndell et al. 2007). This is derived from an analysis of IFIM results that indicate that the majority of habitat optimums determined by RHYHABSIM modeling are at or near a flow of 90% of the MALF.

The proposed National Environmental Standard (NES) on Ecological Flows and Water Levels describes a chart-based methodology for determining the proper methods to use to determine minimum flows. This methodology relates the significance of instream values and risk of deleterious effect to the flow regime to the level of information provided by a particular technical method. In cases where instream values are high and the risk of deleterious effect is also high, more robust technical methods for determining a minimum flow are recommended. It is also recommended that for such cases, at least two technical methods be used, chosen based on the nature of the system being studied.

It is important to note that, to date, the results and recommendations from the 2001 survey have not been able to be duplicated. It is unclear how the initial minimum flow recommendation of 2000 l/s was derived, but it is likely that this figure is not derived solely from modeling results.

Stakeholder inputs regarding critical instream values have not been adequately documented, and their gravity cannot be assessed relative to a purely scientific minimum flow recommendation. This is recognized as a key component of determining minimum flows and allocation limits.

6.0 CONCLUSIONS

6.1 Model Results

The 2008 RHYHABSIM model results show that the rainbow trout in Hawke's Bay are more flow dependant than North American trout. Using the 2001 IFIM survey data, the recommended minimum flow is 2600 l/s, as opposed to the 2000 l/s minimum flow recommended in 1997. It is important to note that the current Hawke's Bay rainbow trout habitat suitability criteria have not undergone a peer review process. This is an important qualification to ensure management decisions based on these habitat data are robust and defensible.

6.2 Flow Records

Setting robust, scientifically defensible minimum flows based on IFIM methodology requires a sound survey design and robust flow records. Critical to the application of the SLFP methodology is the mean annual low flow (MALF). This statistic, calculated as 3400 l/s, is based on a naturalized flow record from 1970 to 1995. Recent hydrologic events such as droughts are likely to influence this statistic. The current naturalized flow record also assumes a constant 45% utilization of consented abstraction volume. It can be deduced that this flow record does not accurately take into account surface water abstraction. Water meter data from 1998-2008 have now been made available. These data can be used to construct a more robust naturalized flow record, thus leading to a more reliable and defensible minimum flow recommendation.

6.3 Instream Values

In addition to scientific evidence, the Resource Management Act requires the consideration of social, cultural and economic values. This is done through a Section 5 analysis and is an essential factor when recommending a minimum flow and allocation limit. The RMA requires that ecological "bottom lines" are maintained, but recognizes that optimal protection of instream values cannot be achieved when social and economic considerations are accounted for. It is the goal of river management to achieve balance between all instream values, while maintaining ecosystem health.

7.0 RECOMMENDATIONS

1. Review and update the naturalized flow record for the Ngaruroro River at the minimum flow site.

2. Submit the provisional Hawke's Bay rainbow trout habitat suitability criteria for peer review.

3. Review fish populations and energetics models for the Ngaruroro River to determine if changes have occurred under previous management schemes.

4. Review stakeholder input and management objectives.

5. Consider revising the Ngaruroro River minimum flow based on results from RHYHABSIM modeling and the recommendations above.

8.0 REFERENCES

Hurndell et al. 2007. Regional Water Allocation Framework: Technical Report to Support Policy Development. Volume 1. Horizons Regional Council 2007/EXT/809.

Lew, et al. 1997. Flow Naturalisation for Six Hawke’s Bay Rivers. Opus International Consultants Limited Client Report. Project No. 596801.AO. Issue 2.

Rutherford 2001. Ngaruroro River water temperatures: modeling the effects of low flow. NIWA Client Report: HBR01203.

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APPENDIX A. RHYHABSIM MODEL RESULTS

