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**IMPACTS OF FLOWS MODIFIED BY HYDRO-
ELECTRICITY GENERATION ON ANGLING AND
TROUT PRODUCTIVITY IN THE
HINEMAIAIA RIVER**

by

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NEW ZEALAND FRESHWATER FISHERIES MISCELLANEOUS REPORTS

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CONTENTS

	Page
Executive summary	1
Recommendations	2
Introduction	3
Physical characteristics	4
Hydrology	6
CHAPTER 1 - Timing of peak spawning, fry emergence, and growth	7
Introduction	7
Study sites	7
Methods	7
Counts of trout > 10 cm FL	7
Fry emergence	8
Estimates of juvenile growth and density	8
Results	9
Time of peak density of adult rainbow trout	9
Time of peak emergence	9
Growth of juvenile rainbow trout	9
Size of trout in different sections	13
Densities of juvenile rainbow trout	13
Common bullies, koaro, periphyton, and water temperature	15
Discussion	16
Time of spawning and emergence	16
Relationship of spawner densities to hatchery traps	20
Effect of the HB dam on the number of spawners	23
CHAPTER 2. Effects of hydro-electric flow regime on trout spawning and rearing	25
Introduction	25

	Page
Methods	25
Trout habitat analysis	25
Ability of juvenile trout to respond to water level changes	28
Results	29
Depths and velocities occupied by juvenile trout	29
Change of habitat with growth	29
Habitat modelling	29
Ability of juvenile trout to respond to water level changes	33
Discussion	42
Change of spawning and rearing habitat and food production with flow increases	42
Change of preferred habitat with increasing size of juvenile trout	43
Ability of juvenile trout to respond to water level changes	44
 CHAPTER 3. Effects of hydro-electric flow regime on trout angling	 46
Introduction	46
Methods	46
Results	46
Discussion	49
 CHAPTER 4. Recommendations for flow regime and angling season	 51
Flow regime	51
HB dam construction	52
Angling season	53
Recommendations	53
 Acknowledgments	 54
 References	 55

	Page
Appendix I Profile and channel features of the lower and middle reaches of the Hinemaiaia River	60
Appendix II Air and water temperatures, and underwater visibility, at time of dive counts in the Hinemaiaia River, 1990-1991	61
Appendix III Counts of adult rainbow trout by divers in the Hinemaiaia River, 1990-1991.	62
Appendix IV Densities of juvenile trout, common bullies and koaro at three sites in the Hinemaiaia River, 1990-1991	63
Appendix V Form soliciting anglers' recollections of their fishing experience in the Hinemaiaia River	65
Appendix VI Form soliciting information on daily fishing trips to the Hinemaiaia River	66

TABLES

1. Numbers of rainbow trout fry, common bullies, and koaro caught overnight by downstream traps set in spring and summer 1990-1991 in the Hinemaiaia River, Lake Taupo catchment. One net was set at each site at each sampling date	10
2. Growth rates of juvenile trout in the Hinemaiaia River, 1990-1991	10
3. Change of territory size with increasing size of juvenile trout at three sites in the hinemaiaia River	13
4. Number of juvenile rainbow trout < 10 cm FL counted by divers in riffles in 1.07 km of main channel above the Hinemaiaia B tailrace	16
5. Survey of methods used by trout anglers and proportions of annual trout catch in each of three locations in the Hinemaiaia River by nine anglers in 1991 and 1992.	47
6. Comparison of trout angling experience in the hinemaiaia River at low (3 m/s ³) and high flow (8 m/s ³) in the Hinemaiaia River in 1991 and 1992	48

FIGURES

1.	Location of the Hinemaiaia River in the Lake Taupo catchment, North Island, New Zealand, and sampling sites used in this study	5
2.	Density of rainbow trout observed by drift diving in the lower, middle, upper and all sections combined in the Hinemaiaia River in 1988, 1990 and 1991	11
3.	Length-frequency of juvenile rainbow trout caught by electroshocking in the Hinemaiaia River between November 1990 and November 1991.	12
4.	Length-frequency of juvenile rainbow trout caught by electroshocking at three sites in the Hinemaiaia River in December 1990 and November 1991	14
5.	Densities of juvenile trout at three sites in the Hinemaiaia River determined by electroshocking	15
6.	Water temperatures in the lower, middle and upper sections of the Hinemaiaia River in 1990 and 1991	19
7.	Total number of spawning rainbow trout passing through traps on two tributaries of Lake Taupo between May and October, 1963 to 1991	21
8.	Proportions of the Lake Taupo rainbow trout run in each month as a proportion of the total run between May and October 1963-1991.	22
9.	Rainbow trout run in May in the Waihukahuka Stream as a proportion of the total run from May to October 1963-1991	23
10.	Position of cross sections in the middle section of the Hinemaiaia River gauged on 13 March 1991	26
11.	Position of cross sections in the lower section of the Hinemaiaia River gauged on 13 March 1991.	27
12.	Plan view of the backwater in the upper section of the Hinemaiaia River used to test the response of juvenile trout to falling water levels	28
13.	Frequencies of trout fry and juveniles occupying different depths and velocities in the Hinemaiaia River compared to probability of use	30
14.	Distributions of depths and velocities in the middle and lower sections of the Hinemaiaia River at high and low generating flows	31

	Page
15. Cumulative change by area in depths and velocities at the middle and lower sections of the Hinemaiaia River with flow	32
16. Suitability of habitat at low flow and high flow in the middle reach of the Hinemaiaia River for rainbow trout fry predicted from the models of Bovee (1978)	34
17. Suitability of habitat at low flow and high flow in the lower reach of the Hinemaiaia River for rainbow trout fry predicted from the models of Bovee (1978)	35
18. Suitability of habitat at low flow and high flow in the middle reach of the Hinemaiaia River for rainbow trout juveniles predicted from the models of Bovee (1978)	36
19. Suitability of habitat at low flow and high flow in the lower reach of the Hinemaiaia River for rainbow trout juveniles predicted from the models of Bovee (1978)	37
20. Suitability of habitat at low flow and high flow in the middle reach of the Hinemaiaia River for rainbow trout spawning predicted from the models of Waters (1976)	38
21. Suitability of habitat at low flow and high flow in the lower reach of the Hinemaiaia River for rainbow trout spawning predicted from the models of Waters (1976)	39
22. Suitability of habitat at low flow and high flow in the middle reach of the Hinemaiaia River for trout food production predicted from the models of Waters (1976)	40
23. Suitability of habitat at low flow and high flow in the lower reach of the Hinemaiaia River for trout food production predicted from the models of Waters (1976)	41
24. Length-frequencies of juvenile trout in stranding experiment in Hinemaiaia River	45

EXECUTIVE SUMMARY

Spawning and rearing populations of rainbow trout in the Hinemaiaia River were studied between June 1990 and December 1991. This report summarises the investigations, and compares some of the major findings to related studies.

Adult trout begin to move into the lower section in significant numbers in mid-May, and appear to remain there from 27-70 days before moving to the middle and upper sections to spawn. In 1990, the number of adult rainbow trout in the river was highest in late July with about 500 fish/km. Peak numbers in the lower section of the river occurred at or before July 1990, at least one month earlier than peak numbers were observed in the middle and upper sections. In 1991, densities were generally lower than in 1990 with a maximum of 200 fish/km, but the timing of spawning was similar. There was no discernable difference in hydro-electric operation between 1990 and 1991.

Juvenile rainbow trout fry emerged from gravels from August to December; numbers of fry drifting downstream peaked in early October. The highest density (6 fish/m²) was measured in November in the upper section (i.e., above the Hinemaiaia B (HB) tailrace, and below the HB dam). By early February 1991 juvenile trout had moved from slow flowing, shallow margins to deeper, faster water, and their density had declined to 0.2-0.3 fish/m². Between October and December juvenile trout grew from a mean fork length (FL) of 27 mm to 49 mm FL, at rates of 0.43-0.54 mm FL/day. The largest age 0 trout in early February 1991 was 93 mm FL.

Habitat modelling at sites representative of the river between the HB tailrace and the S.H.1 bridge suggests that the amount of juvenile habitat is generally reduced at high generating flows (about 8 m³/s) compared to low flows (about 3 m³/s). Habitat suitable for fry rearing was reduced by an average of 49%. Juvenile rearing habitat was reduced by a similar amount (52%).

Spawning habitat reduced by an average of 75% as the flow increased from 3 to 8 m³/s. However, there was only a small amount of habitat suitable for spawning at the sites used for modelling (9.2% at low flow, 2.6% at high flow). Flow changes were unlikely to have affected eggs incubating in redds. Suitability-of-use data indicate that redds are typically made in water 0.37-0.68 m. As water level changes with flow were generally about 0.25 m, redds are unlikely to be dewatered by flow changes. Velocity changes were not sufficiently large to disturb the river gravels in which the redds were formed.

Changes in the area suitable for food production with increase from low to high flow were different in the two reaches surveyed. In one reach the suitable area increased by 10% whereas it reduced by 25% in the other.

Anglers found high flows generally more difficult to fish than low flows. Geometric mean catch rate was 0.85 fish/h at low flow, and 0.21 fish/h at high flow. Differences in catch rate between flows were significant ($p = 0.001$, Kruskal-Wallis one-way analysis of variance). Both wading and angling was rated by the majority of anglers as difficult at high flows, and easy at low flows. Numerous snags, which made fishing difficult, and

lack of fish were two common complaints of anglers. Removal of snags would improve the ease of angling, but would be counterproductive in the loss of cover for juvenile trout.

RECOMMENDATIONS

1. Reduce the rate and frequency of daily changes of discharge downstream of the Hinemaiaia B powerhouse to a minimum consistent with operation of hydro-electric generation.
2. Investigate and rectify the cause of short-lived flow surges from the Hinemaiaia B station, and subsequently generate electricity with a minimum of flow changes during a day.
3. Reduce loss of trout fry resting in shallow water at night by avoiding flow changes during the hours of darkness from November to February inclusive, the primary period of trout rearing.
4. Change the closed season to 1 May to 30 September, reflecting the importance of early-spawning trout to juvenile production. Continue to monitor trout abundance to establish the effectiveness of this measure.

INTRODUCTION

The Hinemaiaia River has a highly-regarded fishery for rainbow trout (*Oncorhynchus mykiss*), and is an important trout spawning tributary of Lake Taupo. Fish reared in the river rears contribute to the productivity of Lake Taupo, and the river itself is a fishery for adult rainbow trout returning to spawn. Recent research has focused on the fisheries values of the Hinemaiaia River. Reproductive biology of rainbow trout in Lake Taupo has been studied in this and similar rivers (Pitkethley 1990; Tully 1989; Rosenau 1991), and the Department of Conservation (DOC) are seeking to have the Waikato Regional Council investigate the hydrological impacts of flow management in the Hinemaiaia River.

The Hinemaiaia River has values other than its fishery; the river has three hydro-electric dams along its length, and generating facilities are operated as peak load stations by Taupo Electricity Limited. The fluctuating flow regime caused by electricity generation has long concerned anglers and fishery managers, but the effects of the dams and the flow fluctuations have not been quantified. In rivers of the Pacific Coast of North America, which have salmonids among their fish species, the effects of hydro-electricity generation have been widely studied, and many effects on freshwater fish have been demonstrated, including the following. Hydro-electric generation can block migrations anadromous fish species, strand fish, change water temperature, alter substrate composition, and change the composition of fish communities (Mundie 1991). Trout from Lake Taupo can spawn in the main channel between the HB dam and the lake. However, before the HB dam was commissioned in 1966, spawning also took place in two tributaries, the Pahikohuru and Kakapo Streams, which are upstream of the HB dam site. Both are spring-fed streams with generally stable flows (Burstall 1955, unpublished report on file with DOC, Turangi).

A serious challenge to evaluating the effects of the hydro-electric generating flow regime on the trout of the Hinemaiaia River is the scarcity of data from before the scheme was established. Also, while the effects of fluctuating flows on fish habitat have been moderately well established, the effects on trout have been poorly documented (Cushman 1985).

DOC has put high priority on management of the fishery in the Hinemaiaia River, and asked the following questions related to the hydro-electric flow regime and timing and duration of the trout angling season:

1. What impact does the present modified flow regime have on numbers of spawning trout and angling opportunities in the river?
2. What modifications to the flow regime would minimise impacts and improve fish numbers?
3. Can the present angling season restrictions be varied to improve fish catch without adversely impacting future angling opportunities?

Time and resources available prevented a direct study of these topics, and a more limited range of objectives was proposed. These were:

1. To compare patterns of spawning, fry emergence, and growth, to see whether data indicate the importance of early-run spawners.
2. To assess the variation of rainbow trout spawning habitat and juvenile rearing habitat under the present hydro-electric regime
 - (a) by measuring instream habitat (water depth, velocity, substrate, and cover) in representative reaches;
 - (b) by developing hydraulic models of the reaches and predicting changes in instream habitat with flow;
 - (c) and assessing the effect of these changes on trout spawning, rearing, and food production.
3. To compare angling at high and low generating discharges.
4. To assess the effects of the present flow regime, and recommend future flow management that is likely to optimise trout production.
5. To consider whether the productivity of the Hinemaiaia could be increased by alteration of angling season.

Physical characteristics

The Hinemaiaia River is a tributary of Lake Taupo, North Island, New Zealand, that drains a catchment of 165 km² on the eastern side of the lake (Fig. 1). Its headwaters are in Kaimanawa greywackes covered by rhyolitic tephra, the middle reaches in Waitahanui breccia and Rangitaiki ignimbrites, and the lower reaches in Taupo pumice (Schouten *et al.* 1981). There are three dams in the middle and lower reaches that are used by Taupo Electricity Limited to generate electricity. Watershed vegetation includes mixed beech (*Nothofagus* spp.) and hardwood forest in the headwaters, scrub and grassland with some hardwood forest in the middle and lower reaches, and extensive exotic pine (*Pinus radiata*) forests in the middle reaches (Schouten *et al.* 1981). Salmonids from Lake Taupo have access to about 7 km of river channel below the most downstream dam. The Hinemaiaia River below the lowest dam (i.e., Hinemaiaia B (HB)) has no tributaries large enough to support spawning, so spawning is restricted to the main river channel. The channel between the HB dam and the State Highway road bridge is generally U-shaped, and is steep-sided in many places. In the lower section (defined as a 1-km reach immediately upstream of the S.H.1 bridge, in the river below the S.H.1 bridge to the lake, the channel is subject to bank erosion.

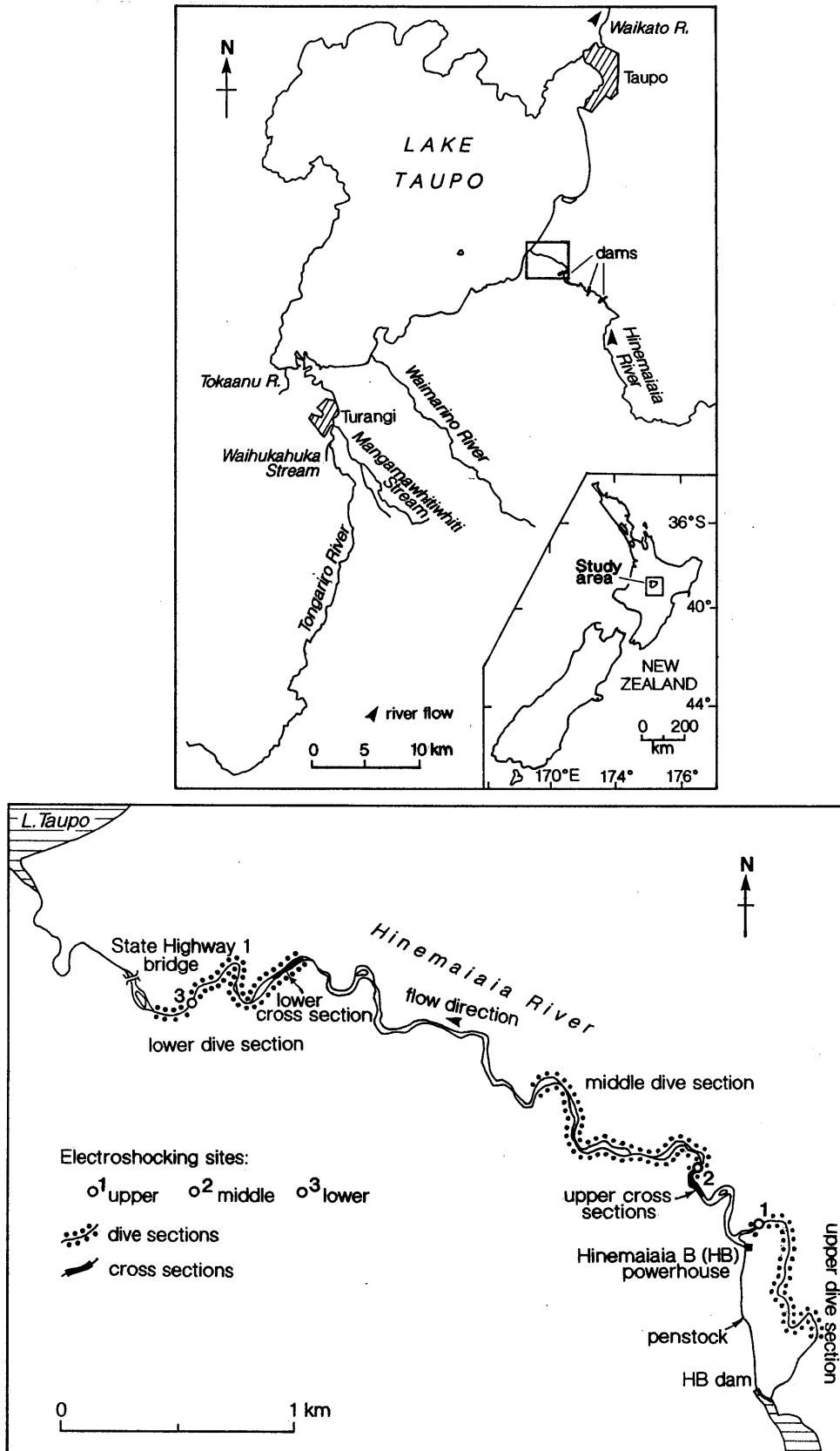


FIGURE 1. Location of the Hinemaiaia River in the Lake Taupo catchment, North Island, New Zealand, and sampling sites used in this study.

Gradients measured from 1:10,000 scale maps for the reach from the HB dam to the Lake Taupo ranged from 2 to 4.8 m/km (Appendix I). The average gradient between the HB dam and Lake Taupo is 3.4 m/km. Gradients for the channel upstream of HB dam (Appendix I) were measured from 1:50,000 scale maps (New Zealand Map Series 260, map number U18).

Hydrology

Mean annual flow of the river is 5.9 m³/s at SH 1, with a maximum recorded discharge of 50.7 m³/s, and a minimum recorded discharge of 0.66 m³/s. Discharge from the base of the HB dam is 0.28 m³/s, and the upper section (between the HB dam and the HB powerhouse) receives only this flow during full generation in dry weather. In wet weather (e.g., winter), or during station trips, water is spilled over the HB dam into the upper section.

The section of channel downstream of the HB powerhouse to Lake Taupo receives a flow that generally varies twice daily according to the peak power needs of Taupo city. Two generating flows are used; low discharge conditions (about 3 m³/s) occur when the station is set at 40% gate (operational capacity), and high discharge conditions (about 8 m³/s) occur when the station is set at 100 % gate at times of peak power demand. In summer, low discharge typically occurs overnight from 2130 h on one day to about 0900 h the next morning, and again from 1200 h to 1800 h (a total of about 17.5 h). High discharge occurs in the intervening periods (for about 4.5 h), with the change from low to high flow and vice versa taking about 20 minutes. In winter, periods of low discharge are generally shorter than in summer typically occurring from about 0000 h to 0700 h, and from 1300 h to 1630 h (a total of about 10 h). High discharge takes place in the intervening periods, for a total of about nine hours, with characteristics of increase and decrease similar to summer. Such operation is typical of hydro-electric peaking stations (Cushman 1985).

Brief periods of reduced discharge can occur within the evening generating period (pers. comm., T. Hollart, Taupo Electricity Limited). During times of plentiful water availability, especially in winter, high discharge may occur for 24 hours per day.

Lakes associated with the hydro-electric scheme affect the flow and sediment transport regimes by trapping gravels and mobile pumice (Schouten *et al.* 1981).

CHAPTER 1.

TIMING OF PEAK SPAWNING, FRY EMERGENCE, AND GROWTH

Introduction

Early-season trout spawning is probably important in maintaining trout productivity in the Hinemaiaia River. Trout growth in the Hinemaiaia is faster than in other Lake Taupo tributaries (Tokaanu and Waimarino Streams, Rosenau 1991). By autumn, over 50% of age 0 trout in the Hinemaiaia have attained a size (≥ 94 mm fork length) that Rosenau (1991) claims is large enough to allow survival in Lake Taupo as age 0 juveniles. From scale patterns of returning adults, and catches of age 1 juvenile trout (Rosenau 1991), few juveniles appear to overwinter in the Hinemaiaia River, which suggests they migrate to the lake as age 0 juveniles. Fry emerging in August-September would have a longer time for growth than fry emerging in October-November, assuming migration to the lake takes place in late summer or early autumn. Whether early spawners are likely to produce more age 0 trout ≥ 94 mm FL than later spawners, and thus whether it is advantageous to encourage early spawning by methods such as restricting angling, needs to be established. The objective of this chapter is to compare patterns of spawning, fry emergence, and growth.

Study sites

Drift diving was carried out in three sections in the main stem Hinemaiaia River below the HB (Fig. 1). The upper site was a reach 1.07 km long, beginning below the dam, and ending just upstream of the tailrace backwater of the HB electricity generating station. The middle section was 1.10 km long, and the lower section was 0.78 km long, ending about 200 m upstream of the S.H.1 road bridge (Fig. 1). The length of the lower section was increased to 0.81 km from 22 May 1991 on by extending the start of section upstream. Sites at which fry drifting downstream were trapped, and at which electroshocking were carried out are also shown on Figure 1.

Methods

Counts of trout > 10 cm FL

Trout > 10 cm FL were counted by a three experienced snorkel divers using methods previously established (Hicks and Watson 1985; Teirney and Jowett 1990). The fish were grouped visually into four approximate size categories:

fry and fingerlings	< 10 cm FL.
small	> 10, < 20 cm FL;
medium	> 20, < 40 cm FL;
large	> 40 cm FL

Underwater visibility was determined by a diver using both Secchi and black disk methods (Davies-Colley 1988).