Reach Geometry Evaluation: NGA2
Proportion of reach : 100.00 %

Flow (m3/s)	Width (m)	Depth (m)	Velocity (m/s)	Area (m{\super 2})	Wetted Perimeter (m)	Froude no.	Pool %	Run %	Riffle %
0	0	0	0	0	0	0	100	0	0
0.2	13.686	0.126	0.149	1.897	13.724	0.182	71.823	13.26	14.917
0.4	16.022	0.15	0.189	2.538	16.069	0.182	71.179	10.78	18.041
0.6	17.229	0.168	0.223	3.018	17.282	0.195	68.878	14.195	16.927
0.8	18.141	0.183	0.251	3.416	18.199	0.209	63.856	17.291	18.854
1	19.528	0.192	0.272	3.765	19.589	0.217	58.359	22.449	19.191
1.2	20.307	0.203	0.292	4.082	20.372	0.222	53.835	27.492	18.673
1.4	20.997	0.212	0.31	4.373	21.066	0.23	49.534	33.96	16.506
1.6	21.61	0.22	0.327	4.644	21.681	0.237	45.358	36.821	17.821
1.8	22.294	0.227	0.342	4.899	22.367	0.243	41.142	41.062	17.795
2	22.788	0.234	0.358	5.14	22.863	0.246	38.339	44.031	17.631
2.2	23.228	0.241	0.373	5.37	23.306	0.252	34.256	47.715	18.029
2.4	23.674	0.248	0.388	5.589	23.753	0.259	31.445	50.353	18.202
2.6	24.153	0.253	0.402	5.799	24.234	0.267	27.773	53.773	18.454
2.8	24.693	0.258	0.414	6.002	24.776	0.267	26.151	55.681	18.168
3	25.258	0.262	0.424	6.199	25.343	0.268	26.251	54.711	19.039
3.2	25.787	0.266	0.434	6.39	25.874	0.277	23.058	56.978	19.964
3.4	26.293	0.269	0.443	6.577	26.382	0.281	22.163	57.835	20.002
3.6	26.792	0.271	0.451	6.759	26.882	0.282	21.35	59.088	19.562
3.8	27.512	0.273	0.458	6.938	27.603	0.291	19.635	60.183	20.182
4	27.932	0.276	0.468	7.115	28.025	0.292	18.91	61.68	19.41
4.2	28.36	0.279	0.477	7.288	28.454	0.299	17.491	62.668	19.841
4.4	28.684	0.282	0.485	7.458	28.78	0.305	16.405	63.093	20.502
4.6	29.001	0.285	0.494	7.625	29.098	0.306	15.29	64.459	20.251
4.8	29.219	0.289	0.505	7.789	29.317	0.308	15.805	62.062	22.133
5	29.423	0.293	0.514	7.949	29.522	0.311	15.977	62.079	21.944
5.2	29.619	0.297	0.524	8.107	29.719	0.314	14.549	63.185	22.267
5.4	29.812	0.301	0.534	8.261	29.913	0.317	14.595	61.379	24.026
5.6	30.054	0.303	0.542	8.413	30.156	0.323	13.622	61.844	24.534
5.8	30.262	0.306	0.55	8.562	30.365	0.323	12.789	62.15	25.061
6	30.523	0.307	0.556	8.709	30.627	0.326	12.31	61.849	25.841
6.2	30.741	0.31	0.564	8.854	30.847	0.327	12.45	60.746	26.804
6.4	30.934	0.312	0.572	8.997	31.041	0.336	11.782	60.284	27.935
6.6	31.111	0.315	0.58	9.138	31.219	0.333	11.784	60.421	27.795
6.8	31.298	0.318	0.587	9.277	31.406	0.334	12.099	59.567	28.334
7	31.483	0.321	0.594	9.414	31.592	0.336	12.929	57.789	29.282
7.2	31.656	0.323	0.601	9.55	31.767	0.337	13.425	55.884	30.691
7.4	31.791	0.326	0.609	9.683	31.902	0.34	12.62	56.833	30.546
7.6	31.911	0.329	0.618	9.815	32.023	0.346	12.425	54.951	32.623
7.8	32.025	0.333	0.626	9.945	32.138	0.346	12.097	54.886	33.017
8	32.137	0.336	0.634	10.074	32.251	0.35	12.147	53.504	34.35
8.2	32.242	0.339	0.641	10.201	32.357	0.351	12.294	50.904	36.802
8.4	32.352	0.342	0.649	10.326	32.468	0.353	11.816	50.665	37.519
8.6	32.464	0.344	0.656	10.449	32.58	0.356	11.903	49.823	38.275
8.8	32.579	0.347	0.663	10.572	32.697	0.357	12.147	49.548	38.306
9	32.693	0.349	0.669	10.692	32.812	0.358	11.801	49.365	38.835
9.2	32.806	0.352	0.676	10.812	32.925	0.36	12.88	47.555	39.565
9.4	32.914	0.355	0.683	10.93	33.034	0.363	12.765	46.459	40.775
9.6	33.011	0.357	0.69	11.047	33.132	0.364	12.863	45.171	41.966
9.8	33.107	0.36	0.696	11.163	33.229	0.365	13.059	43.262	43.68
10	33.202	0.363	0.703	11.278	33.324	0.367	13.25	42.572	44.178

Reach Instream Habitat - WUA (m2/m)
Proportion of reach : 100.00 %
1:- Longfin eel (<300 mm)
2:- Shortfin eel (<300mm)
3:- Common bully
4:- Redfin bully
5:- Torrentfish
6:- Inanga feeding (Jowett 2002)
7:- Food producing (Waters 1976)
8:- Brown trout adult (Bovee 1978)
9:- Rainbow trout fry (Bovee 1978)
10:- Rainbow trout juvenile (Bovee 1978)
11:- Rainbow trout adult (Bovee 1978)
12:- Rainbow trout adult (Raleigh et al. 1984)
13:- Provisional Hawke's Bay Rivers (Rainbow Trout)