Fry emergence

Numbers of fry emerging were estimated from downstream trapping, using 2-mm stainless steel mesh traps with a rectangular orifice 1 m wide by 0.5 m high anchored facing upstream in fast flowing water. Newly-emergent fry drift downstream, principally at night, for a period before they take a benthic existence (Hayes 1988a). Fast water velocities are necessary to trap fish drifting downstream. Traps were set six times, at the same locations at each site on each occasion, for a period of 15-25 hours beginning 1150 to 1810 h, and finishing 0900 to 1250 h. Water velocities at the orifices were 0.42-0.44 m/s for the upper trap and 0.22-1.20 m/s for the middle trap. Amount of water filtered was 0.07-0.08 m³/s (4,700-7,500 m³) for the upper trap, and 0.10-0.20 m³/s (8,162-13,430 m³) for the middle trap. These volumes take into account current velocity, duration of trapping, and changes of discharge with generation. The large variation in velocities and total volume filtered for the middle site is due to variation in generating discharges.

Estimates of juvenile growth and density

Fish were caught using both a battery-powered back-pack electroshocker and a generator-powered electroshocker to measure fish size and density. Discharge was reduced to 3 m³/s at the HB power house for the duration of shocking in the middle and lower sites to limit depths and velocities that otherwise might have compromised shocking efficiency. Stop nets of dark, 5-mm mesh multifilament polyester were placed at the upstream and downstream of the sections to be fished. A number of passes was then made in an upstream direction until a reduction in trout numbers of at least 75% occurred between two successive passes.

Population size was estimated using methods described by White *et al.* (1982) where three or more passes were made, or using methods described by Armour *et al.* (1983) for where only two passes were made. These measurements were made in November and December 1990, and in January, February, October, and November 1991.

Lengths of fish caught by electroshocking were used to calculate means for each sampling, and growth rate was calculated from the increase in size between samplings. To exclude recently emerged fish from the means, fish below a minimum length were omitted on the basis of length-frequency distributions.

Results

Time of peak density of adult rainbow trout

Numbers of adult rainbow trout peaked in the Hinemaiaia River in late July in 1990 (Fig. 2). Underwater visibility during the dive counts of trout was marginal to good, with a horizontal distance measured by 20-cm black disc of 1.7-4.2 m (Appendix II). Previous dives by Tully (1989) in the Hinemaiaia River to assess the time of peak spawning in the lower and upper sections in 1988 did not cover the months of presumed peak spawning activity, i.e., June to August. However, in 1990 we counted trout four times between June and September, and saw a maximum of 1514 fish > 10 cm FL in 3 km of main channel (Fig. 2D) during July. In 1991, trout were counted five times between February and October. Numbers of trout counted on 15 September 1988, 25 September 1990, and 8 October 1991 were 172, 243, and 90 trout/km respectively. Peak numbers, counted on 26 July 1990 and 29 August 1991, were 511 and 202 trout/km respectively. On the basis of ratios of peak counts to September and October counts, the peak number of trout in 1988 would have been about 372 trout/km.

Numbers of trout peaked earlier in the lower river than in the middle and upper sections. The time difference between the peaks was 27 days in 1990, and 70 days in 1991. Actual counts of fish of different sizes are given in Appendix III. Medium and small trout were usually only a small proportion of the total count, except in February, when they dominated counts.

Time of peak emergence

Downstream traps had a consistent bias towards smaller trout than were caught by electroshocking. Both mean and maximum FL of juvenile trout caught in downstream traps were smaller than those caught at the same time by electroshocking. Because of the small size of trout caught in downstream traps, their numbers were assumed to represent rate of emergence. On this basis, fry began to emerge in significant numbers in October, and emerged in large numbers in November; emergence tapered off during December, and had ceased by January (Table 1). As the trap efficiency at each site was not established, catches cannot be compared between traps, but only through time at each trap.

Growth of rainbow trout

Length-frequency distributions of rainbow trout in spring and summer changed as fish grew (Fig. 3). The distribution was positively skewed in November, but negatively skewed in December. Densities were too low to produce valid length-frequency distributions in January and February 1991. Growth rates were calculated from modal length of trout in spring and summer 1990. Calculation of growth rates was confounded somewhat by the prolonged period of emergence (August to December), but by excluding a few uncharacteristically small or large fish growth rates were calculated (Table 2).

TABLE 1. Numbers of rainbow trout fry, common bullies, and koaro caught overnight by downstream traps set in spring and summer 1990-1991 in the Hinemaiaia River, Lake Taupo catchment. One net was set at each site at each sampling date.

Date	Rainbow trout fry		Common bullies	Koaro
	middle	upper		
07-23 Nov 1990	26	116	4	1
11-12 Dec 1990	13	2	0	4
15-16 Jan 1991	0	0	1	3
29-30 Aug 1991	1	6	3	2
08-09 Oct 1991	63	0	8	0
26-27 Nov 1991	21	15	0	3

TABLE 2. Growth rates of juvenile trout in the Hinemaiaia River, 1990-1991 (95% confidence intervals in parentheses).

Date	Time (days)	Fork length (mm)			Fish excluded		Growth rate (mm FL/day)
		mean	95% CL	n	size (FL mm)	n	
Cohort of spring 1990							
07 Nov 1990		30.2	0.45	334	> 35	11	
	35						
12 Dec 1990		49.2	1.26	88	≤35, >65	27	0.54 (0.51-0.57)
	33						
15 Jan 1991		59.7	7.13	10	<49	9	
	22						
08 Feb 1991		69.2	8.66	10	<55	2	
Cohort of spring 1991							
09 Oct 1991		26.5	1.23	23	> 35	5	
	46						
26 Nov 1991		46.3	1.44	57	≤35, >65	67	0.43 (0.37-0.49)

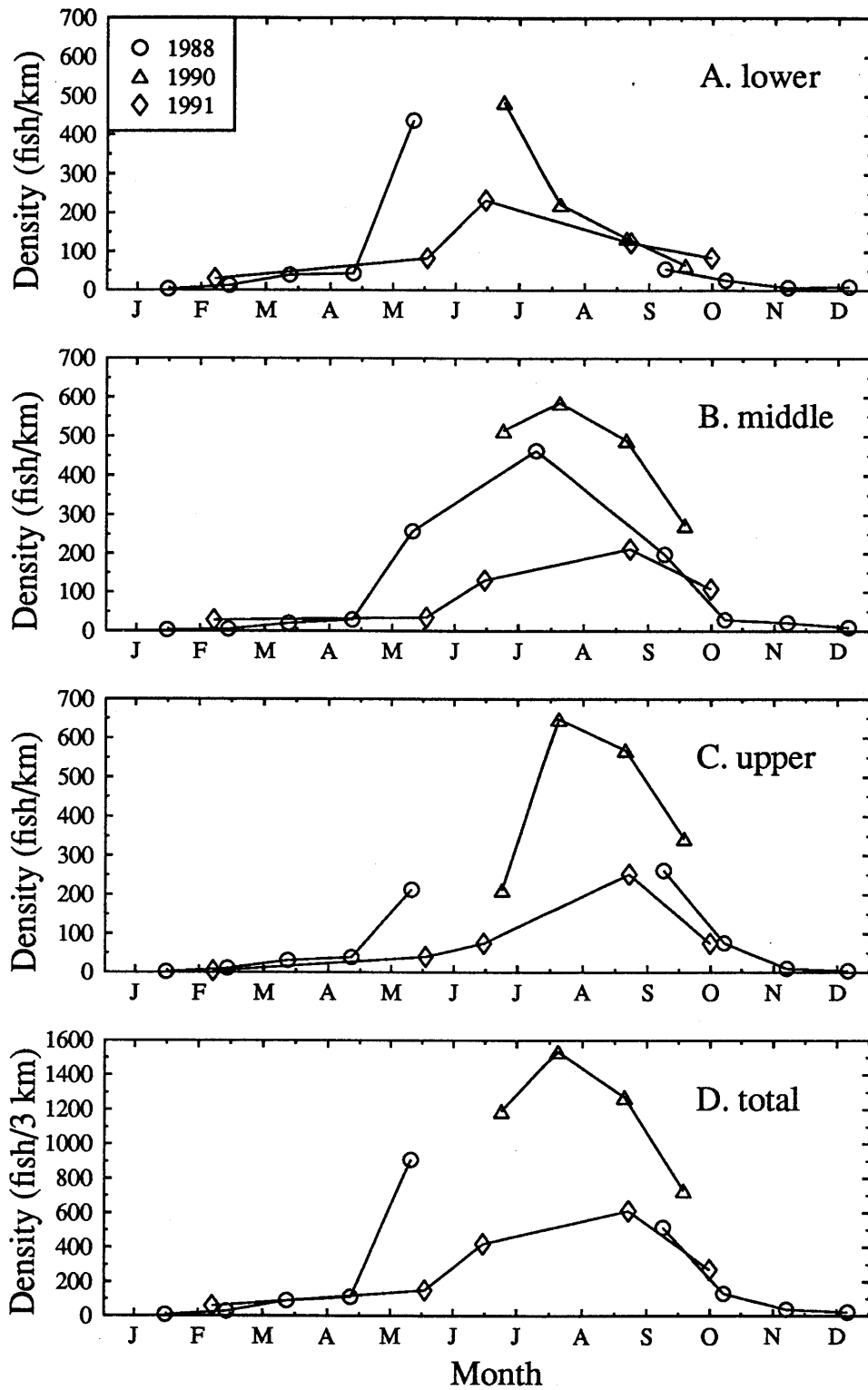


FIGURE 2. Density of rainbow trout >20 cm FL observed by drift diving in the (A) lower, (B) middle, (C) upper and (D) all sections combined in the Hinemaiaia River in 1988, 1990 and 1991.

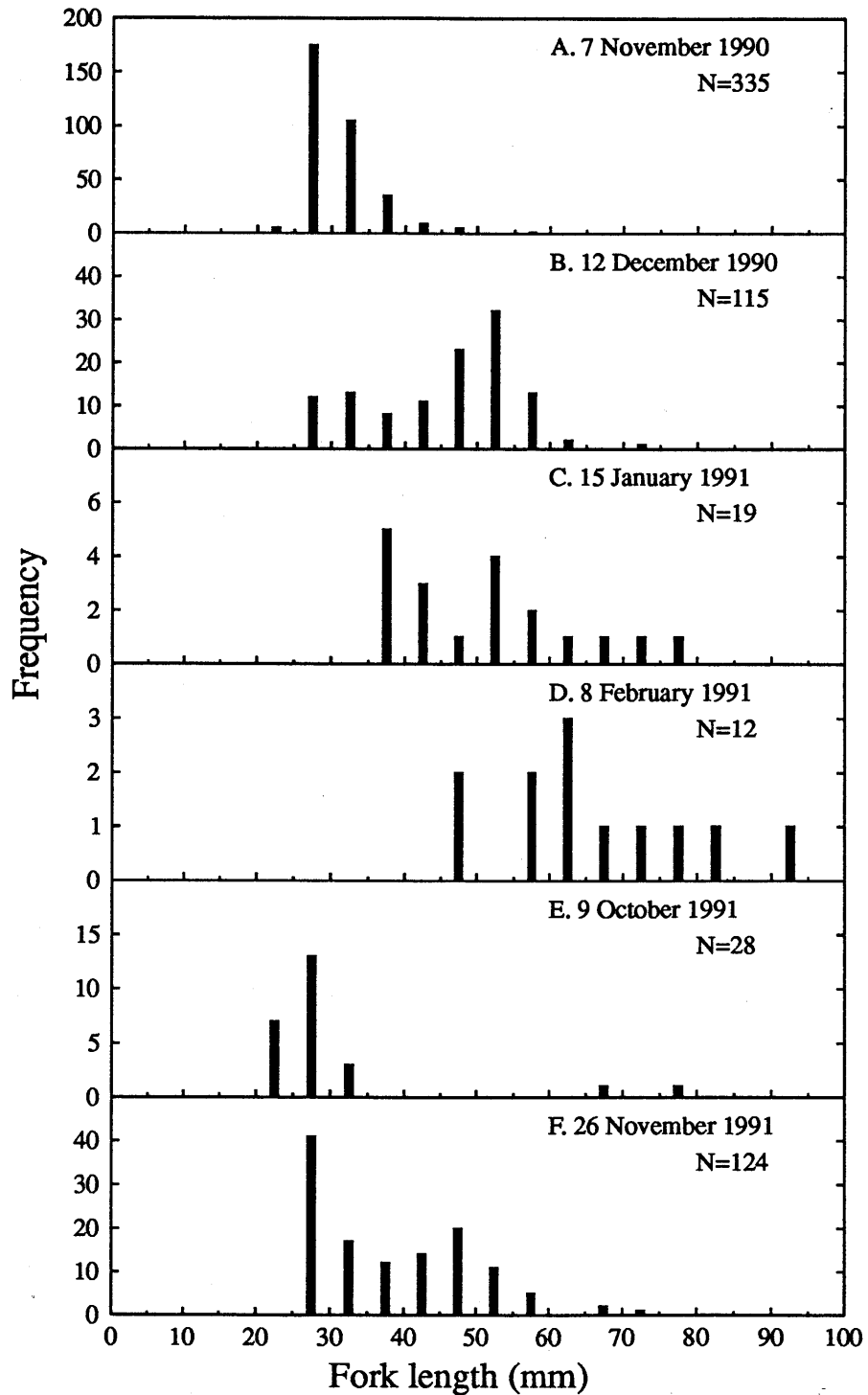


FIGURE 3. Length-frequency of juvenile rainbow trout caught by electroshocking in the Hinemaiaia River between November 1990 and November 1991.

Growth rate between November and December 1990 was 0.54 mm FL/day, but was lower between October and November 1991 (0.43 mm FL/day).

Size of trout in different locations

Juvenile trout in the upper section of the Hinemaiaia River were larger in the upper than in the middle section in December 1990 (Tukey comparison of means test, $p < 0.01$, Fig. 4), and were larger in the upper than in the middle or lower sections in November 1991 (Tukey comparison of means test, $p < 0.001$, Fig. 4).

Densities of juvenile rainbow trout

Rainbow trout fry were first observed in this study in mid-August 1990 by diving, when a few were seen at the shallow margins of pools in the upper section. Densities of juvenile trout in the upper section determined by electroshocking were low in October, and greatest in early November (6 fish/m², Fig. 5, Appendix IVa). By the end of February, densities had declined to 0.3 fish/m². In the middle section densities reduced in a manner similar to the upper section; in the lower section densities also reduced, but were lower initially (0.8 fish/m² in late November). By early January densities were low at all three sites (0-0.2 fish/m²).

The inverse of density (fish/m²) can be considered represent territory size (m²/fish). As trout grow, territory size increases (Table 3). The largest change at the upper site, for which the data are the most reliable, occurred between 44 and 47 mm FL. Territory size apparently increased four-fold between these two sizes.

TABLE 3. Change of territory size with increasing size of juvenile trout at three sites in the Hinemaiaia River.

Date	upper			Section middle			lower		
	territory size (m ²)	mean length (mm FL)	n	territory size (m ²)	mean length (mm FL)	n	territory size (m ²)	mean length (mm FL)	n
07 Nov 1990	0.17	30	339	-	-	-	-	-	-
26 Nov 1990	0.25	44	71	0.30	33	27	1.19	32	26
12 Dec 1990	1.02	47	72	1.17	35	24	3.44	48	19
15 Jan 1991	5.6	51	17	25.0	47	2	*	-	-
08 Feb 1991	3.7	65	12	*	-	-	-	-	-

* = no trout found.

- = no data.

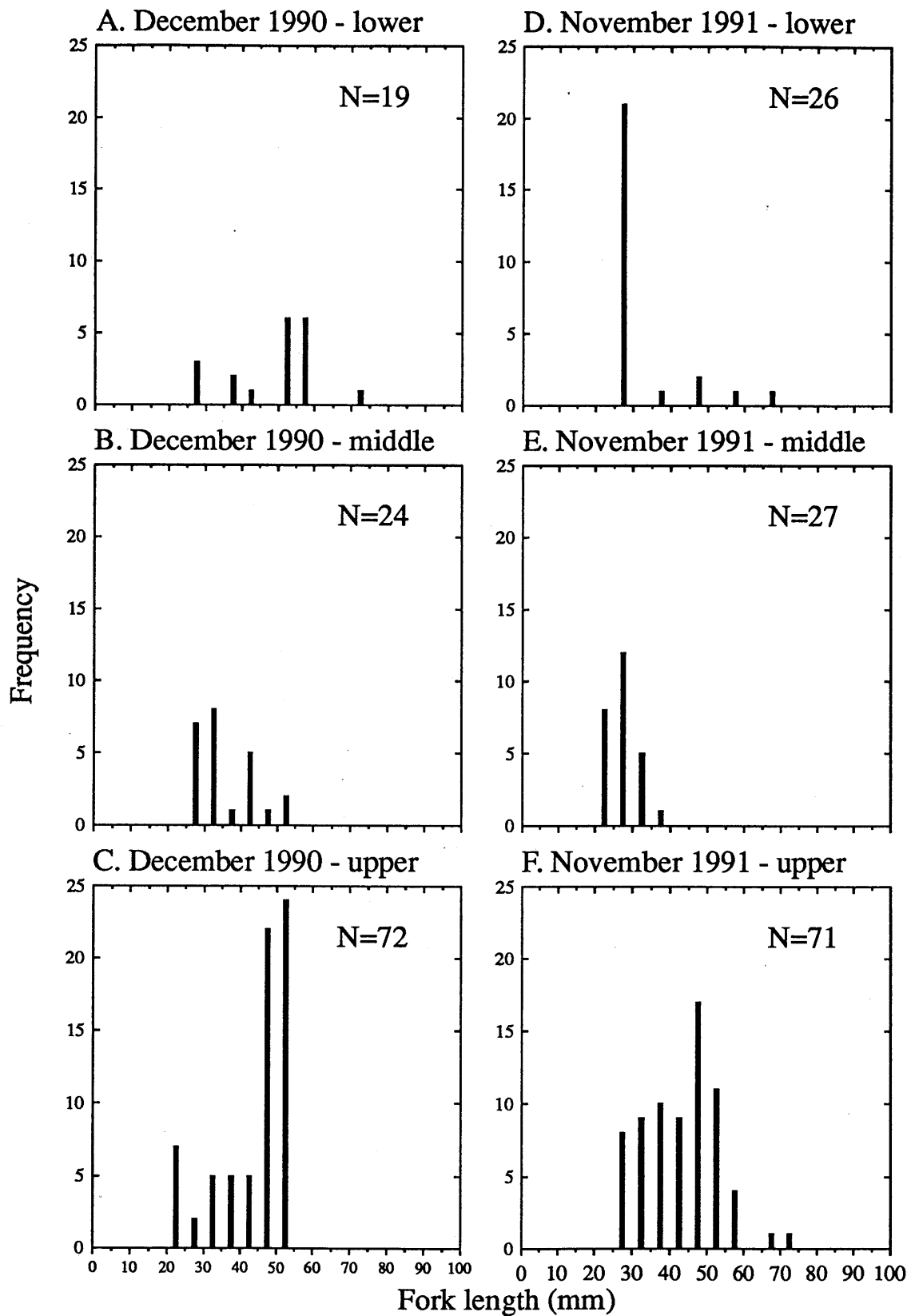


FIGURE 4. Length-frequency of juvenile rainbow trout caught by electroshocking at three sites in the Hinemaiaia River in December 1990 and November 1991.

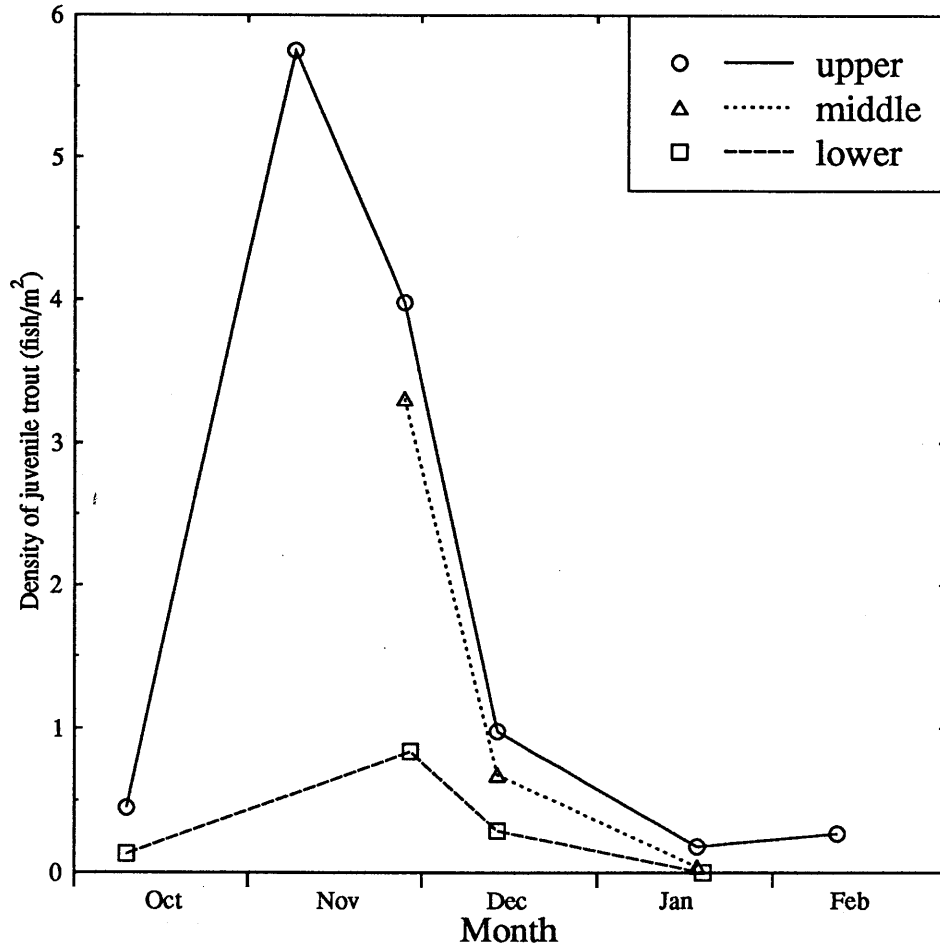


FIGURE 5. Densities of juvenile trout at three sites in the Hinemaiaia River determined by electroshocking.

As juveniles grew, they exchanged their shallow, low velocity habitat at stream margins for riffle habitat (see Chapter 2 for results). A flood in mid-February 1991 caused dramatic changes in densities of trout in riffles. Diving counts of trout showed there was a 78% reduction in the number of fish in glides and riffles between 7 and 22 February (Table 4). This reduction was significant (Mann-Whitney U test, $p=0.016$).

Common bullies, koaro, periphyton, invertebrates, and water temperature

Bullies observed in this study were uniform in colouration and body morphology, and were probably all one species. Two specimens, about 40 and 60 mm TL, were taken from the lower site on 16 January 1990 and positively identified as *Gobiomorphus cotidianus*. Densities of bullies were greatest at the lower site in mid-January (1.36 fish/m², Appendix IVb). Densities of koaro were greatest at the lower site in early October (1.33 fish/m², Appendix IVc). In early February, koaro occupied riffles. However, in comparison to juvenile trout, koaro were found in slightly slower and shallower water at the sides of riffles, 9-22 cm deep, and with current velocities of 0.02-0.35 m/s.

TABLE 4. Number of juvenile rainbow trout < 10 cm FL counted by divers in riffles in 1.07 km of main channel above the Hinemaiaia B tailrace.

Habitat unit	Area (m ²)	Number of trout	
		07 Feb 1991	22 Feb 1991
Cascade	117	9	7
Riffle	66	8	3
Riffle	34	10	0
Riffle	209	15	2
Riffle	149	2	1
Cascade	160	25	2
Total	735	69	15

Abundance of periphyton was limited throughout most of the year. However, from mid-December 1990 to about mid-February 1991 periphyton accumulated in the upper section. Dark green filamentous algae trailing 10-15 cm long in the slow current was collected on 15 January 1991, and was identified as the green alga *Ulothrix zonata* (forming about 80% of the sample). About 10% of the sample was the chain-forming diatom *Melosira varians*. A small amount of fine, filamentous green alga, with cells about third to one half the cell diameter of *U. zonata* was also present, as were some solitary diatoms attached to the filamentous forms. These algae can form under prolonged low flow conditions at any time of the year.

Invertebrates were not specifically studied. However, divers observed abundant nets of net-spinning caddises (*Aoteapsyche* sp., density about 500 nets/m²) in the faster water velocities in the middle section.

Water temperatures, recorded as spot measurements during the daytime rather than as continuous recordings, fluctuated between 7 and 16°C over the course of the study (Fig. 5).

DISCUSSION

Time of spawning and emergence

The life history of rainbow trout in the Hinemaiaia River is similar to that of winter-run steelhead in streams and rivers of the Pacific Coast of North America (e.g., Shapovalov and Taft 1954; Withler 1966; Ward and Slaney 1988). In northern California, at the lowest latitudes of the range of rainbow trout in the Northern Hemisphere, steelhead spend about 16 months in freshwater before migrating to the sea. At higher latitudes in British Columbia steelhead spend 2-4 years in freshwater.

Previous studies of rainbow trout life histories in Lake Taupo allow comparison with the findings of this study. In the Waihukahuka Stream, a spring-fed stream with a winter and a summer run of adult rainbow trout, outmigration of fry (<35 mm FL) peaks in February-March and October-November. Fingerling outmigration peaks in December. As only 2-4 brown trout run up the stream per year, the majority of fry and fingerlings must be rainbow trout. In the Mangamawhitiwhiti Stream, which has no significant summer run of adults, there is a significant run of brown trout in addition to rainbow trout. Fry outmigration peaks in November-December; brown trout comprise 64% of the outmigrants in October, but only 15% in November. Fingerling outmigration peaks in December (Pitkethley 1990). The majority of rainbow trout that survive to adulthood arrive at the lake at 80-150 mm FL after spending at least spring and early summer in tributary streams (Stephens 1989).

Growth is slow in the Waihukahuka and Mangamawhitiwhiti Streams compared to growth the Hinemaiaia River, and 80% of adults returning to the Waihukahuka Stream trap show growth checks on scales in their stream rearing phase, indicating that most trout surviving to maturity have overwintered in the stream or in the Tongariro River before entering the lake (Pitkethley 1990). Acoustic surveys have revealed that the major increase in numbers of trout <150 mm FL in the lake occurs between December and February (Cryer 1991), consistent with migrations in early to midsummer.

Thus a major difference between rainbow trout in the Hinemaiaia and in other Lake Taupo catchment tributaries is that trout in the Hinemaiaia generally reside in the river for only about six months before migrating downstream.

We did not set out to study the extent of utilisation of the available spawning habitat, but estimates of the numbers of spawners indicate that competition for suitable spawning areas may occur. Amount of suitable spawning habitat and area required by a spawning pair determine the number of redds that can be built (Bjornn and Reiser 1991). On the basis of estimates of numbers of adult rainbow trout in the river in late July 1990 (about 500 fish/km), assuming that each spawning pair needs about 20 m² space (including about 4 m² suitable gravel), there would need to be about 5,000 m² of suitable spawning habitat per kilometre. As the river is 8-10 m wide in many places, this means 50-60% of the area must be suitable for spawning if redd superimposition is not to occur. This proportion is an unusually high amount, and redd superimposition almost certainly occurs. Thus increasing the numbers of spawners may not increase the smolt output of the river.

As fry tend to drift passively for a period shortly after emergence from the gravel before adopting benthic behaviour (Hayes 1988a), fry traps can be used to estimate times of peak emergence. Efficiency of capture of fry <35 mm FL can be as high as 80%, but drops rapidly with increasing size of fish (Pitkethley 1990). Assuming that changes in emergence rate follow changes in spawner densities, we predict that the timing of peak emergence will mirror the timing of peak spawner density, delayed by some time interval. Trapping results from the middle reach for 1991 suggest that peak emergence occurred in about mid-October (Table 1), 80 days after late July, when the peak number of spawners were observed in 1990 (Fig. 2).

The 80-day delay between peak spawner density and peak emergence is consistent with the incubation period calculated using equations given by Crisp (1981, 1988) for rainbow trout. Assuming the water temperature was 8°C for the period of incubation (Fig. 5, late July to about mid-October), time from fertilisation to median hatch might have been about 43 days ($\log_{10}D_2 = b \log_{10}(T-\alpha) + a$, where D_2 = time in to median hatch in days, $b = -2.0961$, $\alpha = -6$, and $a = 4.0313$; Crisp 1981). Time from fertilisation to emergence (D_3) has been calculated as $1.7D_2$ for eight species of the genera *Salmo* and *Oncorhynchus* (Crisp 1988), which yields time to emergence of 72 days, close to the observed time between the peaks in adult counts and fry density.

Juvenile trout were generally larger in the upper section of the Hinemaiaia River than in the middle or lower section in November and December (Fig. 4). Water temperatures were higher in the middle and lower sections than in the upper sections (Fig. 5), and therefore are unlikely to account for these differences through earlier emergence or faster growth. Trout might spawn earlier in the upper section than in the middle and lower section, a phenomenon that has been observed with quinnat salmon (*Oncorhynchus tshawytscha*) spawning; the early-run fish spawn the furthest upstream. However, at the onset of the spawning season trout abundance increases first in the lower section, and the peak in abundance in the middle and upper sections occurs 27-70 days later (Fig. 2). In the Mangamawhitiwhiti Stream, a tributary of the Tongariro River, fry emerging caused trout densities to increase at the Pines site in July, whereas at the Detention site, 5 km upstream, densities did not increase until August (Pitkethley 1990). Daily flow fluctuations may prevent juvenile trout in the middle and lower reaches from establishing stable territories, causing the generally lower densities in the middle and lower sections compared to the upper section (Appendix IV). Alternatively, higher growth rates in the upper section could account for these differences. This is unlikely, because water temperature were consistently lower at the upper site than at the middle or lower sites (Fig. 6).

Densities of trout in Lake Taupo, presumed to be numerically dominated by juveniles, have been shown to peak in February (Cryer 1991), which supports the assumption of migration downstream in late summer or early autumn, at least in association with floods. Fry from trout spawning at the time of peak adult numbers (late July) would emerge in early to mid-October, assuming a 70-80 day incubation period. Growing at a rate of 0.43-0.54 mm FL/day, juveniles would reach a length of 86-102 mm FL by the end of February, close to or greater than the size at which juvenile trout are assumed to survive to adulthood in Lake Taupo. Fry emerging in September, the result of spawning in June, might reach 99-118 mm FL by the end of February. Although probably fewer in number, juvenile trout spawned in June might survive better in the lake than their smaller counterparts spawned in late July. However, by these calculations, trout from late July spawning that rear in the Hinemaiaia River and migrate downstream at the end of March could also survive in Lake Taupo. Few juvenile trout appear to overwinter in the Hinemaiaia River. We observed low abundance of trout ≤ 20 cm FL in winter (Appendix III), as did Rosenau (1991). However, if winter water temperatures are less than above 5°C juvenile trout may be amongst the substrate and not visible.

Growth rates of trout in the Hinemaiaia River are high by comparison with other streams in the Lake Taupo basin, and this allows juvenile trout to migrate to the lake as age 0 fish at the end of summer rather than requiring fish to overwinter in the river. These growth

rates have been confirmed in a separate study by Hicks and Rosenau (in prep.), and are among the highest recorded for trout in New Zealand (e.g., Allen 1951).

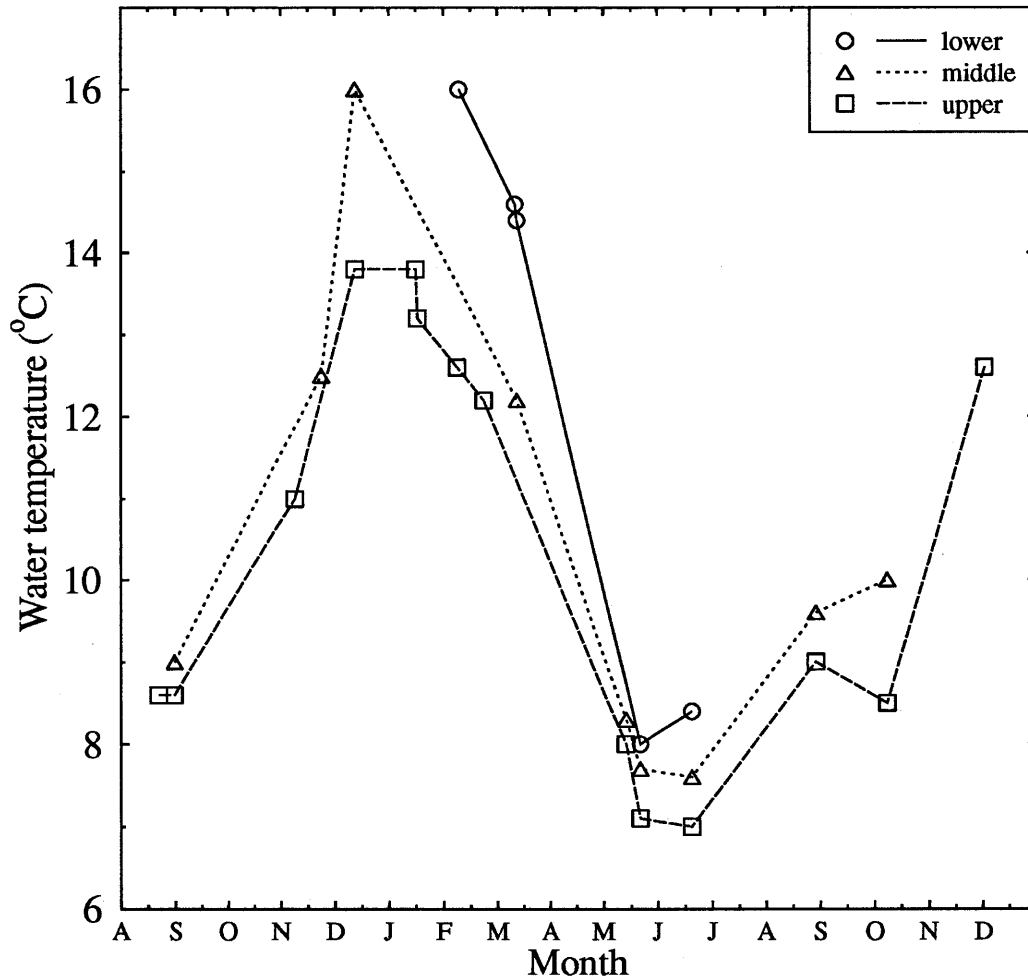


FIGURE 6. Water temperatures in the lower, middle and upper sections of the Hinemaiaia River in 1990 and 1991.

Hinemaiaia rainbow trout have different patterns of downstream migration than do steelhead (*Oncorhynchus mykiss*) in North America, and show differences compared trout in other tributaries of Lake Taupo. These differences are probably a result of high growth rates in the Hinemaiaia. In an extensive study of steelhead in Waddells Creek, California, peak downstream migration of juveniles occurred from spring to midsummer (from March to August, Shapovalov and Taft 1954). Older fish moved first; age 2 and 3 fish migrated downstream from March to May, age 1 fish migrated in May and June. Age 1 fish, however, also migrated in autumn and early winter (October to January). In most years the spring migration was much larger than the autumn migration. Downstream migrants have a complex reaction to factors such as river flow. When few fish are moving, increased flow accelerates migration. However, at the peak of migration, increased flow causes migration to cease (Shapovalov and Taft 1954).

Patterns of downstream juvenile trout movement in tributary streams of Lake Taupo may be variable with regard to time and age of fish. In the Mangamawhitiwhiti Stream, a Tongariro River tributary, trout migrate downstream principally as age 1 fish in spring and summer (Pitkethley 1990). In contrast, in the main stem Tongariro River and another of its tributaries, the Waihukahuka Stream, downstream movement of juvenile trout occurs mainly as age 0 fish moving between spring and autumn (Stephens 1989; Pitkethley 1990). This latter pattern is similar to juvenile trout migration from the Hinemaiaia River, though survival in the lake of age 0 trout migrating in spring and early summer migrants is unlikely to be high. Steelhead smolts show size-dependent mortality, with higher mortality of smaller sized smolts than of larger ones (Ward and Slaney 1988). Size is also a factor regulating smoltification, and thus fast growth allows early smoltification.

Only a small proportion of the trout fry emerging from gravels will remain to rear to a size at which they might successfully survive in the lake. Not only do densities decrease as fish grow (Fig. 6), but floods can also displace trout. Movement of trout from riffles was apparently caused by a flood occurring between 7 and 22 February 1991 (Table 4). Although densities of fish were not estimated in habitats other than riffles on 22 February, after the flood, the size of fish and moderately high water temperatures suggest their requirements for deep, fast-flowing water (Smith and Li 1983) would restrict them to riffles. Underwater visibility was similar on both dates, and could not have accounted for the differences in trout densities observed. We therefore assume that the flood either physically displaced fish downstream, or that it provided a cue for fish to begin active migration downstream towards the lake.

Downstream trapping was selective for early emergent fry (Pitkethley 1990), so the size of trapped fry cannot be used to compare size over time.

Relationship of spawner densities to hatchery trap runs

Counts of adult rainbow trout in the Hinemaiaia River have varied among years for individual months in recent years (Fig. 2). Numbers of spawning trout in September appeared to be 29% lower in 1988 (Tully 1989) than in 1990, and in 1991, numbers of spawning trout were 63% lower than in September 1990.

Returns of spawners to the hatchery traps on the Waihukahuka and Tokaanu Streams between May and October have also fluctuated widely, and have shown a disturbing downward trend from about 1982 (Fig. 7). Returns of trout to the Waihukahuka and Tokaanu traps in September 1988 were 13% and 19% lower respectively than September 1990 counts. In September 1991, returns to the Waihukahuka trap were 28% lower than in September 1990, but returns to the Tokaanu trap were 177% greater than in September 1990. Further evidence of the similarity of Hinemaiaia River trout runs in timing and magnitude to runs in the Waihukahuka Stream is provided by comparison of the monthly proportions of the run between May and October (Fig. 8). Peak numbers occur in July in both the Waihukahuka and the Hinemaiaia (Fig. 2, Fig. 8).

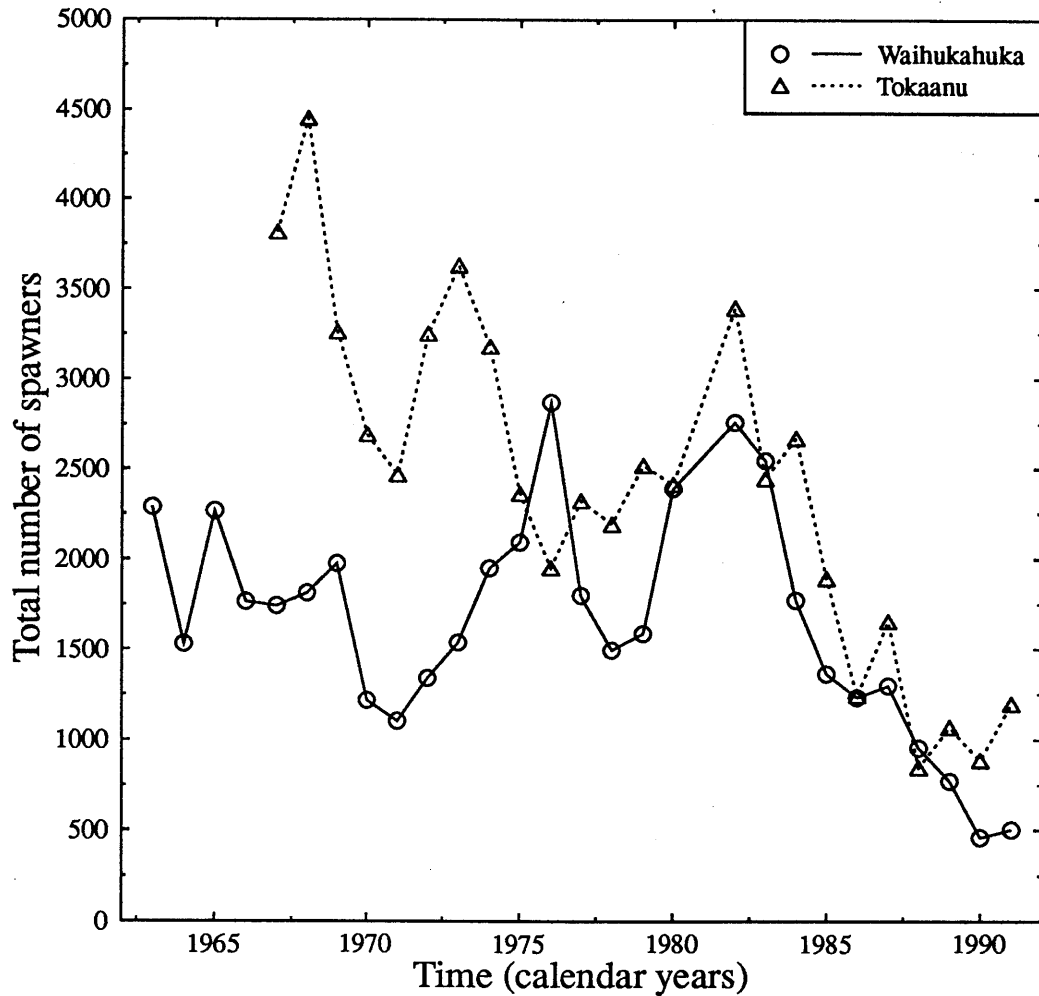


FIGURE 7. Total number of spawning rainbow trout passing through traps on two tributaries of Lake Taupo between May and October, 1963 to 1991.

Anglers have a perception that the number of fish entering the Hinemaiaia River before the close of the angling season (1 June) have declined in recent years. Low numbers of fish in May are of particular concern to anglers because they are fresh-run fish heralding the start of the winter season, and in the Hinemaiaia above SH 1, the only part of the spawning run available to anglers. Of the six months between May and October, May was the only month to show a significant trend of change in the proportion of fish entering the Waihukahuka trap between 1963 and 1991 (Fig. 9, $r^2 = 0.267$, $p = 0.004$). If trout in the Hinemaiaia have reacted in the same way to fish in the Waihukahuka, which is probable judging from the similarity of the two streams in run timing, then there may well have been a trend for a smaller proportion of the run from May-October to enter the Hinemaiaia in May.

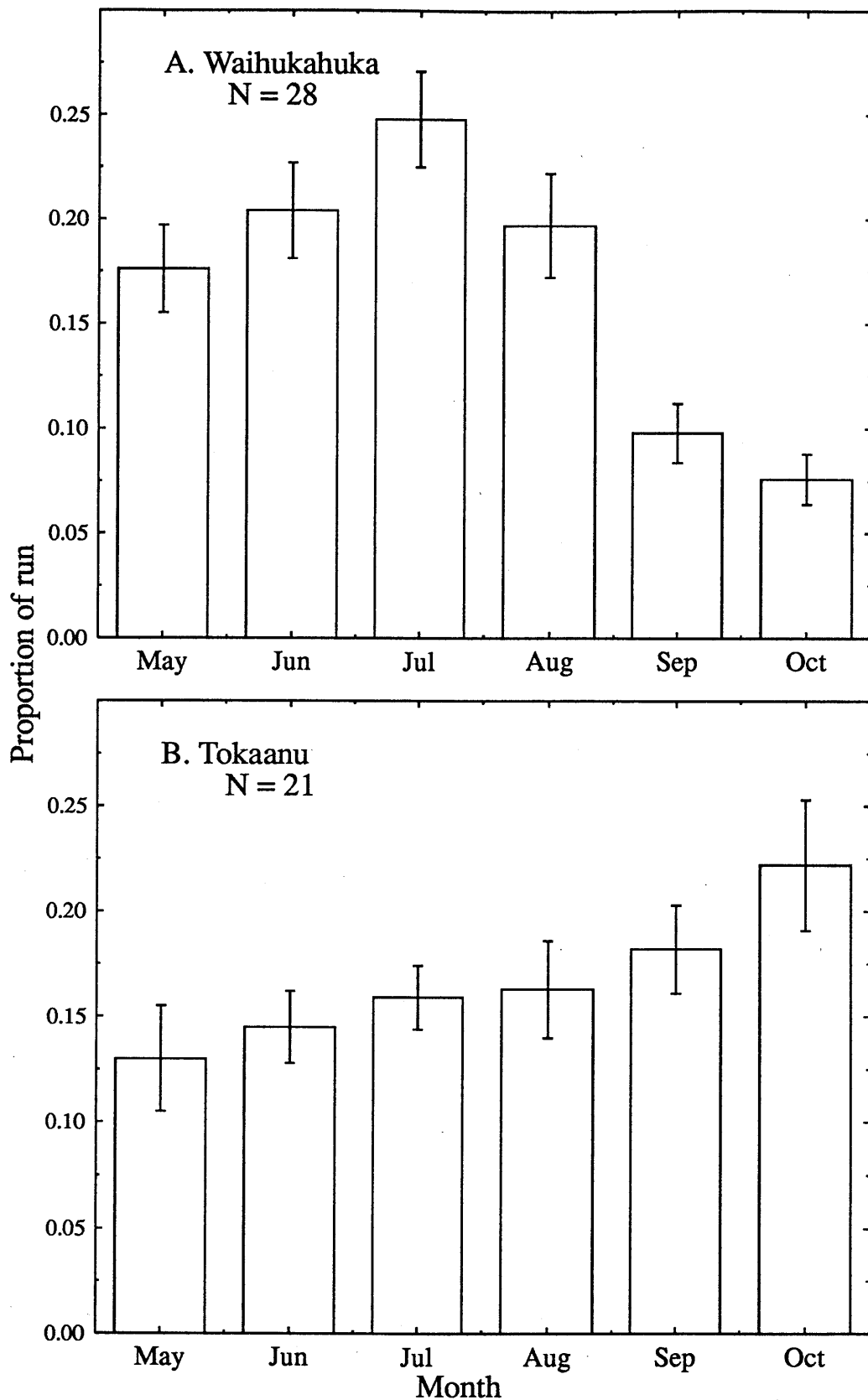


FIGURE 8. Proportions of the Lake Taupo rainbow trout run in each month as a proportion of the total run between May and October 1963-1991. A, Waihukahuka trap; B, Tokaanu trap. Error bars are 95% confidence limits.