Flow (m3/s)	Longfin eel	Shortfin eel	Common bully	Redfin bully	Torrentfish	Inanga feeding	Food producing	Brown trout	Rainbow trout	Rainbow trout	Rainbow trout	Rainbow trout	Provisional Hawke's
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.2	8.643	3.547	4.402	8.254	1	2.553	0.324	1.138	3.577	1.573	0.111	3.468	0.458
0.4	10.244	4.295	5.929	10.658	1.566	1.264	0.947	1.637	6.267	4.007	0.326	4.837	0.852
0.6	10.963	4.73	7.031	11.934	2.067	0.717	1.733	2.066	7.495	5.963	0.599	5.817	1.284
0.8	11.435	5.09	7.896	12.53	2.527	0.487	2.705	2.488	7.943	7.183	0.927	6.568	1.762
1	12.038	5.55	8.674	12.79	2.951	0.386	3.631	2.917	7.963	8.014	1.3	7.206	2.264
1.2	12.433	5.805	9.231	12.887	3.336	0.331	4.479	3.275	7.872	8.618	1.705	7.736	2.774
1.4	12.787	6.018	9.608	12.979	3.687	0.31	5.233	3.549	7.708	9.08	2.127	8.189	3.267
1.6	13.048	6.186	9.829	13.021	4.016	0.298	5.883	3.759	7.518	9.414	2.544	8.579	3.739
1.8	13.315	6.37	10.069	12.989	4.352	0.287	6.457	3.906	7.302	9.661	2.938	8.922	4.188
2	13.502	6.506	10.235	12.913	4.684	0.276	6.968	3.987	7.063	9.834	3.291	9.232	4.611
2.2	13.661	6.613	10.347	12.791	5.013	0.261	7.439	4.038	6.82	9.92	3.589	9.518	5.021
2.4	13.818	6.725	10.466	12.608	5.354	0.248	7.877	4.06	6.613	9.924	3.837	9.783	5.413
2.6	13.992	6.834	10.549	12.41	5.694	0.233	8.291	4.058	6.412	9.872	4.034	10.028	5.784
2.8	14.187	6.937	10.566	12.185	6.02	0.22	8.682	4.032	6.206	9.756	4.19	10.262	6.128
3	14.388	7.035	10.554	11.95	6.337	0.207	9.063	3.983	5.999	9.588	4.306	10.47	6.454
3.2	14.611	7.135	10.564	11.739	6.651	0.195	9.438	3.915	5.794	9.384	4.375	10.635	6.762
3.4	14.842	7.226	10.588	11.565	6.955	0.184	9.783	3.84	5.602	9.153	4.416	10.751	7.057
3.6	15.076	7.306	10.574	11.422	7.25	0.174	10.104	3.764	5.42	8.904	4.43	10.8	7.338
3.8	15.408	7.437	10.646	11.314	7.538	0.167	10.397	3.686	5.246	8.643	4.419	10.768	7.605
4	15.656	7.517	10.655	11.264	7.81	0.159	10.671	3.609	5.077	8.378	4.389	10.656	7.856
4.2	15.926	7.618	10.719	11.241	8.074	0.152	10.926	3.543	4.913	8.111	4.344	10.448	8.095
4.4	16.159	7.704	10.844	11.225	8.332	0.147	11.161	3.48	4.757	7.847	4.284	10.183	8.323
4.6	16.384	7.792	10.961	11.218	8.585	0.143	11.381	3.421	4.609	7.592	4.21	9.884	8.543
4.8	16.55	7.851	11.055	11.221	8.82	0.138	11.59	3.364	4.469	7.349	4.124	9.557	8.754
5	16.691	7.906	11.099	11.234	9.035	0.134	11.789	3.313	4.339	7.118	4.025	9.232	8.955
5.2	16.812	7.954	11.106	11.249	9.236	0.13	11.978	3.264	4.22	6.895	3.916	8.893	9.146
5.4	16.921	8.002	11.113	11.252	9.423	0.127	12.162	3.219	4.114	6.685	3.796	8.577	9.328
5.6	17.045	8.065	11.169	11.253	9.598	0.123	12.34	3.175	4.018	6.489	3.665	8.297	9.497
5.8	17.137	8.107	11.169	11.237	9.753	0.12	12.509	3.135	3.935	6.308	3.531	8.034	9.654
6	17.244	8.173	11.192	11.221	9.896	0.117	12.685	3.095	3.865	6.135	3.392	7.77	9.796
6.2	17.339	8.219	11.211	11.192	10.028	0.112	12.852	3.054	3.804	5.972	3.25	7.517	9.923
6.4	17.43	8.261	11.253	11.126	10.154	0.11	13.008	3.014	3.743	5.818	3.108	7.29	10.038
6.6	17.504	8.288	11.255	11.035	10.27	0.107	13.151	2.973	3.688	5.676	2.969	7.091	10.141
6.8	17.578	8.316	11.256	10.93	10.381	0.105	13.278	2.933	3.642	5.55	2.833	6.922	10.233
7	17.651	8.343	11.255	10.819	10.485	0.103	13.391	2.894	3.604	5.438	2.702	6.774	10.315
7.2	17.72	8.366	11.241	10.709	10.578	0.101	13.482	2.855	3.572	5.333	2.578	6.641	10.386
7.4	17.775	8.377	11.198	10.602	10.659	0.099	13.559	2.818	3.545	5.238	2.465	6.525	10.445
7.6	17.825	8.388	11.162	10.487	10.734	0.097	13.624	2.781	3.522	5.148	2.357	6.43	10.494
7.8	17.86	8.387	11.081	10.371	10.801	0.096	13.676	2.744	3.501	5.069	2.254	6.366	10.532
8	17.893	8.381	11.021	10.255	10.865	0.094	13.719	2.707	3.483	4.998	2.154	6.318	10.561
8.2	17.915	8.365	10.932	10.135	10.921	0.093	13.748	2.674	3.469	4.934	2.059	6.276	10.583
8.4	17.934	8.347	10.857	10.025	10.97	0.091	13.769	2.642	3.456	4.874	1.969	6.229	10.595
8.6	17.951	8.326	10.804	9.924	11.014	0.09	13.783	2.61	3.442	4.818	1.887	6.172	10.597
8.8	17.966	8.302	10.742	9.822	11.055	0.089	13.786	2.58	3.426	4.769	1.812	6.115	10.592
9	17.977	8.275	10.689	9.733	11.092	0.087	13.778	2.549	3.409	4.722	1.747	6.052	10.579
9.2	17.987	8.246	10.638	9.65	11.128	0.086	13.76	2.518	3.392	4.677	1.688	5.983	10.561
9.4	17.998	8.217	10.598	9.574	11.163	0.085	13.732	2.488	3.373	4.632	1.634	5.913	10.539
9.6	18.001	8.182	10.535	9.501	11.195	0.084	13.696	2.459	3.356	4.588	1.586	5.843	10.511
9.8	18	8.148	10.469	9.434	11.226	0.083	13.653	2.43	3.339	4.543	1.545	5.769	10.48
10	17.998	8.115	10.398	9.371	11.254	0.082	13.605	2.403	3.321	4.5	1.51	5.693	10.443