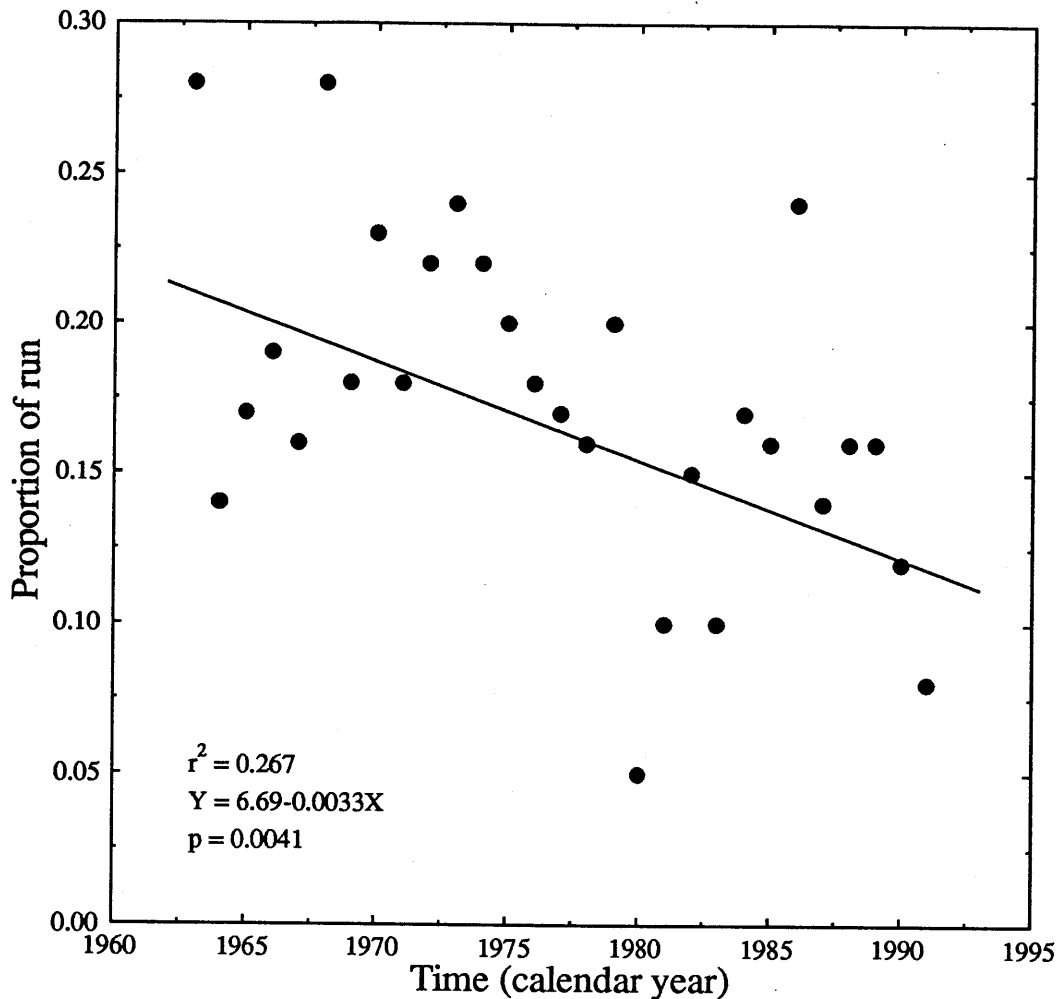


FIGURE 9. Rainbow trout run in May in the Waihukahuka Stream as a proportion of the total run from May to October 1963-1991.

Effect of the HB dam on the number of spawners

Construction of the HB dam prevented spawning trout from reaching two tributaries upstream of the dam site. The importance of these tributaries for spawning was investigated by staff of the Wildlife Service before dam construction (Burstall 1955, Merton 1957, and Ewing 1965). Spawning conditions in the Kakapo Stream were assessed as very limited (Burstall 1955), and only 10 adult trout were seen, occupying five redds, on 31 July 1957 (Merton 1957).

A mark-recapture and trapping survey of the number of fish in the Pahikohuru between 14 July and 8 September 1965 estimated that at least 414 adult rainbow trout used the stream in this part of the spawning season (Ewing 1965). The trap was installed in the

Pahikohuru Stream about 50 m upstream of its confluence with the Hinemaiaia River on 14 July 1965. On the same day, 100 adult rainbow trout already in the Pahikohuru were driven downstream towards the trap, caught, and marked by removal of the tip of the right pectoral fin. Subsequently, all trout moving upstream past the trap were counted and similarly marked, and those moving downstream past the trap were counted, and their mark condition noted. Trapping continued until 18 September 1965. During the time the trap was in place, 188 rainbow trout (134 females 72 males) moved upstream, and 206 (134 females and 72 males) moved downstream. Of these 394 fish, 64% were females. Upstream migrants had a mean length of 514 mm, and a mean weight of 1625 g. Downstream migrants had a mean length of 522 mm, and a mean weight of 1362 g. Estimates of variability are not available.

Unmarked kelts moving downstream past the trap numbered 119, and seven unmarked carcasses were found, therefore there were at least 226 trout upstream of the trap when it was installed. This number is a conservative estimate, because on the last day of trapping, six of the 11 downstream migrants were unmarked.

CHAPTER 2.

EFFECTS OF HYDRO-ELECTRIC FLOW REGIME ON TROUT SPAWNING AND REARING

Introduction

The habitat requirements of trout for feeding, spawning, and rearing are relatively well known (Nickelson 1975; Bovee 1978; Nickelson *et al.* 1979; Bovee 1982; Shirvell and Dungey 1983; Bovee 1986). A combination of hydraulic modelling and knowledge of habitat requirements have been used in the past to predict the effect of flow modifications on salmonid habitat both overseas and in New Zealand (Bovee 1978; Stephens 1989, Mosley and Jowett 1985), and the technology is generally known as Instream Flow Incremental Methodology (IFIM). We used these methods to model existing trout habitat in the lower Hinemaiaia River (Jowett 1989).

Effects of fluctuating flows downstream of hydro-electric stations have been documented, and include reduction of invertebrate food species, thermal and oxygen stress, interruption to migrations, stranding on gently-shelving shores, and increased bird predation (Cushman 1985). Daily flow fluctuations have been shown to have a profound effect on fish communities in rivers, affecting fish using shallow, slow-flowing microhabitat (Bain *et al.* 1988). Trout fry occupy shallow slow-flowing margins, and are therefore particularly vulnerable to fluctuating flows. However, trout tend to seek faster, deeper water as they grow (Lister and Genoe 1970, Everest and Chapman 1972). The objective of this part of the study was to assess the variation of rainbow trout spawning habitat and rearing habitat for juvenile trout under the present hydro-electric generation regime

- (a) by measuring instream habitat (water depth, velocity, substrate, and cover) in representative reaches;
- (b) by developing hydraulic models of the reaches and predicting changes in instream habitat with flow;
- (c) and assessing the effect of these changes on spawning, rearing, and food production.

Methods

Trout habitat analysis

The methods described by Jowett (1989) were used to establish 10 cross sections in each of two representative reaches in the main stem channel below the HB power station tailrace (Figs. 10 and 11). Depths and velocities were measured on 13 March 1991 at low flows (40% gate, about 3 m³/s), and the water level was measured at this flow.

Cross sections gauged
1128-1330 h
13 March 1991

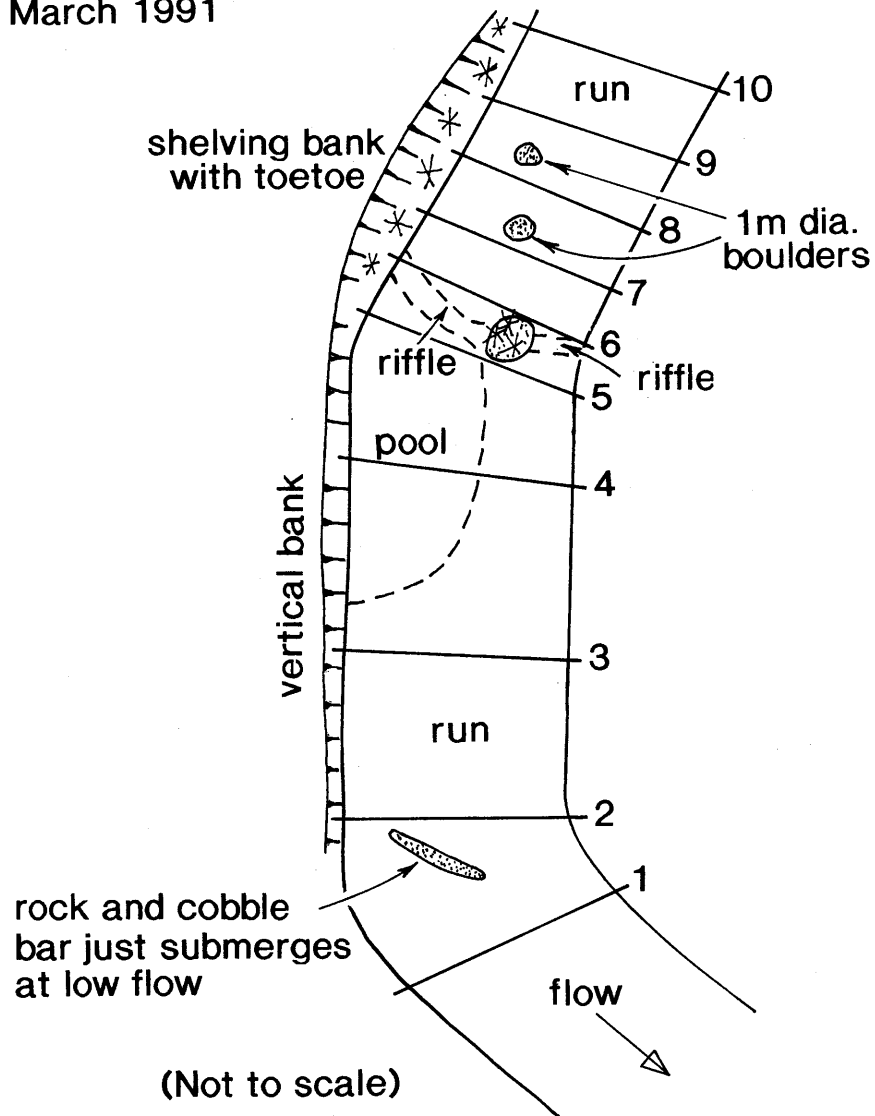


FIGURE 10. Position of cross sections in the middle section of the Hinemaiaia River gauged on 13 March 1991.

Cross sections gauged
 1400-1645 h
 13 March 1991

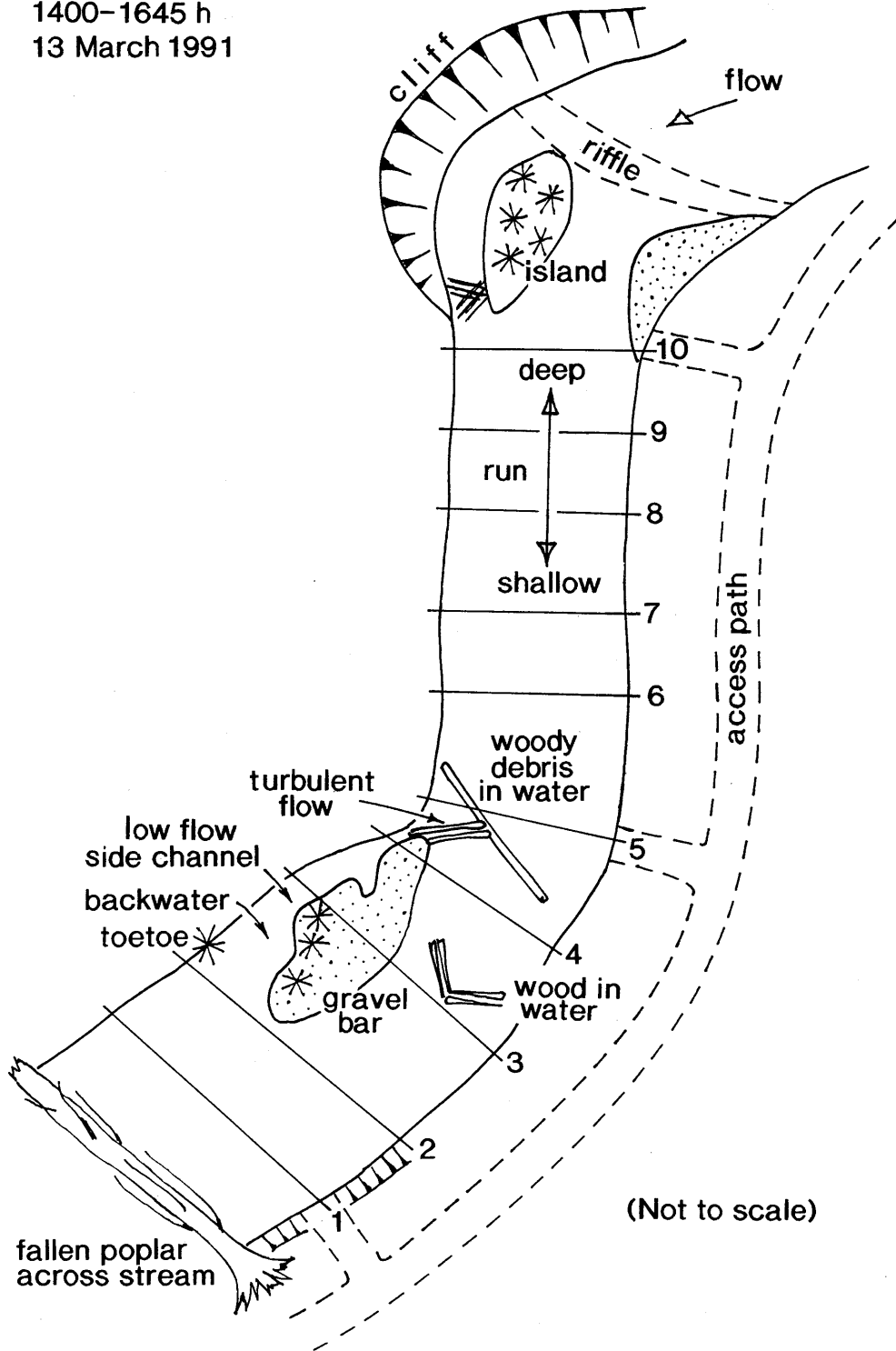


FIGURE 11. Position of cross sections in the lower section of the Hinemaiaia River gauged on 13 March 1991.

Water level and discharge were also measured at full generating flow (100% gate) on 14 March 1991. Depths and velocities at 100% gate were estimated from a combination of the discharge and water level measured at 100% gate, and depths and velocities measured at 40% gate. Discharge measurements are accurate to within 4%. Changes in amounts and suitability of spawning and rearing habitat with flow, and in potential food production, were modelled from these measured and estimated depths and velocities (e.g., Jowett *et al.* 1991). Methods described by Mosley and Jowett (1985) were used to calculate weighted usable area.

Fry habitat was differentiated from juvenile habitat. Fry were defined as trout from emergence to <60 mm FL, and juveniles were defined as trout \geq 60 mm to 170 mm FL.

Ability of juvenile trout to respond to water level changes

The ability of juvenile trout to escape stranding as water levels dropped with the cessation of electricity generation was tested using a gently shelving area in the channel inundated by the tailrace backwater above the Hinemaiaia B generating station (Fig. 12). Juvenile trout caught by electroshocking and downstream trapping were released into the upstream part of a 9-m² backwater that was previously observed to dry completely with the cessation of generation. This area was divided into four parts (A-D, Fig. 12) for the purposes of the experiment, with an adjacent 6-m² area (E) downstream that was covered by water at all times. The substrate in the experimental area was dominated by small cobbles and very coarse gravel, with sand and fine gravel in interstices.

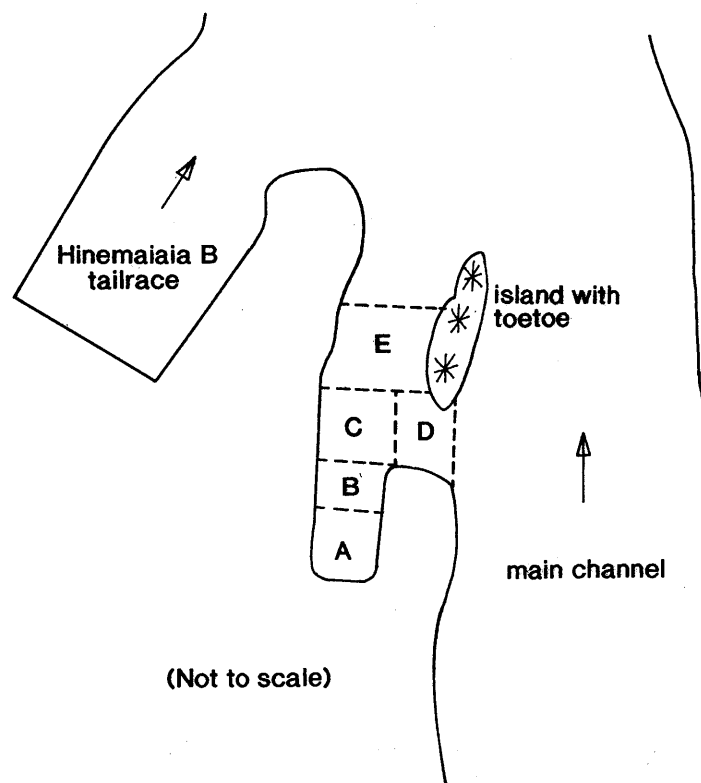


FIGURE 12. Plan view of the backwater in the upper section of the Hinemaiaia River used to test the response of juvenile trout to falling water levels. Arrows indicate direction of water flow.

In Experiment 1, 96 juvenile trout 25-67 mm FL were released in to area A at 1000 h, just as generation ceased, and over the next 10 minutes their reaction to the falling water level was observed. The number of trout that had not escaped the dewatered area was determined by recovering stranded trout from the substrate (from 1010 h to 1020 h). Fork length of these trout was measured, and they were then allowed to recover.

The water level rose in the experimental area as generation recommenced at 1026 h. For Experiment 2, the recovered trout were marked with Bismark brown (by immersion in 2 g to 15 l of water for six minutes), and the 59 remaining live trout were released back into the area A at 1120 h to acclimate. After 1 hour 13 minutes (at 1233 h) generation again ceased, and the reaction of the remaining acclimated trout to the falling water level was observed. In 10-20 minutes (at 1242 h) areas A-D were again dry, and the trout stranded in the substrate were recovered, counted, and measured.

Results

Depths and velocities occupied by juvenile trout

Change of habitat with growth

On emergence in August to November trout fry (23-26 mm FL) in the upper section occupied stream margins in areas of very slow current velocities (<0.01 m/s) and shallow depths (5-15 cm). By December to January, as juvenile trout grew to about 40-60 mm FL they moved into slightly deeper water between 15-25 cm deep, and with current velocities of 0.10-0.30 m/s. In early February, when trout were about 55-93 mm FL, they had largely vacated glides (or runs), and had instead occurred in riffles 12-35 cm deep, with current velocities from 0.04-0.38 m/s. Small schools of trout generally occupied deeper pockets within riffles.

Habitat modelling

We compared various habitat suitability curves with habitat used by trout fry and juvenile trout in the Hinemaiaia River, and decided that Bovee's (1978) curves for trout fry and juvenile trout best fitted the depths and velocities we observed to be used. Comparisons of depths and velocities occupied by trout and equivalent Bovee suitability-of-use curves are shown in Figure 13. Frequency distribution of trout at different depths and velocities was generally similar to Bovee's curves, considering the limited range of habitats at which trout were sampled.

Depths and velocities increased from the low flow of $3 \text{ m}^3/\text{s}$ to the high flow of $8 \text{ m}^3/\text{s}$. Median velocities increased from 0.55 to 0.75 m/s in the middle section, and from 0.65 to 1.05 m/s in the lower section (Fig. 14). Median depths increased from 0.35 to 0.65 m in the middle section, and 0.65 to 0.95 in the lower section. Mean velocities increased from 0.41 to 0.65 m/s at the middle site, and from 0.47 to 0.69 m/s at the lower site as flow increased (Fig. 15). Mean depths increased from 0.50 to 0.74 m at the middle site, and from 0.51 to 0.76 m at the lower site as flow increased (Fig. 15).

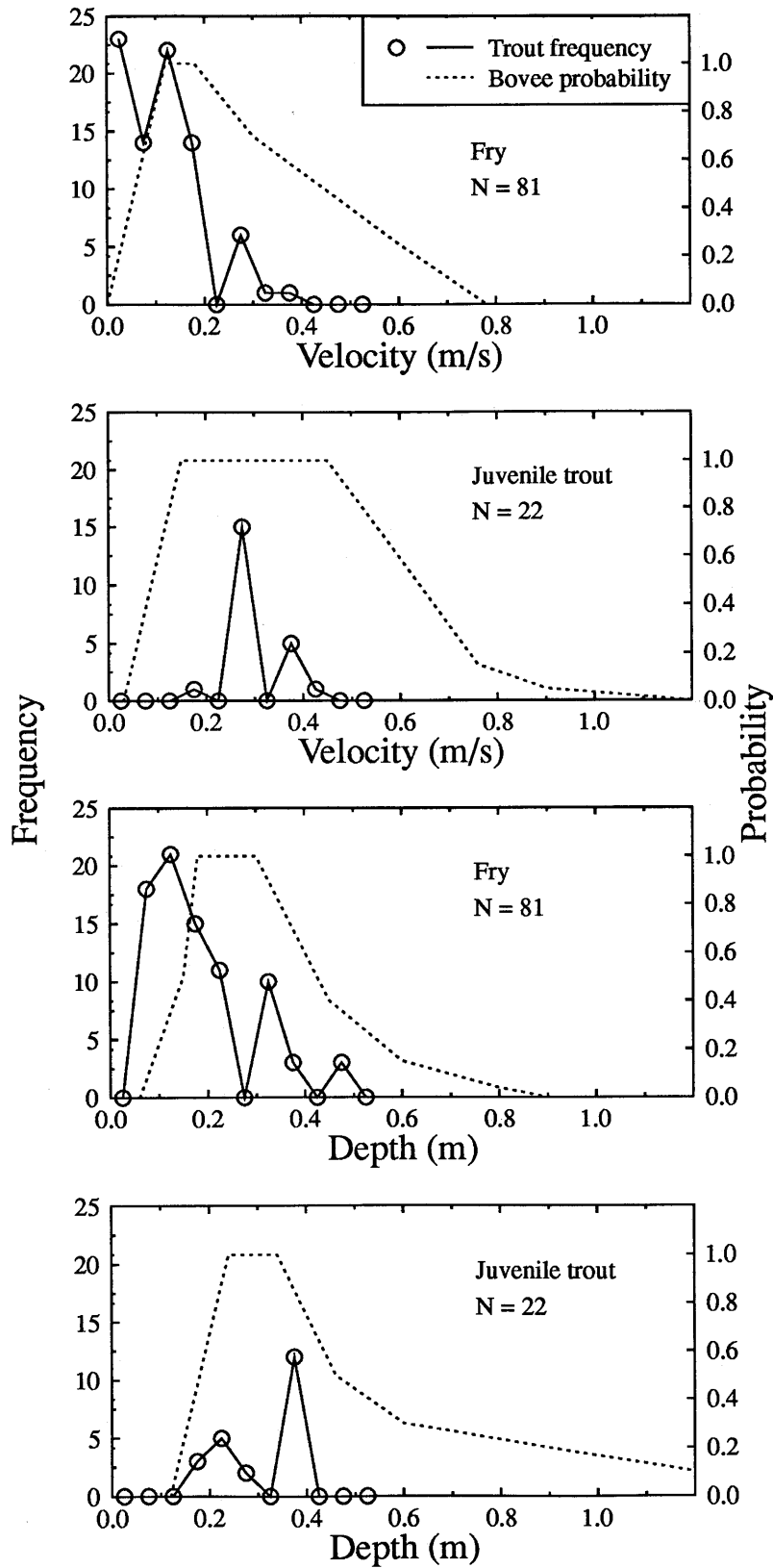


FIGURE 13. Frequencies of trout fry and juveniles occupying different depths and velocities in the Hinemaiaia River compared to probability of use (Bovee 1978).

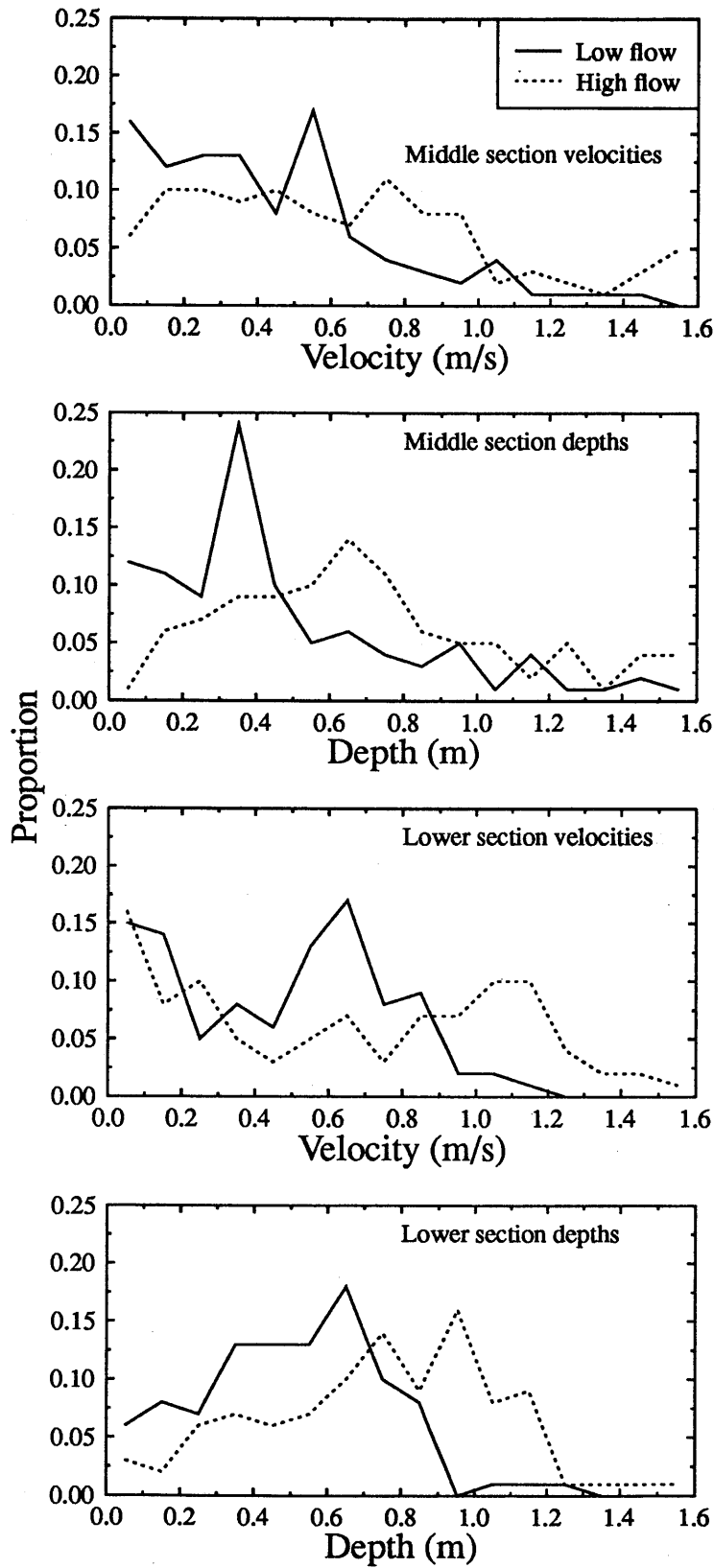
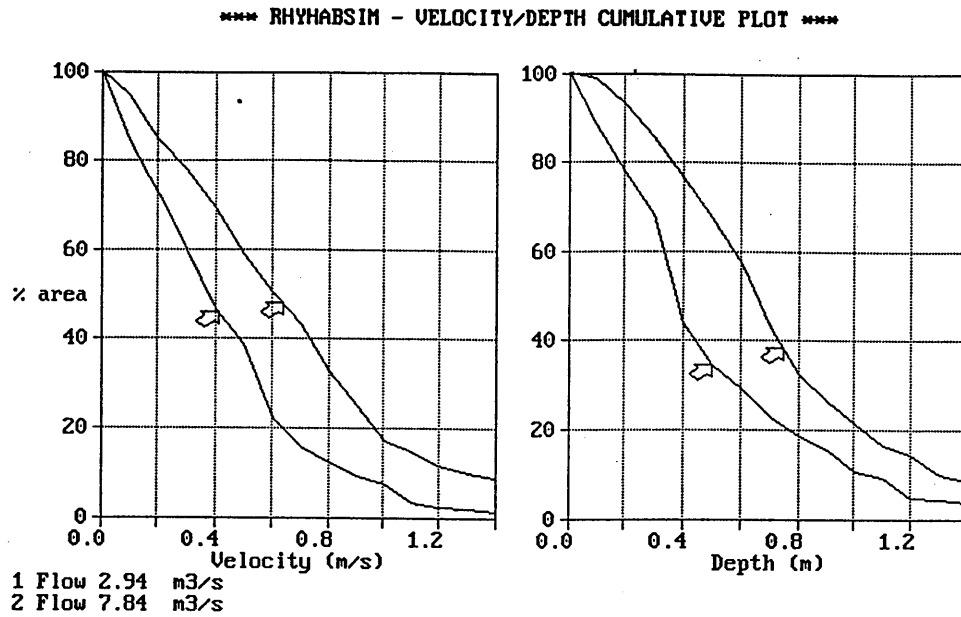


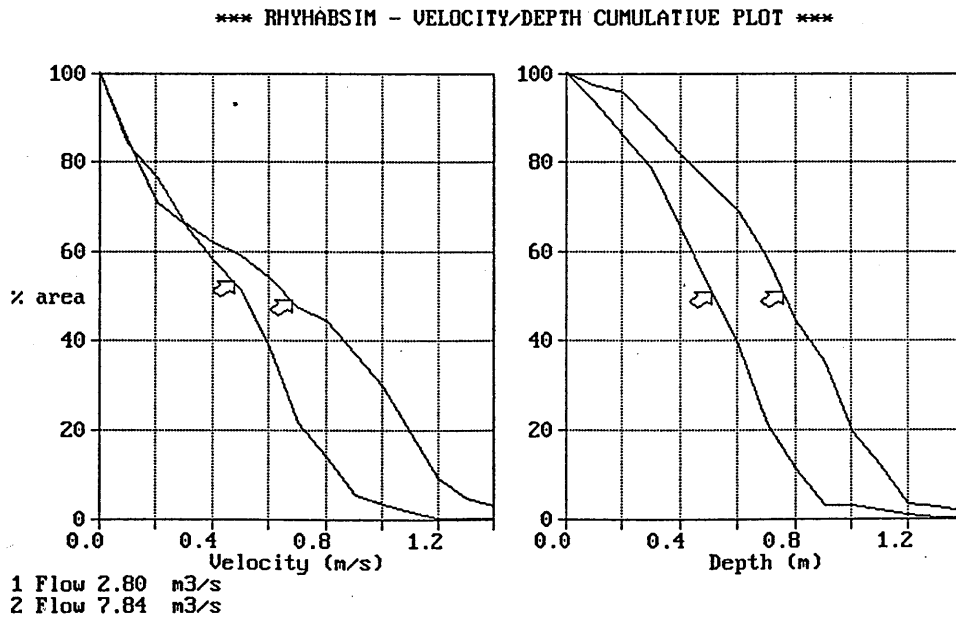
FIGURE 14. Distributions of depths and velocities in the middle and lower sections of the Hinemaiaia River at high ($8 \text{ m}^3/\text{s}$) and low ($3 \text{ m}^3/\text{s}$) generating flows.

A. Middle



File > HINE1

B. Lower



File > HINE2

FIGURE 15. Cumulative change by area in depths and velocities at the (A) middle and (B) lower sections of the Hinemaiaia River with flow.

Habitat modelling suggests that the amount of fry habitat is generally reduced at high generating flows (about 8 m³/s) compared to low flows (about 3 m³/s). Habitat suitable for fry rearing was reduced by 44-56% at two sites (Figs. 16 and 17). Percentage of the stream bed available for fry rearing at the was 7.7-12.6% at low flow, and 4.3-5.5% at high flow. Suitability of individual cells is represented by the horizontal width of the black bar within a cell (Figs. 16 to 23). A bar filling the entire width of a cell shows 100% suitability. Flow increase reduced the number of cells with suitable habitat, and also reduced the suitability of those still containing suitable habitat. Position of suitable cells changed little, indicating minimal movement was needed to cope with flow changes where habitat remained suitable.

Juvenile rearing habitat was reduced by similar amounts (50-53%, Figs. 18 and 19). Percentage of the stream bed available for juvenile rearing (13.6-21.2% at low flow, 5.1-10.5% at high flow) was greater than that available for fry rearing because of the greater velocities required by juveniles compared to fry. Changes in location of habitat for fry and juveniles rearing were minimal despite the changes in suitability.

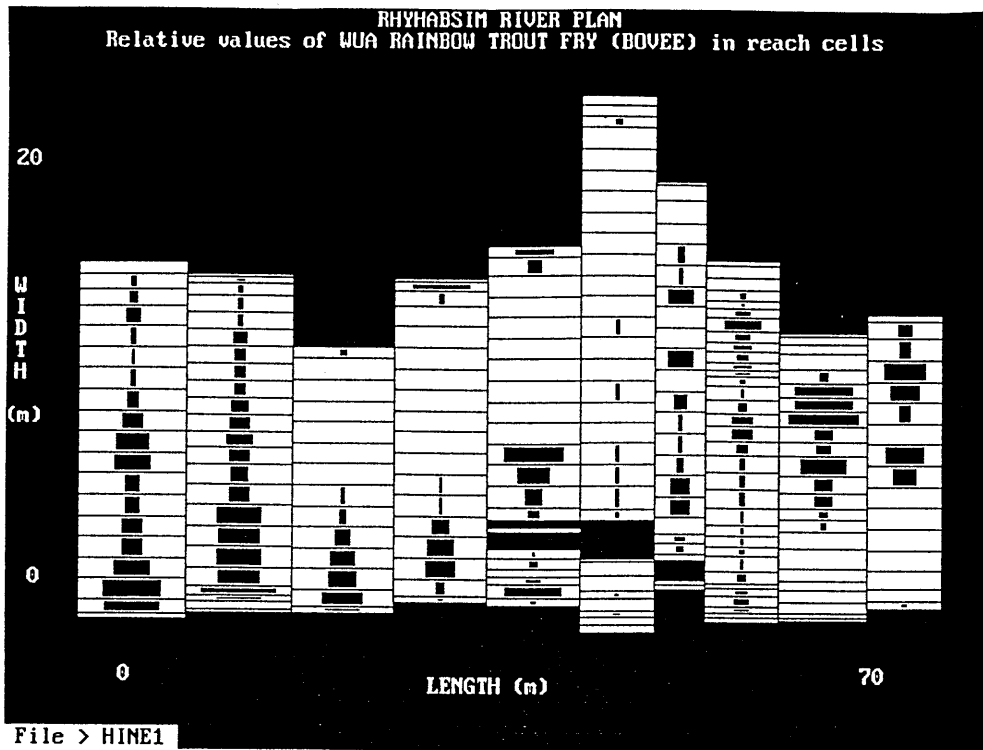
Spawning habitat reduced by 57-88% as the flow increased from 3 to 8 m³/s (Figs. 20 and 21). However, there was only a limited amount of habitat suitable for spawning at the sites used for modelling (7.8-11.4% at low flow, 0.9-4.9% at high flow) as a consequence mainly of depth and velocity increases. These habitat changes are unlikely to have affected eggs already incubating in redds made at low flows. Suitability-of-use data show that redds are usually made in water 0.37-0.68 m. As water level decreases with flow average about 0.25 m, redds made at high flow are unlikely to be dewatered by flow reductions. Changes in location of spawning habitat were minimal despite the changes in suitability.

The areas suitable for food production increased by 10% at the middle reach with flow, but reduced at the lower site by 25% (Figs. 22 and 23). Location of habitat suitable for food production also changed little.

Ability of juvenile trout to respond to water level changes

The water level in area E dropped 28 cm with a reduction in flow from full generating flow (about 8 m³/s) to minimum generating flow (about 3 m³/s). This reduction in water level was sufficient to completely dewater areas A-D. Of the 96 trout initially released in Experiment 1, 68 (71%) were stranded in the substrate. The trout stranded were predominantly small; more than 80% of the trout <45 mm FL were trapped by the receding water (Fig. 24). No trout ≥55 mm FL were stranded, and only 27% and 17% of the trout in the 45-49 and 50-54 mm size classes respectively were stranded.

All but two of trout stranded were recovered by careful removal of substrate. When the water level rose at 1026 h, trout that were not recovered emerged from the substrate. In Experiment 2, following release of the marked fish at 1120 h, the four largest individuals (44-50 mm FL) moved downstream and out of the experimental area within two minutes of release. The remaining trout started feeding from the surface by 1139 h. Area A was still occupied by 25-30 trout at 1141 h. By 1200 h, 10-15 larger trout (35-40 mm FL)



B. High flow

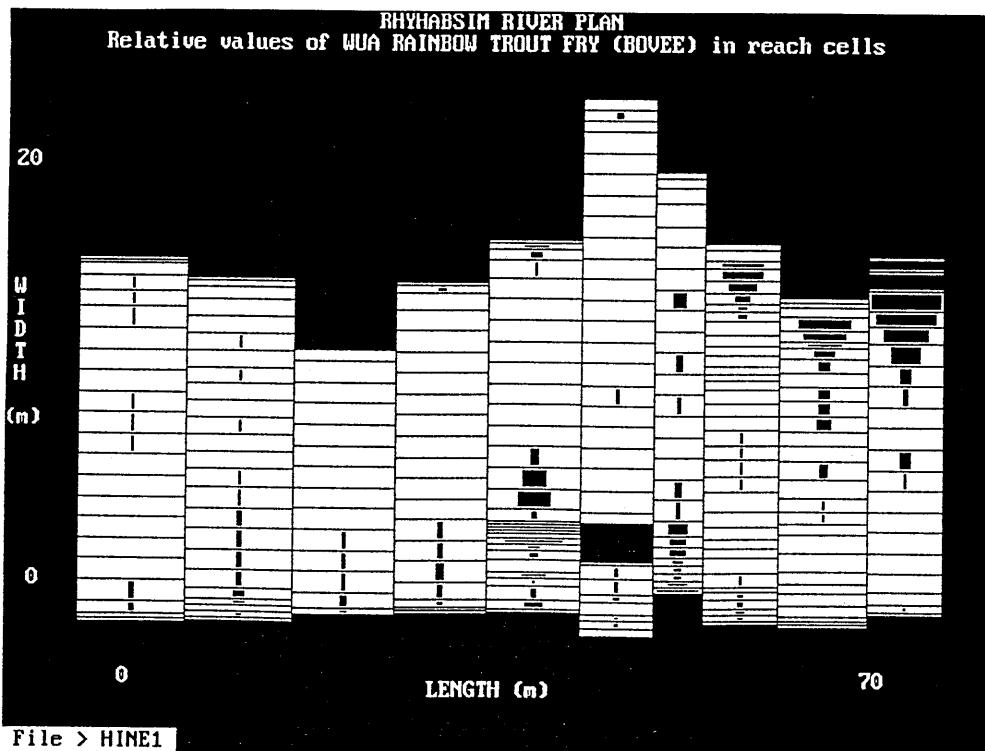
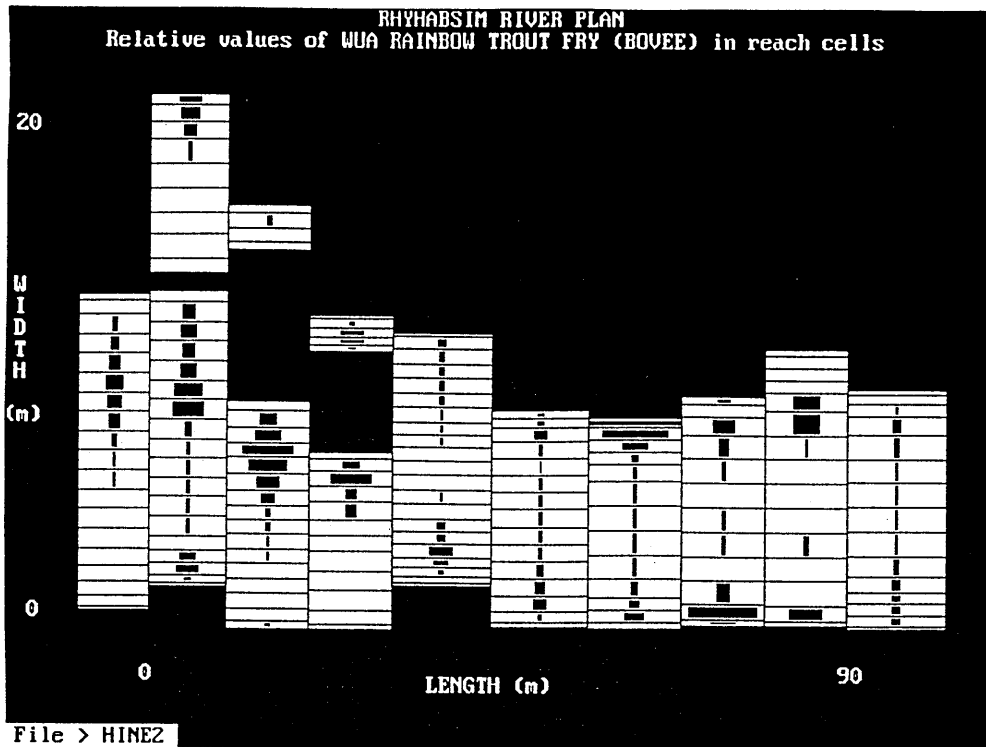


FIGURE 16. Suitability of habitat at (A) low flow and (B) high flow in the middle reach of the Hinemaiaia River for rainbow trout fry predicted from the models of Bovee (1978). Suitability of individual cells represented by horizontal width of the black bar in each cell. Solid black areas are dry.