Reach Instream Habitat - HSI
Proportion of reach : 100.00 %
1:- Longfin eel (<300 mm)
2:- Shortfin eel (<300mm)
3:- Common bully
4:- Redfin bully
5:- Torrentfish
6:- Inanga feeding (Jowett 2002)
7:- Food producing (Waters 1976)
8:- Brown trout adult (Bovee 1978)
9:- Rainbow trout fry (Bovee 1978)
10:- Rainbow trout juvenile (Bovee 1978)
11:- Rainbow trout adult (Bovee 1978)
12:- Rainbow trout adult (Raleigh et al. 1984)
13:- Provisional Hawke's Bay Rivers (Rainbow Trout)

Flow (m3/s)	Longfin eel	Shortfin eel	Common bully	Redfin bully	Torrentfish	Inanga feeding	Food producing	Brown trout	Rainbow trout	Rainbow trout	Rainbow trout	Rainbow trout	Provisional Hawke's
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.2	0.631	0.259	0.322	0.603	0.073	0.187	0.024	0.083	0.261	0.115	0.008	0.253	0.033
0.4	0.639	0.268	0.37	0.665	0.098	0.079	0.059	0.102	0.391	0.25	0.02	0.302	0.053
0.6	0.636	0.275	0.408	0.693	0.12	0.042	0.101	0.12	0.435	0.346	0.035	0.338	0.075
0.8	0.63	0.281	0.435	0.691	0.139	0.027	0.149	0.137	0.438	0.396	0.051	0.362	0.097
1	0.616	0.284	0.444	0.655	0.151	0.02	0.186	0.149	0.408	0.41	0.067	0.369	0.116
1.2	0.612	0.286	0.455	0.635	0.164	0.016	0.221	0.161	0.388	0.424	0.084	0.381	0.137
1.4	0.609	0.287	0.458	0.618	0.176	0.015	0.249	0.169	0.367	0.432	0.101	0.39	0.156
1.6	0.604	0.286	0.455	0.603	0.186	0.014	0.272	0.174	0.348	0.436	0.118	0.397	0.173
1.8	0.597	0.286	0.452	0.583	0.195	0.013	0.29	0.175	0.328	0.433	0.132	0.4	0.188
2	0.593	0.285	0.449	0.567	0.206	0.012	0.306	0.175	0.31	0.432	0.144	0.405	0.202
2.2	0.588	0.285	0.445	0.551	0.216	0.011	0.32	0.174	0.294	0.427	0.154	0.41	0.216
2.4	0.584	0.284	0.442	0.533	0.226	0.01	0.333	0.172	0.279	0.419	0.162	0.413	0.229
2.6	0.579	0.283	0.437	0.514	0.236	0.01	0.343	0.168	0.265	0.409	0.167	0.415	0.239
2.8	0.575	0.281	0.428	0.493	0.244	0.009	0.352	0.163	0.251	0.395	0.17	0.416	0.248
3	0.57	0.279	0.418	0.473	0.251	0.008	0.359	0.158	0.238	0.38	0.17	0.415	0.256
3.2	0.567	0.277	0.41	0.455	0.258	0.008	0.366	0.152	0.225	0.364	0.17	0.412	0.262
3.4	0.564	0.275	0.403	0.44	0.265	0.007	0.372	0.146	0.213	0.348	0.168	0.409	0.268
3.6	0.563	0.273	0.395	0.426	0.271	0.007	0.377	0.14	0.202	0.332	0.165	0.403	0.274
3.8	0.56	0.27	0.387	0.411	0.274	0.006	0.378	0.134	0.191	0.314	0.161	0.391	0.276
4	0.561	0.269	0.381	0.403	0.28	0.006	0.382	0.129	0.182	0.3	0.157	0.382	0.281
4.2	0.562	0.269	0.378	0.396	0.285	0.005	0.385	0.125	0.173	0.286	0.153	0.368	0.285
4.4	0.563	0.269	0.378	0.391	0.29	0.005	0.389	0.121	0.166	0.274	0.149	0.355	0.29
4.6	0.565	0.269	0.378	0.387	0.296	0.005	0.392	0.118	0.159	0.262	0.145	0.341	0.295
4.8	0.566	0.269	0.378	0.384	0.302	0.005	0.397	0.115	0.153	0.252	0.141	0.327	0.3
5	0.567	0.269	0.377	0.382	0.307	0.005	0.401	0.113	0.147	0.242	0.137	0.314	0.304
5.2	0.568	0.269	0.375	0.38	0.312	0.004	0.404	0.11	0.142	0.233	0.132	0.3	0.309
5.4	0.568	0.268	0.373	0.377	0.316	0.004	0.408	0.108	0.138	0.224	0.127	0.288	0.313
5.6	0.567	0.268	0.372	0.374	0.319	0.004	0.411	0.106	0.134	0.216	0.122	0.276	0.316
5.8	0.566	0.268	0.369	0.371	0.322	0.004	0.413	0.104	0.13	0.208	0.117	0.265	0.319
6	0.565	0.268	0.367	0.368	0.324	0.004	0.416	0.101	0.127	0.201	0.111	0.255	0.321
6.2	0.564	0.267	0.365	0.364	0.326	0.004	0.418	0.099	0.124	0.194	0.106	0.245	0.323
6.4	0.563	0.267	0.364	0.36	0.328	0.004	0.421	0.097	0.121	0.188	0.1	0.236	0.324
6.6	0.563	0.266	0.362	0.355	0.33	0.003	0.423	0.096	0.119	0.182	0.095	0.228	0.326
6.8	0.562	0.266	0.36	0.349	0.332	0.003	0.424	0.094	0.116	0.177	0.091	0.221	0.327
7	0.561	0.265	0.357	0.344	0.333	0.003	0.425	0.092	0.114	0.173	0.086	0.215	0.328
7.2	0.56	0.264	0.355	0.338	0.334	0.003	0.426	0.09	0.113	0.168	0.081	0.21	0.328
7.4	0.559	0.264	0.352	0.333	0.335	0.003	0.427	0.089	0.112	0.165	0.078	0.205	0.329
7.6	0.559	0.263	0.35	0.329	0.336	0.003	0.427	0.087	0.11	0.161	0.074	0.202	0.329
7.8	0.558	0.262	0.346	0.324	0.337	0.003	0.427	0.086	0.109	0.158	0.07	0.199	0.329
8	0.557	0.261	0.343	0.319	0.338	0.003	0.427	0.084	0.108	0.156	0.067	0.197	0.329
8.2	0.556	0.259	0.339	0.314	0.339	0.003	0.426	0.083	0.108	0.153	0.064	0.195	0.328
8.4	0.554	0.258	0.336	0.31	0.339	0.003	0.426	0.082	0.107	0.151	0.061	0.193	0.328
8.6	0.553	0.256	0.333	0.306	0.339	0.003	0.425	0.08	0.106	0.148	0.058	0.19	0.326
8.8	0.551	0.255	0.33	0.301	0.339	0.003	0.423	0.079	0.105	0.146	0.056	0.188	0.325
9	0.55	0.253	0.327	0.298	0.339	0.003	0.421	0.078	0.104	0.144	0.053	0.185	0.324
9.2	0.548	0.251	0.324	0.294	0.339	0.003	0.419	0.077	0.103	0.143	0.051	0.182	0.322
9.4	0.547	0.25	0.322	0.291	0.339	0.003	0.417	0.076	0.102	0.141	0.05	0.18	0.32
9.6	0.545	0.248	0.319	0.288	0.339	0.003	0.415	0.074	0.102	0.139	0.048	0.177	0.318
9.8	0.544	0.246	0.316	0.285	0.339	0.002	0.412	0.073	0.101	0.137	0.047	0.174	0.317
10	0.542	0.244	0.313	0.282	0.339	0.002	0.41	0.072	0.1	0.136	0.045	0.171	0.315

Appendix B

~~~ Hilltop Hydro ~~~ Version 5.66
11-Jun-2008
~~~ P3 ~~~

Source is \\KP\data\Hilltop\archive\allsites.hts
Naturalised Flow (l/s) at Ngaruroro River at Fernhill
Annual stats from 01-Jan-1970 00:00:00 to 1-Jul-1996 00:00:00

Year	Minimum	Mean	Maximum
1970	4996	34015.6	224348
1971	5951	50839.4	381494
1972	2738	27653.5	322996
1973	1214	25612.7	497331
1974	3979	53580.8	743046
1975	1641	42829.3	298718
1976	7944	67260.3	1808673
1977	2426	58988	712791
1978	1616	35315.5	450754
1979	1181	48534.4	495121
1980	5059	52316.5	1112793
1981	9593	63344.5	666220
1982	3801	24299.6	210350
1983	246	29719.1	181052
1984	3754	25170.2	231009
1985	1691	56766.9	955654
1986	4007	32059	247562
1987	4017	43063.8	1101090
1988	2085	70788.9	3778900
1989	2425	72361.5	1108970
1990	2577	37701	472307
1991	1968	40867.7	921495
1992	4165	59152	1149071
1993	4554	24437.8	216918
1994	1474	36425.1	714105
1995	2457	34240.9	539355
Average	3367.654		

Ngaruroro River Investigations

IFIM Study April 2001

Introduction

This report documents the continuing work of the Hawke's Bay Regional Council to develop a scientific understanding of the Ngaruroro river. It builds upon earlier investigations reported in the HBRC report "Sustainable Low Flow Project – Ngaruroro River" (HBRC 1997) and seeks to further develop the scientific background for the sustainable management of the river and its ecosystem.

Background

The Ngaruroro river was the subject of an IFIM study in March 1997 as part of the Hawke's Bay Regional Council Sustainable Low Flow Project assessment of the Minimum Flow on that river. That survey was focussed on the reach from which most of the abstraction occurs, from upstream of the Maraekakaho confluence to the Minimum Flow site reach at Fernhill Bridge. A total of 21 cross-sections were used to model the habitat provided by the river within the abstractive reach. The subsequent report (HBRC 1997) showed that flows upstream of the recharge zone at Roy's Hill were always able to provide adequate levels of habitat even in low flow situations at the Fernhill Bridge. Because of the very large and near constant losses (approximately 4 200 l/s) to groundwater in the vicinity of the Roy's Hill it became evident that it was in the Fernhill Bridge reach alone that low flows become critical in terms of habitat for stream species. Based largely on this survey, the 1997 report recommended the Minimum Flow at the Fernhill Bridge site could be reduced from the existing 2800 l/s to 2000 l/s. This proposal was incorporated in the proposed regional Water Plan Variation #2 which was notified in November 1999.