A. Low flow



B. High flow

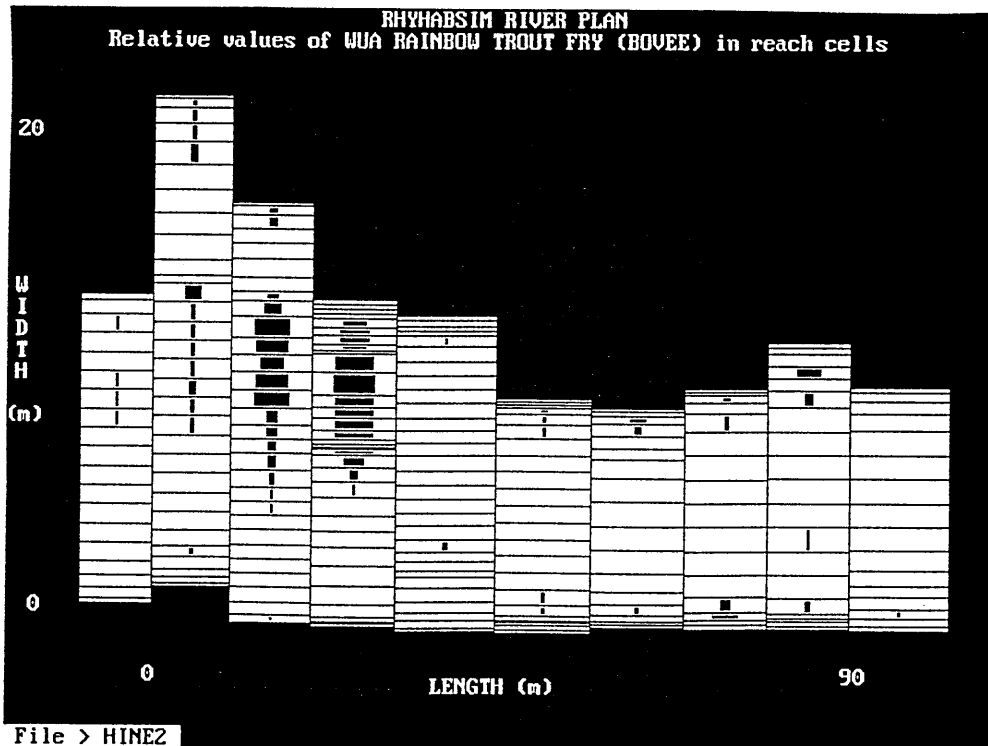
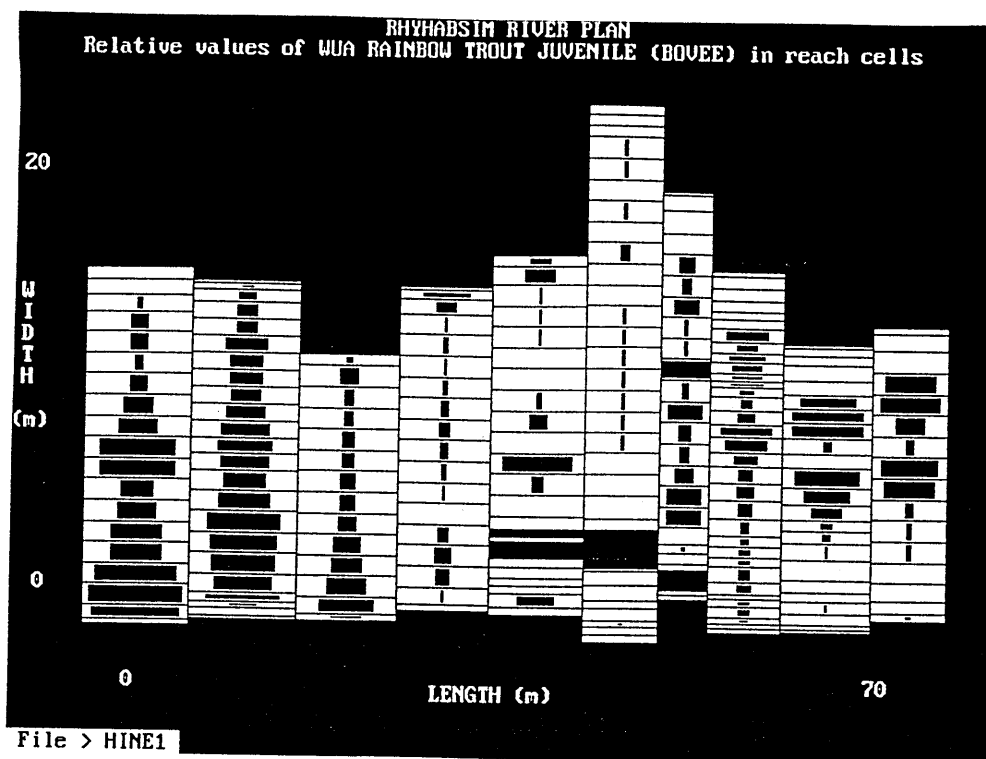


FIGURE 17. Suitability of habitat at (A) low flow and (B) high flow in the lower reach of the Hinemaiaia River for rainbow trout fry predicted from the models of Bovee (1978). Suitability of individual cells represented by horizontal width of the black bar in each cell. Solid black areas are dry.

A. Low flow



B. High flow

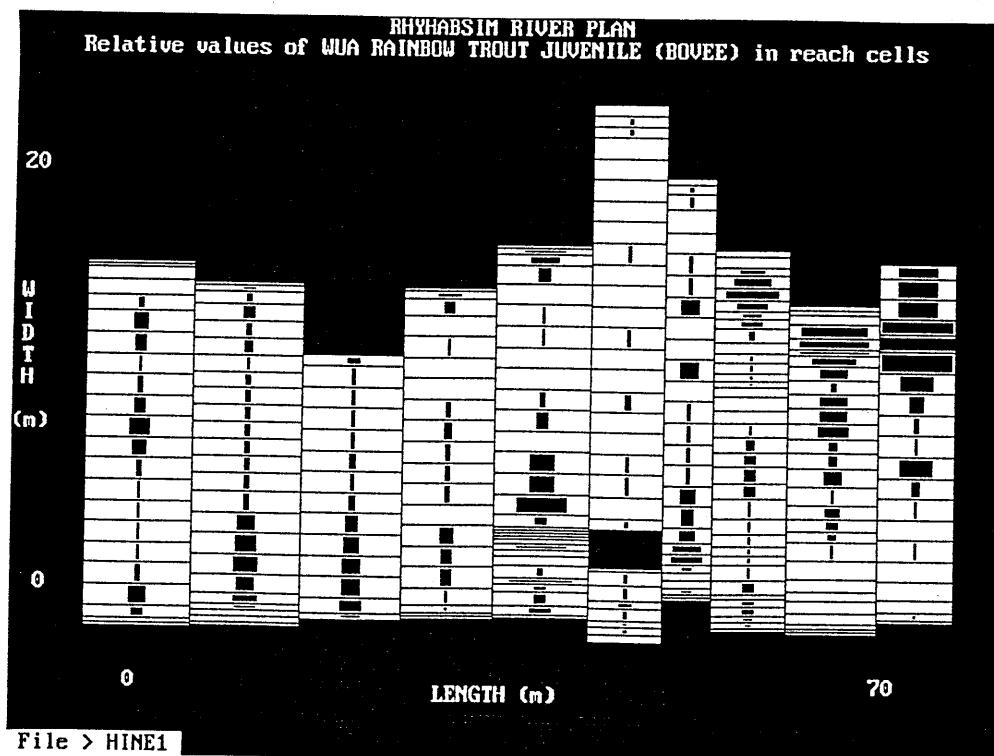
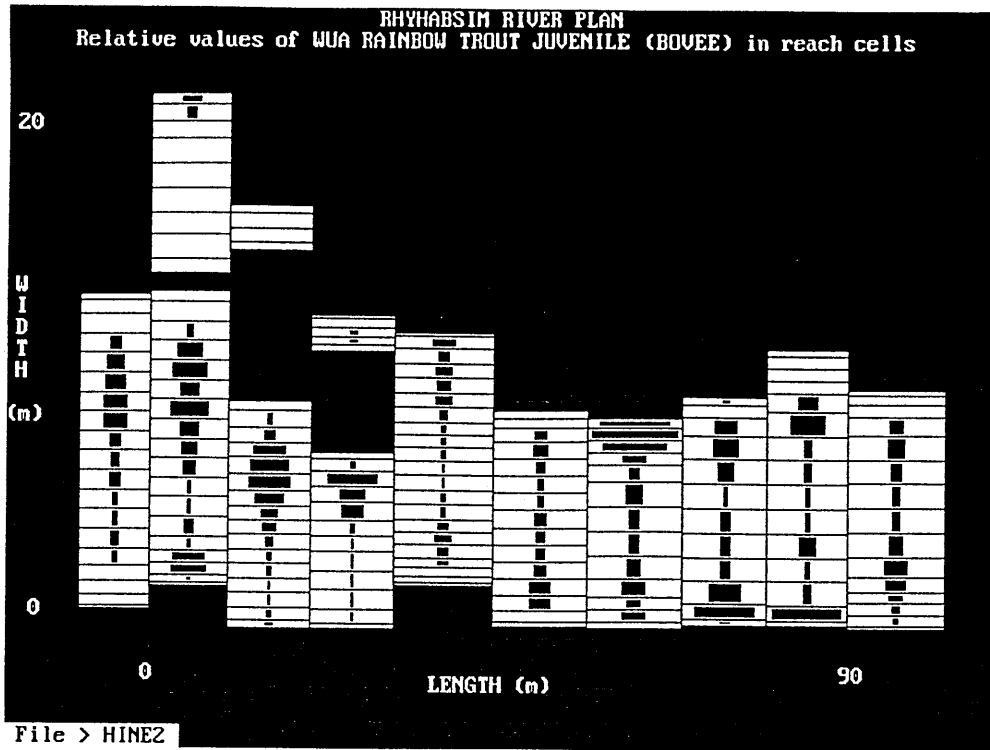


FIGURE 18. Suitability of habitat at (A) low flow and (B) high flow in the middle reach of the Hinemaiaia River for rainbow trout juveniles predicted from the models of Bovee (1978). Suitability of individual cells represented by horizontal width of the black bar in each cell. Solid black areas are dry.

A. Low flow



B. High flow

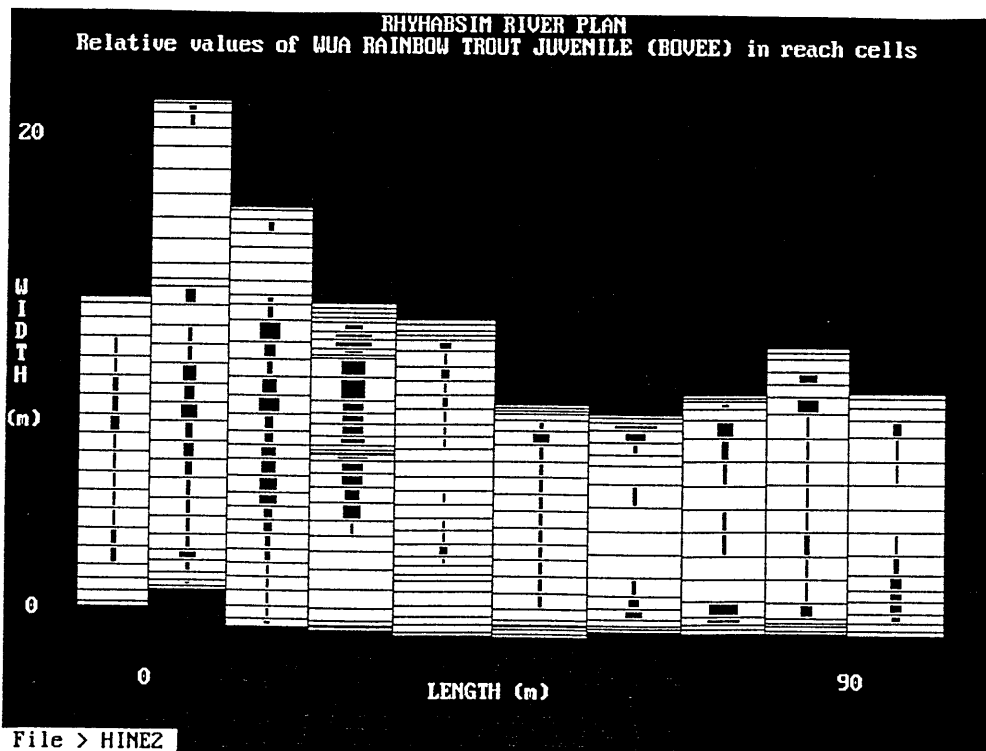
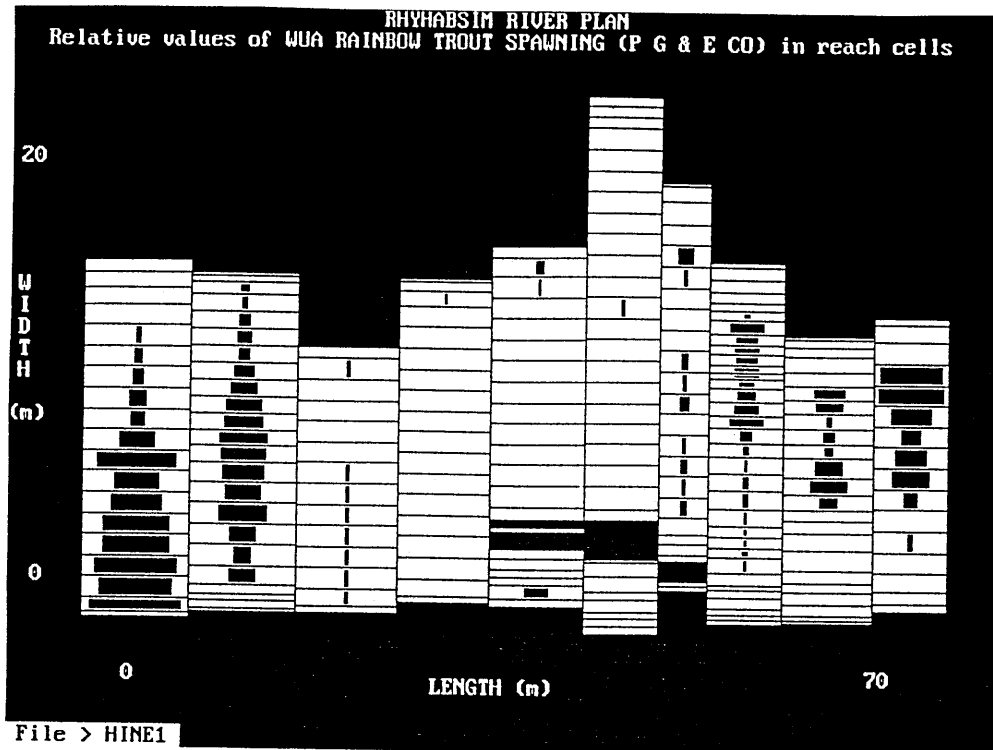


FIGURE 19. Suitability of habitat at (A) low flow and (B) high flow in the lower reach of the Hinemaiaia River for rainbow trout juveniles predicted from the models of Bovee (1978). Suitability of individual cells represented by horizontal width of the black bar in each cell. Solid black areas are dry.

A. Low flow



B. High flow

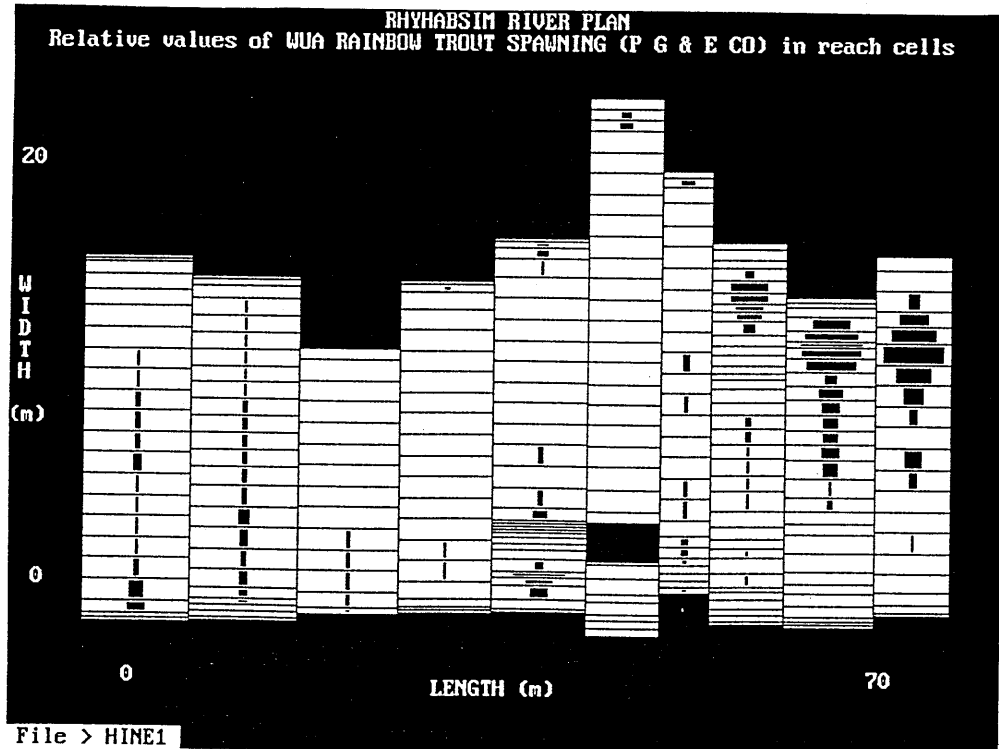
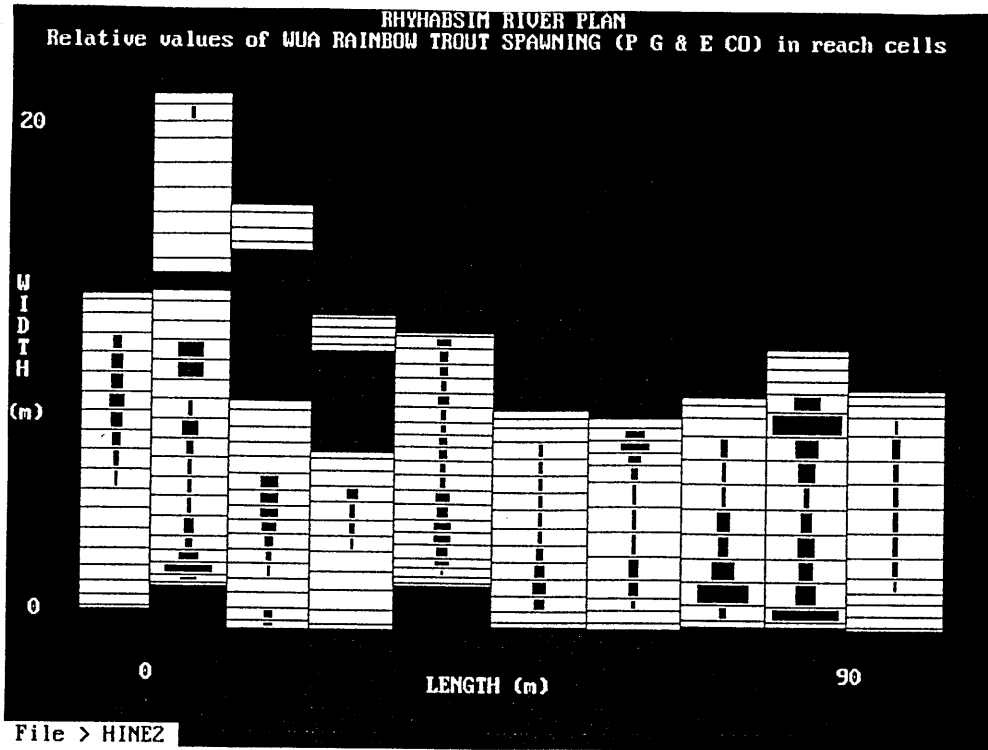


FIGURE 20. Suitability of habitat at (A) low flow and (B) high flow in the middle reach of the Hinemaiaia River for rainbow trout spawning predicted from the models of Waters (1976). Suitability of individual cells represented by horizontal width of the black bar in each cell. Solid black areas are dry.

A. Low flow



B. High flow

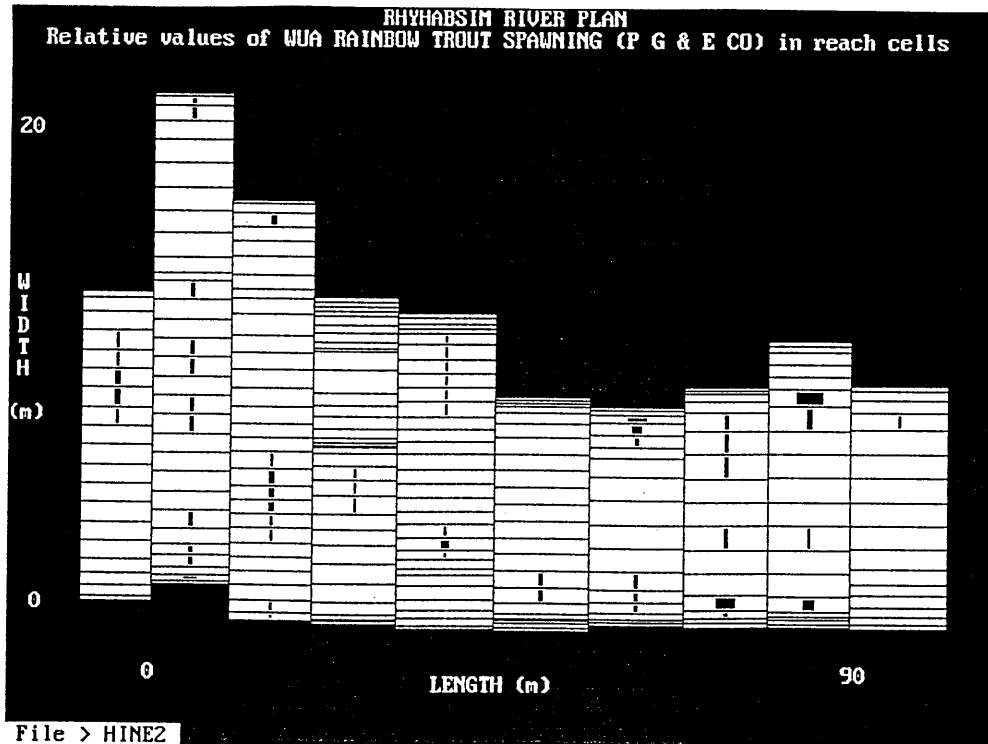
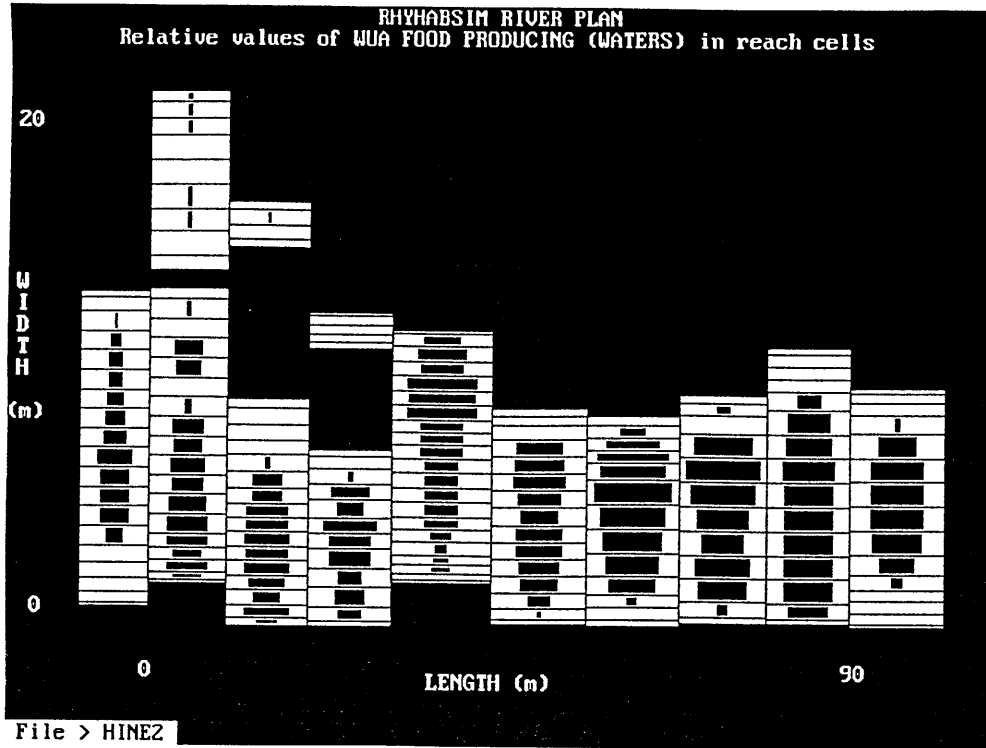


FIGURE 21. Suitability of habitat at (A) low flow and (B) high flow in the lower reach of the Hinemaiaia River for rainbow trout spawning predicted from the models of Waters (1976). Suitability of individual cells represented by horizontal width of the black bar in each cell. Solid black areas are dry.