Further work for the proposed regional Water Plan Variation #2 indicated that there were some losses of flow downstream of the Fernhill Bridge reach. It was recognised that the three cross-sections surveyed in this critical reach caused concern that the estimates were insufficient to sustain the aquatic ecosystem at times of low flow. Although the reach between Fernhill Bridge and the Tutaekuri-Waimate confluence is small in relation to the overall length of the river, it is of major importance to the local communities for which it is both a cultural and recreational resource. As a consequence a further study has been carried out and more information gathered within the critical reach from Fernhill Bridge to the Tutaekuri-Waimate confluence. Data gathered has consisted of three specific areas

- an IFIM survey between the two sites in April 2001
- a series of stream gaugings at established cross-sections in order to monitor the pattern of losses and gains within the reach
- a series of temperature records both along the reach and in the bed at a number of sites. This provides information on the degree of heating that occurs within the reach, and on the likely interchange between the surface and subsurface flows within the gravel substrate. This last study is the subject of a separate report by NIWA.

This report describes the IFIM survey and subsequent modelling of habitat within the reach.

Lower Ngaruroro Gauging Surveys

The lower Ngaruroro is gauged frequently for a variety of reasons. These include

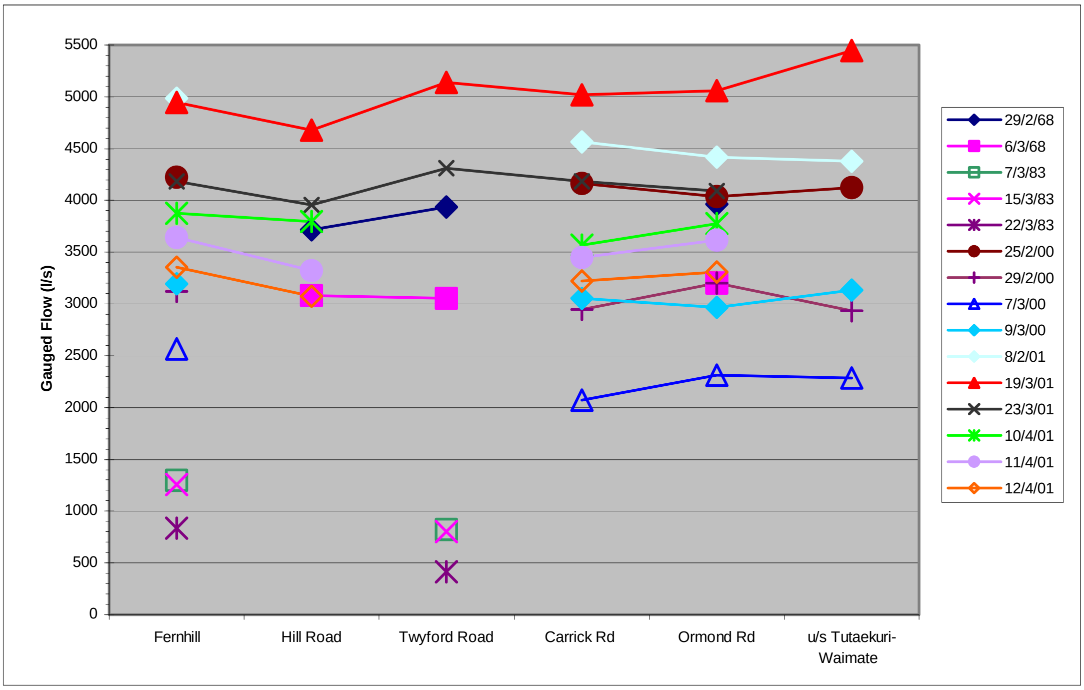
- maintenance of rating curves at flow recorder sites
- flood gaugings
- gaugings made concurrent with State of Environment water quality sampling
- compliance low flow gaugings
- resource investigations

Following concerns raised about the effects of low flows in the lower Ngaruroro reach a series of concurrent gauging runs have been carried out over the low flow period 2000-2001. These together with the historical data from numerous past gaugings are assessed below.

Data has been collated from six sites within the lower Ngaruroro. It is important to understand that the "site" is in fact a reach. That is the movement of the river over time means that the optimum measurement site will shift slightly. In the lower Ngaruroro, under the current river management regime a reach will consist of a series of runs and riffles within a single channel at low flows. At higher flows (>5000 l/s) the channel becomes considerably more braided so that a number of riffles and runs may exist within a single cross-section. Rivers and streams are normally gauged within a 'run' flow type. Within a run streamlines are generally at right angles to the cross-section and flow is fairly steady past the current meter. In this situation gauging accuracies of ± 8% are achievable. The reachesuse in this analysis are

- Fernhill Bridge
- Hill Road
- Twyford Road
- Carrick Road
- Ormond Road
- upstream of the Tutaekuri-Waimate confluence

Figure xx shows the pattern of gaugings at the six gauging reaches at or about the Mean Annual Low Flow of 5000 l/s. While all the gaugings shown in figure 1 include a measured flow at Fernhill, not all other sites have been gauged concurrently. This is particularly so with the historical data. While it has been possible to fill the gaps over the higher end of the low flow range, it has not been possible to gauge



the loss pattern at extreme low flows because these have not been experienced for some time.

The overall pattern is for a decrease of flow to be recorded below Fernhill Bridge at Hill Road.

Fernhill	Hill Road	Twyford Road	Carrick Rd	Ormond Rd	u/s Tutaekuri-Waimate
8556	-860	-989	-883	-498	-1460
4987			-422	-567	-612
4948	-272	190	69	109	496
4224			-62	-185	-101
4185	-227	128	1	-93	
3879	-84		-312	-103	
3642	-321		-191	-25	
3352	-281		-134	-42	
3195			-138	-226	-58
3122			-172	77	-186
2566			-495	-252	-280
1295		-470.2			
1254		-449.7			
833		-418			
Mean Loss	-237	-204	-185	-130	-123

Lower Ngaruroro IFIM Survey April 2001

The Instream Flow Incremental Methodology (IFIM)

Lower Ngaruroro Field Survey

The survey was carried out at representative cross-sections within the Lower Ngaruroro from the Fernhill Bridge to upstream of the Tutaekuri-Waimate confluence. A total of 18 cross-sections were identified from aerial photographic mosaics and from field survey. These were identified in four different reaches at Fernhill Bridge; Hill Road; Carrick Road and Motorway Bridge (Ormond Road). Each of these reaches consisted of beaches around which the single channel of the Ngaruroro flowed in a wide meander. Evidence of braiding was obvious at higher flows but both at the survey flow and at flows below the survey flow the river was in a single channel.

Because of their importance in providing habitat at low flows, special effort was made to identify pool habitat. Only two were identified in the survey reach. This may have been because of failure to identify them correctly from the aerial photo mosaics but the photos were checked against the experiences of the hydrological teams who had been surveying the lower Ngaruroro throughout the low flow period. The amount of pool habitat was reviewed on completion of the longitudinal survey that identifies the proportions of the survey reach in each flow type. It was evident that even if the field survey had overlooked pool habitat that pools would have made up only a small proportion of the survey reach. That is, the lower Ngaruroro was dominated by run and riffle flow types.

Field survey of the 18 identified cross-sections was carried out on April 9 2001 with subsequent resurvey of the change in stage at each of the cross-sections on each of the succeeding four days. During the survey period, immediately before Easter, the river had receded gradually to a level less than the Mean Annual Low Flow of the lower Ngaruroro of 5000 l/s. Although it had been affected by a number of freshes in the preceding period all forecasts indicated a further week of recession. The initial survey was therefore followed by a daily resurvey as the river dropped away before the next fresh occurred.

On the initial survey the discharge at each cross-section was measured, the cross-section profile defined, and substrate and downstream control depth recorded. At each visit thereafter the discharge within the reach was recorded at a single run. This provided the most accurate estimation of the flow within that reach. At the time of initial survey the proportion of flow types within the survey reaches was assessed by measuring the length of all flow types within the reaches. This was used to calculate the proportion of each flow type that the measured cross-sections represent, and to calculate the weighting to be given by the model to each cross-section in order to represent the habitat within the lower Ngaruroro.

Modelling of the lower Ngaruroro.

The recorded data were entered into a spreadsheet. For each cross-section, meter constants used to calculate flow from recorded current meter revolutions were recorded, along with the percentage of each flow type the cross-section represented. Also recorded were the change in stage and flow at subsequent gaugings in the reach, the depth of downstream control (stage of zero flow) and for each vertical within the cross-section, data of depth, current meter revolutions and percentage of each substrate class. Once initial data checks were complete the data for all 18 cross-sections were loaded into the Rhyhabsim (Jowett 1996) modelling program.

The Rhyhabsim program carries out further checks on data entry to identify any missing data or gross errors. The next step is to calculate cross-section flows from the depth and velocity measurements (revolutions of the flow meter). These are calculated for each cross-section and averaged over the reach. These cross-section flows are used in an iterative process to define an accurate section stage-discharge relationship for each cross-section. It was found that there were noticeable differences at each individual reach within the survey reach. Initial (calibration) gaugings were selected so as to define the best possible stage-discharge relationship. This is determined by the R^2 of the log-log regression relationship between stage and measured flow.

Once the cross-section discharge relationships are defined the reach is ready to be modelled. The species of relevance to the lower Ngaruroro were chosen and their suitability curves selected. Suitability Curves for eight species of fish were used in the modelling, together with a single curve representing the macroinvertebrate species that inhabit the river. Fish species included

- Common Bully and Redfin Bully
- Inanga
- Longfin and Shortfin eel
- Torrentfish
- Rainbow Trout – adult, fry and juvenile
- Brown Trout – adult

The reach was modelled under a number of different scenarios. The most detailed scenario made use of the gauging information gained from intensive gaugings along the lower reaches over the past twelve months, together with historical gaugings. A mean flow loss figure was derived from these gaugings for each of the three reaches downstream of the Fernhill Bridge reach. These showed a mean decrease (loss) of flow at Hill Road of 250 l/s. Below this reach mean flow loss relative to Fernhill Bridge decreased. That is flow increased relative to the Hill Road reach. The four reaches were therefore modelled as shown in table 1. Four scenarios are discussed in the results below. these are the model of the whole lower Ngaruroro reach, taking account of the loss and gains in flow below the Fernhill Bridge, and the modelled provision of habitat at each of the individual reaches shown in Table 1. The modelled flow range was chosen as covering the flow range of interest for low flows with the Fernhill Bridge maximum set close to the Mean Annual Low Flow for that site. The increment of 400 l/s was chosen to define accurately the shape of the habitat–flow curve, and to provide habitat estimates at the Minimum Flows of 2400 and 2800 l/s .

Table 1. Pattern of losses downstream from Fernhill Bridge modelled by Rhyhabsim. All flows in litres/second.

	Loss	Minimum	Maximum	Increment
Fernhill Bridge	0	400	5200	400
Hill Road	-250	150	4950	400
Carrick Road	-200	200	5000	400
Motorway Br.	-125	275	5075	400

Results

Figure 1 shows the habitat estimates for the whole of the lower Ngaruroro between Fernhill Bridge and upstream of the Tutaekuri-Waimate confluence. These are shown in terms of both the area of the river that provides habitat (WUA m^2/m) and as the proportion of the river reach which provides habitat (WUA %). Both are useful in identifying the effects of decreasing flow levels on aquatic species. WUA in terms of area identifies the flow which maximises habitat, WUA in terms of percentage (figure 1a) is more useful for comparisons between rivers and for identifying "the most efficient flow" – that is where the highest proportion of the stream is "usable".