A. Low flow



B. High flow

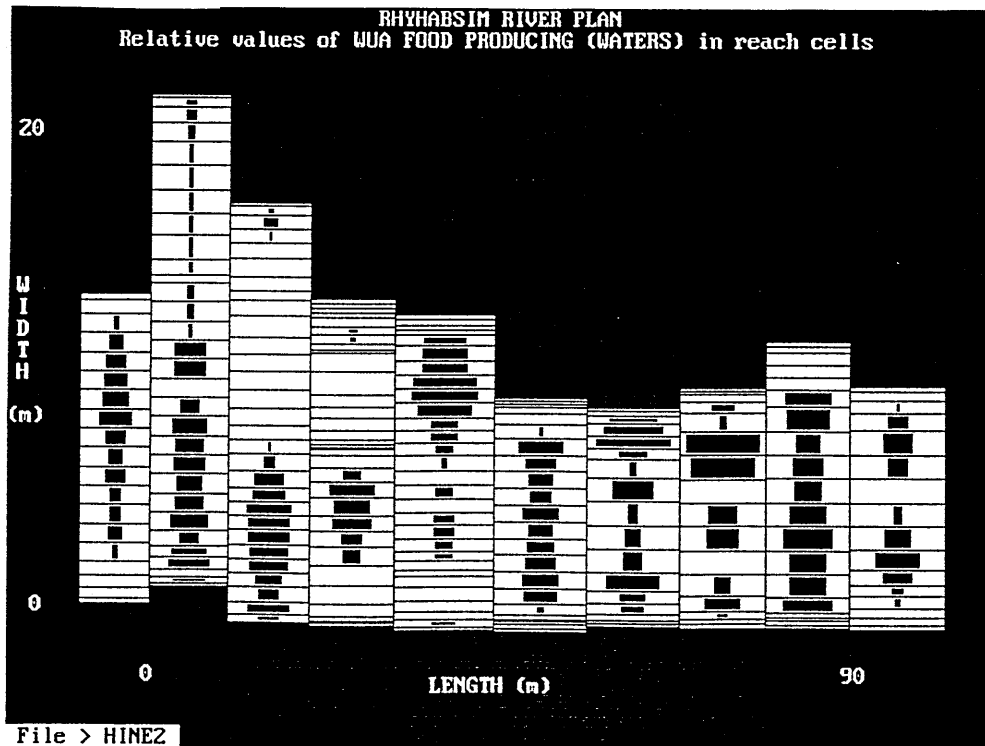


FIGURE 23. Suitability of habitat at (A) low flow and (B) high flow in the lower reach of the Hinemaiaia River for trout food production predicted from the models of Waters (1976). Suitability of individual cells represented by horizontal width of the black bar in each cell. Solid black areas are dry.

had moved to area B, and 10 smaller trout remained in area A. Two trout about 35 mm FL had moved to area C by this time. The larger fish appeared to orient to pulses of current direction more effectively than the smaller trout. The smallest trout were close to the surface, and did not change orientation with variations in current direction. At 1233 h generation ceased, and again 10 minutes later areas A-D were dry. When generation ceased, the current direction changed to flow downstream as the water level dropped. The response of trout was to swim actively upstream into the current. As the water level dropped enough to cut off escape, most of the fish remaining in areas A and B sought refuge under cobbles in the deepest areas. It was from these positions that we recovered them.

Flow changes with cessation of generation were relatively rapid. On 13 March 1991, at a site about 1 km downstream of the HB tailrace, the river was observed at high flow from 1100 h on. Water level started to fall at 1116 h, and had ceased to fall further at 1127 h. Such a rate of fall is consistent with observations immediately upstream of the HB tailrace, and indicates suggests that flow rate reduces from high to low flow at a rate of 5 m³/s in about 10 minutes.

DISCUSSION

Changes of spawning and rearing habitat and food production with flow increases

Of the available models of habitat suitability, Bovee's curves seemed to represent the habitats occupied by trout in the Hinemaiaia best. In addition, these Bovee's curves models gave the most detrimental effects of discharge fluctuations of any model, and are probably a "worst case" scenario. Our determinations of the actual depths, velocities, and substrate occupied by juvenile trout in the Hinemaiaia do not match Bovee's curves of habitat suitability well because of the limited ranges of these variable present at the test sites, and the small sample sizes. No models yet devised, however, take into account the behavioural response of fish to short-term discharge fluctuations.

Rainbow trout, in common with other salmonids, occupy and defend a territory. What part of the available habitat used by an individual trout as a territory depends food availability, competitors and predators present, and habitat suitability (Bjornn and Reiser 1991). At six months after emergence, salmonids generally occupy territories of 0.01-0.6 m², increasing to 1-10 m² at the end of their first year (Allen 1969). From the densities measured in this study, we conclude that territory size in November, when mean trout length was 30-44 mm FL, was 0.17-0.25 m² in the upper section. As size increased to 47 mm FL, territory size increased dramatically to 1.0 m². At equivalent times, territory sizes were larger in the middle section than in the upper section, and were larger in the lower section than in the middle section. These results probably reflect more stable habitat conditions in the upper section than in the middle or lower sections.

Minimal changes in location of suitable habitat means that rearing trout have only changes in suitability to contend with, and do not have to change position to accommodate new conditions under high flow conditions. Velocities close to the bed are likely to provide refugia for juvenile trout as discharge and water velocity increases, giving trout some

protection from unsuitable conditions. Under the influence of daily flow fluctuations, small shallow water fish are more affected than larger fish, and specialist feeders are more affected than generalists (Bain *et al.* 1988). Thus the most vulnerable life stage of juvenile trout is likely to be fry (<60 mm FL). Increases in flow above 8 m/s³ would reduce habitat suitability to zero at those locations that were previously suitable, and at this point rearing trout are likely to have to move to survive.

The impact of low flows at night in the channel below the HB generating station on juvenile trout have not been determined. Previous observations of feeding and resting behaviour suggest that juvenile trout feed primarily in the daytime, and rest in shallow, slow-flowing water at night (Bisson 1978, Campbell and Neuner 1985, Angradi and Griffith 1990). We would expect that the impact of low discharge at night would depend on its timing. If the drop in discharge were to start daylight hours, presumably trout would be able to reposition themselves successfully. However, if the drop in discharge occurred in the dark, when trout were already resting in shallow water, they would presumably be much less able to respond to the drop in water level, and incidence of stranding would be higher than in daylight.

A relatively large amount of the channel at the surveyed reaches was suitable for trout rearing and spawning. In 66 New Zealand rivers the mean amount of rainbow trout juvenile rearing habitat was 3.7%, and the maximum 14% (Jowett 1990), compared to 5-13% in the Hinemaiaia River, depending on flow. However, the amount of fry rearing habitat available at the surveyed reaches at low flow was substantially reduced at high generating flows and this should apply generally throughout most of the main channel of the Hinemaiaia River because the channel is U-shaped with relatively steep banks for much of its length.

Habitat suitable for food production was not greatly adversely affected by flow fluctuations, probably because water velocities suitable for benthic invertebrates are generally higher than those for rearing salmonids. Flow fluctuations may, however, have caused simplification of invertebrate communities compared to the natural state of the river, as was recorded in the regulated section of the Clearwater River, Idaho (Munn and Brusven 1991). Substrate was a little fine and would inhibit food production.

Net-spinning caddises, which can be affected by fluctuating flows because of their requirements for specific velocities for food capture (Cushman 1985), were abundant at the middle site throughout the study.

Change of preferred habitat with increasing size of juvenile trout

Juvenile rainbow trout moved into faster, deeper water as they grew, and as water temperatures increased through spring and summer. This is consistent with the behavioural changes observed for most trout species. Smith and Li (1983) ascribed such changes to an increased requirement for food as fish grew, and as water temperatures warmed. Fast water velocities increase delivery rates of drifting invertebrates compared to slow flowing water. The amount of fast flowing water in the upper section is limited in summer, and may account for the habitat shift that occurred.

Ability of juvenile trout to respond to water level changes

The period of acclimation used in Experiment 2 appeared to reduce stranding of trout <45 mm FL compared to Experiment 1 from 80-100% to 27-67% (Fig. 24, C. and F.). The water level drop was very rapid, but the larger fish in Experiment 1 still managed to escape. The response of juvenile trout ≥ 55 mm FL to seek areas >25 cm deep protected them from stranding, because on release into an area of unsuitable habitat (area A), their immediate response was to leave to find deeper water. However, trout <45-50 mm FL were extremely susceptible to stranding because of the shallow depths they often occupy. This was a severe experiment, because in most parts of the river fish could escape to safety by swimming upstream, and only in backwaters that drain with reducing flow are they trapped by swimming upstream. Small depressions in the bed and cobbles substrate also reduce the ability of trout to avoid stranding. In Experiment 2, trout gradually moved out of the unsuitable area into which they were released.

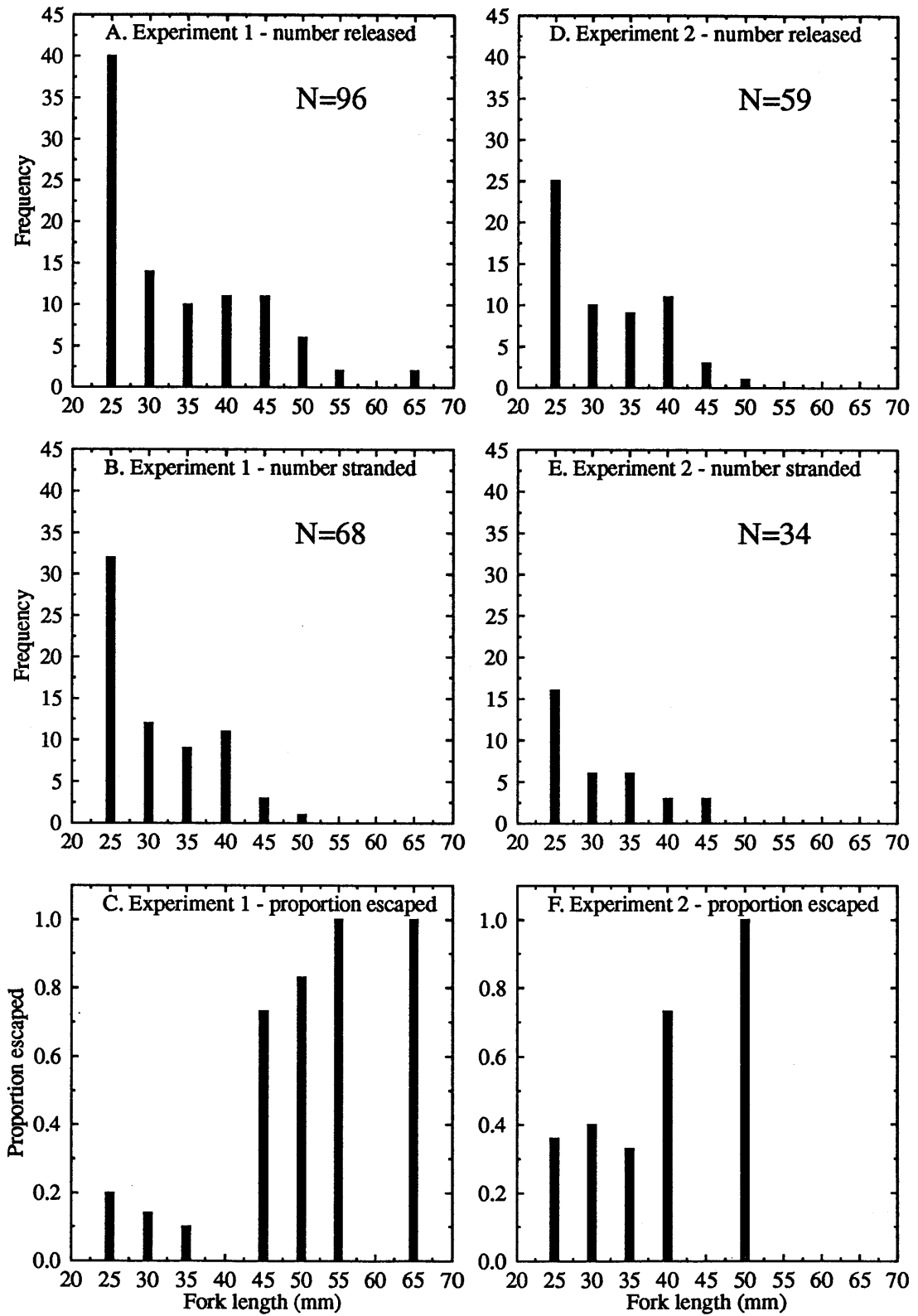


FIGURE 24. Length-frequencies of juvenile trout in stranding experiment in Hinemaiaia River.

CHAPTER 3.

EFFECTS OF HYDRO-ELECTRIC FLOW REGIME ON TROUT ANGLING

Introduction

Flow variation in the Hinemaiaia River has the potential to influence angling in two major ways. Firstly, flow might influence catch rate, as is the case with salmon fishing (Glova 1988, Potts and Malloch 1991). Secondly, anglers might choose to avoid certain flows for a variety of reasons, including difficulty of using different angling methods and spotting fish, and ease of wading. Factors influencing avoidance may not actually affect catch rate, but would affect the angling experience. In the Rakaia River, where spinning was the principal method used, the total daily catch of 12 experienced anglers was optimal over a narrow range of flows, and was lower at flows outside this narrow range. Turbidity was the factor limiting angling success, however, and turbidity is often related to flow in rivers with natural flow regimes.

The objectives of this section were to compare angling at high and low generating discharge, and to investigate factors influencing choice of specific flows. Only two flows were evaluated (3 and 8 m/s³), as these are the predominant operating flows in the Hinemaiaia River.

Methods

Two types of questionnaires were sent to 27 anglers who either said they fished the Hinemaiaia River, or were reputed to fish the river by other anglers. Questionnaires were sent in early May 1991, requesting detailed information about the influence of flow conditions on angling in the Hinemaiaia River, and the impacts these flows have on angling conditions and catch rates (Appendices 6 and 7). In addition, information regarding perceptions of changes in catch rates was canvassed. In December 1991 non-respondents were contacted again, firstly by mail and then by telephone.

Results

Replies were received from 13 anglers, nine of whom fished the Hinemaiaia River regularly enough to return completed forms. The anglers had fished the Hinemaiaia for 5-31 years (mean 16 years), and the principal methods used were upstream nymphing and downstream wet fly fishing (Table 5). Information was given about 37 angler days fishing. This information was divided into 15 occasions at high flow, and 28 occasions at low flow (Table 6). Anglers used a combination of angling methods: wet fly, upstream nymph, and dry fly. An average of 29 trout per year (range 2-80 fish) was caught by each angler. Catch rates for all methods combined were different at low flow compared

TABLE 5. Survey of methods used by trout anglers and proportions of annual trout catch in each of three locations in the Hinemaiaia River by 9 anglers in 1991 and 1992.

Angler's name	Years fishing	Trout caught per year	Methods used			Percentage caught in three reaches		
						above S.H.1	below S.H.1	in rip
Hanna	14	35	wf	un	df	5	15	80
Hart	30	25	wf	un	-	10	60	30
Rieger	11	25	wf	un	-	35	15	50
Allan	7	10	wf	un	-	36	42	22
Anonymous 1	9	10	-	un	-	40	50	10
Greer	31	30	wf	un	-	44	55	1
Mclean	5	2	wf	un	-	80	20	-
Johnson	16	40	-	un	-	100	-	-
Anonymous 2	24	80	wf	un	-	33	33	33

wf = wet fly.
 un = upstream nymph.
 df = dry fly.
 - = missing data.

to high flow ($p=0.001$, Mann-Whitney U test). Geometric mean catch rates were 0.21 and 0.85 fish/h for high and low flows respectively.

Average weight of trout caught was 1.57 kg (± 0.139 kg, 95% confidence interval, $N=34$). Average length of trout caught was 51 cm (± 5.232 cm, $N=24$). There was no difference between high or low flows in the weight or length ($p=0.698$ and $p=0.602$ respectively, Mann-Whitney U test) of trout caught.

Anglers spread their fishing effort between three sections: the rip at the river mouth, the river from the rip the State Highway 1 bridge, and the river between the S.H.1 bridge and a point 100 m below the Hinemaiaia B powerhouse. Proportions of annual catch caught in each area varied among anglers (Table 5), with one angler specialising in fishing the rip, and two others fishing almost exclusively in the section below the Hinemaiaia B powerhouse. Effort expended in the upper river was generally inversely proportional to effort expended at the rip. Because of the wide spread of proportion of fish caught in any one section, however, there was no difference between sections, considering all anglers in one section ($p=0.296$, Mann-Whitney U test).

Anglers rated their experience angling and wading as easy, moderate, or difficult at each location at each flow (Table 6). Wading in all sections combined was easier at low flow than at high. Angling analysed for each section individually was also easier at low flow than at high. Angling methods were analysed individually at the two flows. All methods

TABLE 6. Comparison of trout angling experience in the Hinemaiaia River at low (3 m/s³) and high flow (8 m/s³) in the Hinemaiaia River in 1991 and 1992.

Angler's name	Date*	Trout Number caught	catch Rate (no./h)	Location**		Time start (h)	Time stop (h)	Total time (h)	Flow	Method used***			Ability to wade fish	
Hanna	910206	0	0.0	-	-	rip	0900	1030	1.5	high	wf	-	-	d d
Greer	910520	0	0.0	ab	-	-	0800	1100	3.0	high	wf	un	-	d d
Johnson	910512	0	0.0	ab	-	-	0800	1200	4.0	high	-	un	-	d d
Johnson	910524	0	0.0	ab	-	-	1100	1430	3.5	high	-	un	-	d d
Noakes	910700	0	0.0	-	bb	rip	1000	1130	1.5	high	wf	-	-	d d
Noakes	910600	0	0.0	-	bb	rip	0700	0900	2.0	high	wf	un	-	d m
Hanna	910207	0	0.0	-	-	rip	0930	1030	1.5	high	wf	-	-	d d
Anon.	910526	0	0.0	-	bb	-	1000	1200	2.0	high	-	un	-	d d
Hanna	910125	1	0.3	-	-	rip	0830	1230	4.0	high	wf	-	-	d d
Johnson	910522	1	0.3	ab	-	-	0830	1230	4.0	high	-	un	-	d d
Johnson	910430	1	0.3	ab	-	-	0930	1230	3.0	high	-	un	-	d d
Johnson	910508	1	0.3	ab	-	-	0800	1100	3.0	high	-	un	-	m d
Johnson	910419	1	0.7	ab	-	-	0930	1100	1.5	high	-	un	-	d d
Anon. 1	911204	3	1.0	ab	-	-	0900	1200	3.0	high	wf	-	-	m e
Noakes	911200	3	1.0	ab	-	-	1800	2100	3.0	high	-	-	df	d m
Hanna	910408	1	-	ab	-	-	1300	-	-	low	-	un	-	m m
Hanna	910507	0	-	-	bb	rip	0500	0700	-	low	wf	un	-	e e
Hanna	910209	0	0.0	-	-	rip	1100	1200	1.0	low	wf	-	-	e e
Hanna	910212	0	0.0	-	-	rip	1100	1200	1.0	low	wf	-	-	e e
Greer	910520	0	0.0	ab	-	-	0630	0800	1.5	low	wf	un	-	e e
Hanna	910208	0	0.0	-	-	rip	0500	0630	1.5	low	wf	-	-	-
Johnson	910330	0	0.0	ab	-	-	1400	1530	1.5	low	-	un	-	m e
Hanna	910407	2	0.4	-	bb	-	0600	1100	5.0	low	-	un	-	e e
Rieger	910528	1	0.4	ab	-	-	1515	1730	2.3	low	-	un	-	e m
Anon. 2	920703	1	0.5	-	-	rip	1850	2050	2.0	low	wf	-	-	e e
Hanna	910209	1	0.7	-	-	rip	0500	0630	1.5	low	wf	-	-	e e
Noakes	910700	1	0.7	-	bb	rip	1130	1300	1.5	low	wf	-	-	m m
Rieger	910527	1	0.8	-	-	rip	1715	1830	1.3	low	wf	-	-	- e
Hanna	910120	1	0.8	-	-	rip	0730	0845	1.3	low	wf	-	-	e e
Rieger	910215	3	0.9	-	-	rip	2030	2400	3.5	low	wf	-	-	- m
Hanna	910118	1	1.0	-	-	rip	0615	0715	1.0	low	wf	-	-	e e
Hanna	910208	2	1.0	-	-	rip	1000	1200	2.0	low	wf	-	-	e e
Anon. 2	920701	2	1.0	-	-	rip	1850	2050	2.0	low	wf	-	-	e e
Hanna	910124	1	1.0	-	-	rip	1130	1230	1.0	low	wf	-	-	e e
Noakes	911200	4	1.1	ab	-	rip	1300	1630	3.5	low	-	un	df	e m
Hanna	910206	3	1.2	-	-	rip	0500	0730	2.5	low	wf	-	-	e e
Anon. 2	920604	3	1.5	-	-	rip	1850	2050	2.0	low	wf	-	-	e e
Anon. 2	920606	3	1.5	-	-	rip	1850	2050	2.0	low	wf	-	-	e e
Hanna	910207	5	2.0	-	-	rip	0500	0730	2.5	low	wf	-	-	e e
Hanna	910207	3	2.0	-	-	rip	1030	1200	1.5	low	wf	-	-	e e
Allan	910531	1	2.0	ab	-	-	1700	1730	0.5	low	-	un	-	e m
Hanna	910119	2	2.0	-	-	rip	0615	0715	1.0	low	wf	-	-	e e
Hanna	910206	5	3.3	-	-	rip	1030	1200	1.5	low	wf	-	-	e e

* = date of the form YYMMDD, where YY = year code, MM = month code, DD = day code.
 ** = ab = above SH1 bridge, bb = below SH1 bridge, rip = rip at mouth.
 *** = wf = wet fly, un = upstream nymph, df = dry fly
 - = missing data.

were easier at low flow than at high. Anglers' comments about the effects of flow on angling were varied. Five of the seven respondents who commented on flows found low flows easier to fish than high flows, especially for spotting fish. One respondent found high flows easier to fish than low flows, and two respondents gave complex responses, with the effect of flow conditions varying with the reach fished. Two respondents observed that fish began to feed at the onset of high flows, and that this rendered trout easier to catch for a short time. Another angler commented that although high flows made fish move to more accessible positions than they occupied at low flows, fishing was more difficult at high flows because increased current velocities prevented lines from sinking.

Seven out of eleven anglers commented about the presence of snags, especially in the section below S.H.1 bridge, that increased the difficulty of fishing, sometimes considerably. Five out eleven anglers made special mention of the difficulty of wading at high flow.

Discussion

There were clear links between flow and the angling experience; angling and access to the river was easier at low flow ($3 \text{ m}^3/\text{s}$) than at high flow ($8 \text{ m}^3/\text{s}$). All fishing methods, wading, and spotting fish were almost universally easier at low flow than at high. Methods that worked at low flow (e.g., upstream nymph fishing) were ineffective at the higher flow because increased water velocities did not allow tackle to sink efficiently. Some anglers remarked on an increase in catch rate as flows increased initially, but this higher catch rate was short-lived.

The frequency of flow fluctuations frustrated anglers, sometimes causing them to stop fishing at the flow increase. Most anglers commented on the frequency and speed of change of flow fluctuations. These flow fluctuations in themselves detracted from the angling experience, and in several cases stranded anglers unexpectedly on one bank. One angler described cessation of high flow at 1050 h, followed by a rapid flow increase one hour later at 1150 h.

Some positive comments were received. One angler noted that the presence of dams on the river seemed to reduced turbidity normally associated with floods. Flow fluctuations did not always detract from angling success. One angler who regularly fished one spot in the river about 150 m upstream from the mouth between early May and the end of June used his knowledge of flow fluctuations to good advantage:

"Once I learnt where the fish were lying, I could guarantee getting a fish in a short space of time. The most important thing was to start fishing just before the flow was increased at the dam..... Once the flow had reached its maximum, usually [in] about 10 minutes, the fish would take. This only lasted for about 30 minutes or so and [then] either the fish moved up or down stream, I'm not sure which (I'm sure I never spooked them!)."

Changes in flow have been observed to increase drift rates (Cushman 1985), so the response of trout to start moving at the onset of flow increases might be a response to increasing drift. However, as most adult fish in the Hinemaiaia are not resident in the river, and might not be feeding, movement after a flow increase may be more a migratory than a feeding response. Nevertheless, adult trout are hooked on representations of food items. Further work is necessary on this aspect of the trout response to flow fluctuations. Fluctuating flows can also deplete an invertebrate community over time, but zooplankton from dams upstream can supplement the tailwater food base (Cushman 1985).

Previous studies have found that increased flows lead to increased catch rates. Catch rate of quinnat salmon in the Rakaia River increased with increasing flow to an optimum, then declined rapidly with further flow increases (Glova 1988). However, Glova investigated the interaction of natural flow and catch rates rather than daily flow fluctuations. The changes reported by Glova were more related to turbidity than to flow changes alone.

A major shortcoming of the angler survey was the low response rate. Fewer than 50% of anglers to whom questionnaires were sent eventually responded, and of these 13 who did reply, four anglers either fished too irregularly to be included in the analysis, or had ceased fishing the Hinemaiaia River. Most anglers felt that angling in the Hinemaiaia River had declined in the past 4-5 years, and this feeling may be restricting the number of anglers fishing the river. Consistent complaints about the angling in the Hinemaiaia River focused on the amount woody debris that hindered casting, the difficulty of wading at high flows, and the disruptive influence of frequent flow fluctuations on angling. The anglers who did respond were also the keen, experienced anglers.

Without previous estimates of catch rates for the Hinemaiaia River, it is not possible to tell if in fact there has been a decline. Ease of fishing would be improved by removal of snags. However, instream woody debris has been shown to provide fish cover (Bustard and Narver 1975), and slows water velocity. Regions of low velocity are preferred by fry and juveniles. Thus removal of snags, though it may help angling in the short term, would probably be counterproductive for trout production in the long term.

CHAPTER 4.

RECOMMENDATIONS FOR FLOW REGIME AND ANGLING SEASON

The objective of this section is to formulate recommendations, based on the information presented in the preceding chapters, for

1. future flow management, and
2. angling season restrictions

that may improve trout production and angling in the Hinemaiaia River.

Flow regime

The present flow regime does not appear to compromise juvenile trout rearing, as the number of spawning adults suggests. While the total size of the spawning run of rainbow trout into the Hinemaiaia River is not known, trout counts in July and August suggests that at least 1400-3600 fish are in the river at the time of peak abundance (Appendix III). Tully (1989) estimated the number of fish in the Hinemaiaia River in July as 5600, but this figure is probably an overestimate because he assumed he counted only 54% of the fish present, based on a tagging experiment. Tully acknowledged that the proportion of fish seen compared to the total population predicted by the tagging experiment was probably a minimum estimate.

The size and nature of the main channel below the Hinemaiaia B station provides a relatively large amount of rearing habitat (8-13%) at low flow. Even though the amount of habitat suitable for fry and juvenile rearing is reduced at high flow, the amount is still greater than an average New Zealand river (Jowett 1990). The dominant flow in spring, summer, and autumn is low flow, which provides the greater amount of rearing habitat.

On the basis of the velocity measurements and habitat modelling, it appears that the Hinemaiaia River provides a large amount of trout spawning and rearing habitat relative to other New Zealand rivers. In addition, there is ample habitat suitable for food production. For optimal rearing conditions, suitable depths, velocities, substrates, and food production are necessary. Improvements could be gained if the river contained coarser substrate, which is of course beyond river managers' control, and with lower flows rather than higher. However, the conditions for trout spawning and rearing are satisfactory compared to most New Zealand rivers.

Fluctuating flows may strand juvenile trout (Cushman 1985). Our studies show that susceptibility to stranding diminishes rapidly with increasing size of juvenile trout. Fish ≥ 55 mm FL are effectively immune from stranding because of their habitat requirements and the magnitude of depth variations. Smaller trout could be stranded in backwaters

with gently-shelving shores, but these are relatively infrequent in the generally U-shaped channel of the Hinemaiaia River. For this reason we do not regard stranding as a major source of mortality.

Reduction in peak flow would improve rearing habitat and slightly reduce food production. However, differences in juvenile densities in November 1991 (Appendix IV) show that flow fluctuations are not the only factor limiting fish densities. Densities were similar in the upper and middle reaches (4.0 and 3.3 fish/m² respectively), even though the middle section is affected by flow fluctuations, whereas the upper section is not. Densities in the lower section were 0.8 fish/m² at the same time. Substrates were generally smaller in the lower reaches than in the middle and upper sections, and vegetation at the water's edge was less stable than in the upper and middle sections. Thus the steep-sided channel, combined with bank erosion and finer substrate, may limit habitat suitability in the lower section.

An issue critical to juvenile production in the Hinemaiaia River is the fate of juveniles <94 mm FL in Lake Taupo. There is evidence to suggest that trout smaller than 90 mm can survive to adulthood in lakes. Lake-shore spawning in Lake Rotoma, where this is regarded as the main form of spawning, suggests that juvenile trout can successfully survive in lakes to adulthood from fry (Penlington 1983).

There was a 20-fold difference between peak fry densities in November (6 fish/m²) and juvenile densities in February (0.3 fish/m²). Hayes (1988b) found similar initial densities in Scotts Creek, Lake Alexandrina. If only 5% of fry and juveniles in the Hinemaiaia migrating downstream before they reach the size of 94 mm FL survive in the lake to adulthood, their numbers would equal trout migrating in late summer from the river.

In rivers draining to the sea, size on downstream migration is a component of survival in the sea because fish must undergo the physiological changes of smoltification in order to withstand the osmotic shock of entry to seawater. Smoltification is a process induced by photoperiod and temperature in fish of >90 mm (Zaugg and Wagner 1973; Wagner 1974).

HB dam construction

Since construction of the HB dam, trout have been denied access to the Kakapo and the Pahikohuru Streams for spawning. However, many trout now spawn in the main channel between the dam and the HB powerhouse. Our peak count of spawners was over 600 fish. This reach would have been also have been available spawners before building of the dam, but rearing conditions have undoubtedly been improved by diversion of the main flow out the channel past this section. High velocities, at both high and low generating discharges, are the main constraint on juvenile rearing habitat in the channel below the HB powerhouse. Juvenile trout rearing in the section between the dam and the powerhouse do not have these high velocities to deal with. The considered opinion of N.B Ewing, who was involved in the investigation of the Pahikohuru Stream spawning potential, was that spawning and rearing conditions were generally improved following dam construction.

Angling season

Protection of early spawners from angling is probably very important to production of large sized juveniles in the Hinemaiaia River. Assuming the peak of downstream migration of juveniles large enough to survive in Lake Taupo occurs in February, trout spawning in June probably enter the river in April or May and provide a disproportionate number of larger juveniles compared to later spawners. In contrast, trout spawning in September-December probably contribute relatively few successful recruits to the lake. Later spawners are less likely to contribute successful juveniles because of the limitation of high water temperatures on incubation in spring, and low water temperatures on growth in autumn.

Recommendations

1. Reduce the rate and frequency of daily changes of discharge downstream of the Hinemaiaia B powerhouse to a minimum consistent with operation of hydro-electric generation.
2. Investigate and rectify the cause of short-lived flow surges from the Hinemaiaia B station, and subsequently generate electricity with a minimum of flow changes during a day.
3. Reduce loss of trout fry resting in shallow water at night by avoiding flow changes during the hours of darkness from November to February inclusive, the primary period of trout rearing.
4. Change the closed season to 1 May to 30 September, reflecting the importance of early-spawning trout to juvenile production. Continue to monitor trout abundance to establish the effectiveness of this measure.

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APPENDIX I. Profile and channel features of the lower and middle reaches of the Hinemaiaia River.

Distance from Lake Taupo (km)	Height above sea level (m)	Gradient (m/km)	Channel feature
0	357		Lake Taupo
1.35			SH 1 bridge
1.52	360	2.0	
3.45			trib A TLB
3.60	370	4.8	
4.33			trib B TLB
5.07			powerline
5.42			trib C TRB
6.72	380	3.2	
6.92	400		Hinemaiaia B dam
9.74			Kakapo Stream TLB
10.15			Pahikohuru Stream TLB
10.74			upper end of HB lake (417.9 m)
11.16	420	5.4	
12.28	440	17.8	
12.52			
12.66			upper end HC lake (457.2 m)
12.73	460	45.4	
14.93	480	9.1	
14.97			
16.28			upper end HA lake (493.3 m)
16.97	500	9.8	
17.27			Waiwhiowhio Road bridge

APPENDIX II. Air and water temperatures, and underwater visibility, at the time of dive counts in the Hinemaiaia River, 1990-1991. (NA = not applicable, - = missing data).

Date	Time (h)	Section	Temperature (°C)		Underwater visibility (m)		Generation (% gate)
			water	air	black disk	Secchi disk	
29 Jun 1990	1110	upper	-	-	3.2	5.0	NA
29 Jun 1990	1000	middle	9.0	6.0	3.3	4.1	100
29 Jun 1990	1330	middle	-	-	3.3	5.2	40
29 Jun 1990	1455	lower	-	-	4.2	5.9	40
26 Jul 1990	1055	upper	9.6	9.0	2.5	3.5	NA
26 Jul 1990	1315	middle	-	-	1.9	3.6	40
26 Jul 1990	1430	lower	-	-	3.0	4.4	40
22 Aug 1990	1110	upper	8.6	10.0	1.7	3.5	NA
31 Aug 1990	1045	middle	9.0	11.0	2.6	5.1	40
25 Sep 1990	1120	upper	10.0	11.3	3.2	5.0	NA
25 Sep 1990	1325	middle	-	-	2.9	5.0	40
25 Sep 1990	1435	lower	-	-	3.6	5.8	40
07 Nov 1990	1150	upper	12.0	18.0	-	-	-
08 Nov 1990	0945	upper	11.0	14.0	-	-	-
23 Nov 1990	1015	middle	12.5	14.5	-	-	-
12 Dec 1990	1335	upper	13.8	19.2	-	-	-
12 Dec 1990	1000	middle	16.0	16.9	-	-	-
15 Jan 1991	1145	upper	13.8	19.0	-	-	-
16 Jan 1991	0947	upper	13.2	15.5	-	-	-
16 Jan 1991	1246	lower	15.0	18.5	-	-	-
07 Feb 1991	1100	upper	12.6	19.8	2.1	2.5	NA
07 Feb 1991	1420	middle	-	-	2.1	3.6	40
08 Feb 1991	1105	lower	16.0	22.0	-	-	-
08 Feb 1991	1415	upper	16.0	20.5	-	-	-
22 Feb 1991	1040	upper	12.2	14.5	-	-	-
12 Mar 1991	1445	lower	14.6	21.1	-	-	40
13 Mar 1991	1444	lower	14.4	19.0	-	-	40
13 Mar 1991	1020	middle	12.2	14.2	-	-	40
14 May 1991	1035	upper	8.0	8.6	1.9	2.9	-
14 May 1991	1035	upper	-	-	1.4	3.3	-
14 May 1991	1225	middle	8.3	11.6	2.8	3.9	Spill
22 May 1991	1035	upper	7.1	9.1	2.7	4.5	NA
22 May 1991	1250	middle	7.7	11.0	3.0	5.3	40
22 May 1991	1415	lower	8.0	11.7	3.0	5.1	40
20 Jun 1991	1055	upper	7.0	7.4	3.3	5.1	NA
20 Jun 1991	1300	middle	7.6	8.1	3.0	4.0	40
20 Jun 1991	1422	lower	8.4	8.4	3.1	4.6	40
29 Aug 1991	1115	upper	9.0	11.2	2.3	3.3	NA
29 Aug 1991	1345	middle	9.6	12.0	2.5	3.3	40
08 Oct 1991	1040	upper	8.5	11.0	2.9	4.8	NA
08 Oct 1991	1320	middle	10.0	13.5	2.9	4.8	40
02 Dec 1991	0930	upper	12.6	13.2	-	-	100

NA = not applicable.
 - = missing data.

APPENDIX III. Counts of adult rainbow trout by divers in the Hinemaiaia River, 1990-1991. Lengths of sections - lower, 0.79 km before May 1991, 0.81 in May 1991 and subsequent dives; middle, 1.10 km; upper 1.07 km.

Date	Number of trout >10 cm FL per kilometre												Black disc visibility (m)	
	lower section				middle section				upper section				all sections	
29 Jun 1990	485	(472	8	5)*	515	(509	3	3)	212	(212	0	0)	397	3.2-4.2
26 Jul 1990	223	(214	6	3)	585	(585	0	0)	649	(647	2	0)	511	1.9-3.0
22-31 Aug 1990	135	(129	6	0)	490	(481	9	0)	569	(567	2	0)	424	1.7-2.6
25 Sep 1990	65	(58	6	0)	274	(267	6	0)	344	(340	4	0)	243	2.9-3.6
07 Feb 1991	29	(5	13	11)	28	(4	6	18)	4	(3	0	1)	20	2.1
22 May 1991	83	(58	7	17)	35	(25	4	5)	40	(36	5	0)	50	2.7-3.0
20 Jun 1991	233	(205	23	5)	131	(120	10	1)	75	(73	2	0)	139	3.0-3.1
29 Aug 1991	123	(119	5	0)	212	(199	13	0)	252	(239	13	0)	202	2.3-2.5
08 Oct 1991	84	(60	16	7)	108	(97	7	4)	75	(71	4	0)	90	2.9

* numbers in brackets refer to large, medium, and small fish respectively

APPENDIX IV. Densities of (A) juvenile trout (< 10 cm FL), (B) common bullies, and (C) koaro at three sites in the Hinemaiaia River, 1990-1991.

Date	Mean depth (cm)	Length (m)	Mean width (m)	Area (m ²)	Population estimate		
					number	95% CL	fish/m ²
A. JUVENILE TROUT							
Upper site							
07 Nov 1990	0.13	8.5	8.0	68.0	391	17.0	5.75
12 Dec 1990	0.18	10.0	8.0	80.0	78	4.6	0.98
15 Jan 1991	0.19	11.0	8.4	92.4	17	0.3	0.18
08 Feb 1991	0.19	17.8	8.0	142.4	39	-	0.27
09 Oct 1991	-	11.0	8.4	92.4	42	-	0.45
09 Oct 1991	-	17.8	8.0	142.4	11	-	0.08
26 Nov 1991	-	17.8	8.0	142.4	51	-	0.36
26 Nov 1991	-	8.7	5.25	45.7	182	-	3.98
Middle site							
12 Dec 1990	0.38	10.0	4.7	47.0	32	8.8	0.68
15 Jan 1991	0.47	9.9	4.6	45.5	2	0.0	0.04
26 Nov 1991	-	11.9	1.5	17.9	59	-	3.31
Lower site							
12 Dec 1990	0.31	17.4	3.8	66.1	19	0.5	0.29
16 Jan 1991	0.31	17.8	3.8	67.6	0	-	0.00
09 Oct 1991	-	17.8	3.8	67.6	9	-	0.13
27 Nov 1991	-	17.8	3.8	67.6	57	-	0.84
B. COMMON BULLIES							
Upper site							
07 Nov 1990	0.13	8.5	8.0	68.0	1	-	0.01
12 Dec 1990	0.18	10.0	8.0	80.0	0	-	0.00
15 Jan 1991	0.19	11.0	8.4	92.4	0	-	0.00
08 Feb 1991	0.19	17.8	8.0	142.4	0	-	0.00
09 Oct 1991	-	11.0	8.4	92.4	2	-	0.02
09 Oct 1991	-	17.8	8.0	142.4	0	-	0.00
26 Nov 1991	-	17.8	8.0	142.4	0	-	0.00
26 Nov 1991	-	8.7	5.2	545.7	0	-	0.00
Middle site							
12 Dec 1990	0.38	10.0	4.7	47.0	1	8.8	0.02
15 Jan 1991	0.47	9.9	4.6	45.5	6	-	0.13

Date	Mean depth (cm)	Length (m)	Mean width (m)	Area (m ²)	Population estimate		
					number	95% CL	fish/m ²
26 Nov 1991	-	11.9	1.5	17.9	12	-	0.67
Lower site							
12 Dec 1990	0.31	17.4	3.86	6.1	40	0.5	0.60
16 Jan 1991	0.31	17.8	3.86	7.69	2	-	1.36
09 Oct 1991	-	17.8	3.86	7.64	6	-	0.68
27 Nov 1991	-	17.8	3.86	7.63	8	-	0.56
C. KOARO							
Upper site							
07 Nov 1990	0.13	8.5	8.06	8.0	5	1.2	0.07
12 Dec 1990	0.18	10.0	8.08	0.0	6	-	0.08
15 Jan 1991	0.19	11.0	8.49	2.4	4	0.0	0.04
08 Feb 1991	0.19	17.8	8.0	142.4	21	-	0.15
09 Oct 1991	-	11.0	8.4	92.4	3	-	0.03
09 Oct 1991	-	17.8	8.	142.4	17	-	0.12
26 Nov 1991	-	17.8	8.0	142.4	17	-	0.12
26 Nov 1991	-	8.7	5.2	545.7	22	-	0.48
Middle site							
12 Dec 1990	0.38	10.0	4.7	47.0	1	-	0.02
15 Jan 1991	0.47	9.9	4.6	45.5	1	-	0.02
26 Nov 1991	-	11.9	1.5	17.9	0	-	0.00
Lower site							
12 Dec 1990	0.31	17.4	3.8	66.1	25	14.0	0.38
16 Jan 1991	0.31	17.8	3.8	67.6	32	45.0	0.47
09 Oct 1991	-	17.8	3.8	67.6	90	-	1.33
27 Nov 1991	-	17.8	3.8	67.6	78	-	1.15

- = missing data

APPENDIX V. Form soliciting anglers' recollections of their fishing experience in the Hinemaia River.

RECOLLECTIONS OF FISHING IN THE HINEMAIAIA RIVER

(Please circle one choice, or fill in as appropriate) I WISH TO REMAIN ANONYMOUS: YES/NO

ANGLER'S NAME: _____ PHONE:() _____

ADDRESS: _____

FOR HOW MANY YEARS HAVE YOU FISHED THE HINEMAIAIA RIVER? 19__ TO 19__

APPROXIMATELY HOW MANY FISH HAVE YOU CAUGHT EACH YEAR? _____

METHOD GENERALLY USED: Downstream wet fly Upstream nymph Dry fly Other _____

WHERE DO YOU GENERALLY FISH ON THE RIVER?

Above SH 1 bridge Below SH 1 bridge River mouth rip Other: _____

PERCENTAGE OF FISH CAUGHT AT EACH LOCATION:

Above SH 1 bridge _____ % Below SH 1 bridge _____ % River mouth rip _____ % Other _____ %

EASE OF FISHING AT DIFFERENT FLOWS (RATE EASY, MODERATE, OR DIFFICULT):

METHODS	LOCATION					
	Above SH 1 bridge		Below SH 1 bridge		Rip at mouth	
	high flow	low flow	high flow	low flow	high flow	low flow
Downstream wet fly	_____	_____	_____	_____	_____	_____
Upstream nymph	_____	_____	_____	_____	_____	_____
Dry fly	_____	_____	_____	_____	_____	_____

HAVE CATCH RATE, SEASON OF BEST FISHING, OR EASE OF FISHING CHANGED OVER THE YEARS (ESPECIALLY BEFORE AND AFTER ABOUT 1983), AND IF SO, HOW? (COMMENT ON METHODS USED, LOCATION ON THE RIVER, AND FLOW (HIGH OR LOW)):

CATCH RATE: _____

SEASON OF BEST FISHING: _____

EASE OF FISHING: _____

OTHER COMMENTS (E.G. EASE OF WADING: _____

Please return completed forms to:
Dr Brendan Hicks
Freshwater Fisheries Centre
MAF Fisheries
P.O. Box 6016
Rotorua

If you have any questions or comments,
call Brendan Hicks collect (07) 346 3730 (work)
(07) 345 7701 (home)
(07) 348 0091 (fax)

CALL OR WRITE FOR MORE STAMPED, ADDRESSED ENVELOPES

APPENDIX VI. Form soliciting information on daily fishing trips to the Hinemaiaia River.

FISHING EXPERIENCE IN THE HINEMAIAIA RIVER IN 1991

(Please circle one choice, or fill in as appropriate) I WISH TO REMAIN ANONYMOUS: YES/NO

ANGLER'S NAME: _____ PHONE: () _____

ADDRESS: _____

DATE: _____ 199_ REACH: Above SH 1 bridge River below SH 1 bridge

Rip at mouth

TIME STARTED FISHING: _____ h TIME STOPPED FISHING: _____ H

RIVER FLOW DURING FISHING (NOTE LEVEL COMPARED TO GRASS AT EDGE, EXPOSED MUD):

HIGH LOW

METHOD: Downstream wet fly Upstream nymph Dry fly Other: _____

NUMBER OF FISH CAUGHT: _____

SIZE OF FISH (FORK LENGTH): _____ CM/INCHES

WEIGHT OF FISH: _____ KG/LBS

EASE OF WADING: Easy Moderate Difficult Not appropriate

EASE OF ANGLING: Easy Moderate Difficult

COMMENTS (e.g., effects of flow, problems with casting, line drift, hooking efficiency, ability to see fish, etc.)

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Freshwater Fisheries Centre
MAF Fisheries
P.O. Box 6016
Rotorua

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