The results for the lower Ngaruroro show a consistent pattern with other IFIM surveys that have been carried out on gravel bed rivers in the region. Habitat response to flow is of two basic types. For many species habitat is more or less constant over a range of flows before decreasing sharply below a certain critical flow. This is the case with many native species for whom habitat in the lower Ngaruroro reaches a maximum between 1200 and 2000 l/s at Fernhill Bridge. For many native species, represented in these results by the inanga, habitat shows a steady decrease with increasing flow. This is considered to be the case for those species who prefer slower moving water and who are more responsive to increasing velocities than the greater depths associated with higher flows. Other species, mainly native fish species but also the Rainbow trout juvenile and fry stages, reach a more or less steady degree of habitat suitability. These species are thought to benefit from the greater depths provided by the river at higher flows but who are less sensitive with the higher velocities occurring at the same time. The Common and redfin bullies show this sort of response, as well as the rainbow trout life stages. A third type of response to decreasing flow is shown by eels, who are insensitive to changes in flow conditions and adult game fish species who prefer the benefits of both deeper and faster water. Also in this third group are the native torrentfish who live in the faster riffles and the macroinvetebrates, represented in this modelling exercise by the (trout) food producing suitability curves of Waters (1976). This last represents a number of macroinvertebrate suitability curves that have been produced for New Zealand stream insects. Invertebrate response, while reflecting the preferences of trout have a different basis. It is thought that by being dependent for habitat on a wetted surface they benefit from the increase in depth, and hence area. At the same time they are relatively insensitive to flow because velocities are noticeably less at the bed and they are not subject to the stress of increased velocity in the same way as small fish are.

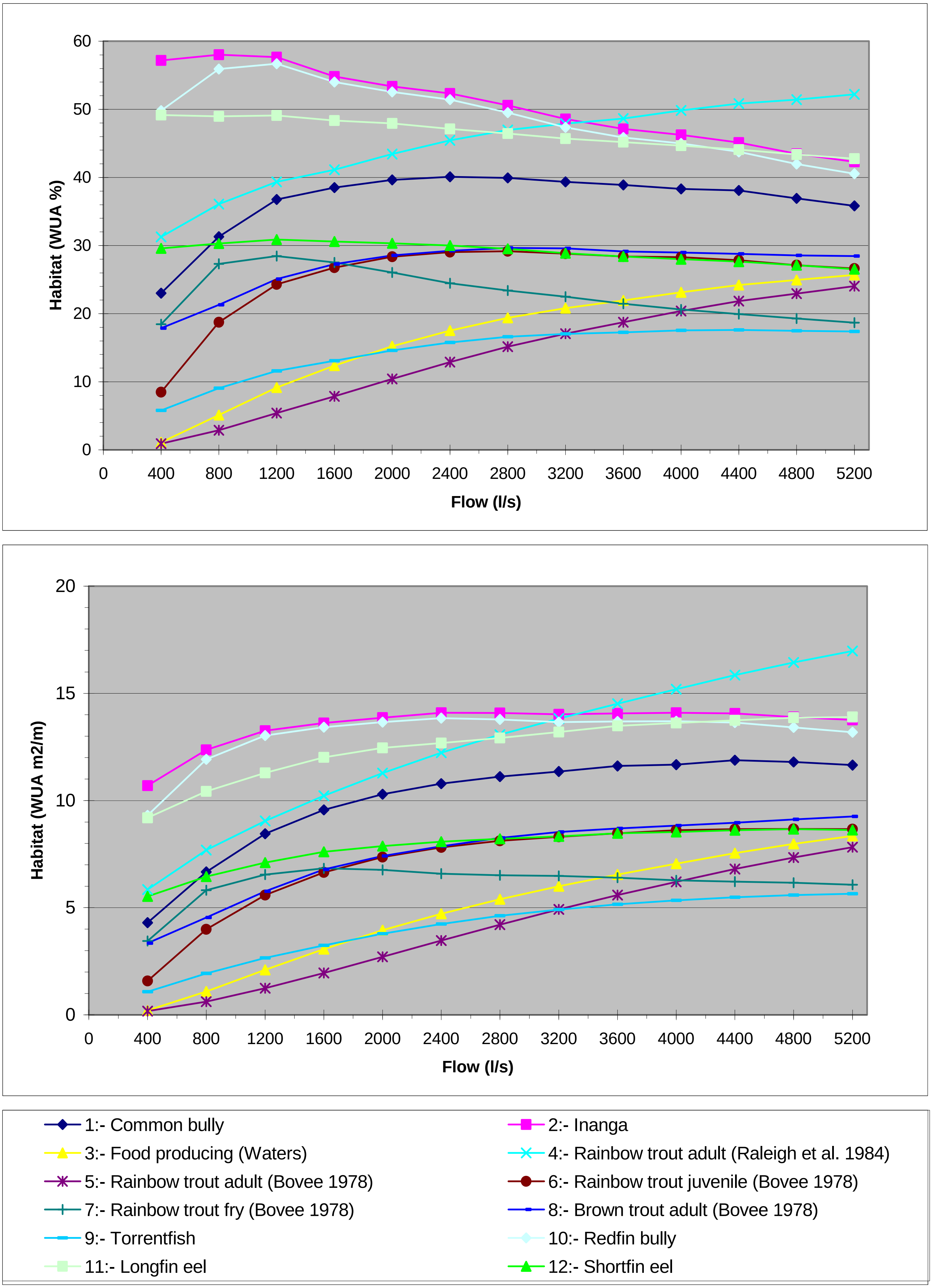


Figure 1. Habitat estimates at all lower Ngaruroro reaches.