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FISHERIES ENVIRONMENTAL REPORT NO. 22

THE WHAKAPAPA RIVER:

A STUDY OF A TROUT FISHERY

UNDER A MODIFIED FLOW REGIME

FISHERIES RESEARCH DIVISION
MINISTRY OF AGRICULTURE AND FISHERIES
WELLINGTON

THE WHAKAPAPA RIVER:
A STUDY OF A TROUT FISHERY
UNDER A MODIFIED FLOW REGIME

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1. INTRODUCTION

The Tongariro power project, a state hydroelectric scheme, is administered by New Zealand Electricity (NZE), a division of the Ministry of Energy. Water for power generation is diverted from over 30 rivers and streams in the central plateau region of the North Island. The power scheme collects water from within and outside the Taupo catchment. One section accumulates water from the Moawhango River and unpolluted tributaries of the Whangaehu River. This water is delivered, along with water from the Tongariro River system, via the Poutu canal, to Lake Rotoaira. The Western Diversion collects water from the Whakapapa, Mangatepopo and Wanganui headwaters. Water abstracted from the Whakapapa River contributes about 70% of the Western Diversion flow and approximately a quarter of the total (McCreight 1973). Water from both diversions and the Tongariro system is stored in Lake Rotoaira and from there passes through the Tokaanu power station into Lake Taupo. The Tokaanu power station has a generating capacity of 200 MW and generates electricity for the national grid.

Following the diversion of Whakapapa River water in November 1972, the Ministry of Agriculture and Fisheries was asked by the Waimarino Acclimatisation Society (now the Waimarino Ward of the Central North Island Wildlife Conservancy [CNIWC]), to recommend ways of minimising impacts which the abstraction of water from the river was observed to have had on the trout fishery. Due to a lack of detailed pre-diversion data, these impacts could not be quantified exactly. A fisheries study was initiated however, with the following objectives:

1. To investigate the trout stocks, habitat and fishery currently supported by the Whakapapa River.

2. To assess, as far as possible, what effects the diversion of water have had on the trout stocks, habitat and fishery.

3. To recommend ways in which these effects could be minimised, taking

into account the fact that water will continue to be abstracted for power generation.

4. To recommend other ways in which the existing trout stocks, habitat and fishery might be improved.

2. CATCHMENT DESCRIPTION AND BACKGROUND

The Whakapapa River, which originates on the western slopes of Mt Ruapehu, is a major tributary of the Wanganui River, which it joins southeast of Taumarunui (Fig. 1). The river is approximately 53 kms in length, from its headwaters in the Whakapapanui Glacier to the Wanganui confluence, and has a mean annual discharge of 16.5 cubic metres per second (m^3/s) near the power scheme diversion intake site. The catchment area covers about 389 km^2 and includes parts of Tongariro National Park, two Lands and Survey farm blocks and Tongariro State Forest. Only the true left bank supports pastureland which is not intensively grazed. Access to the upper and middle reaches of the river, below State Highway (S.H.) 47, is restricted by steep banks, which support native forest and scrub. Further downstream, where banks are not as steep and access is easier, forest and scrub remain the predominant riparian vegetation.

The source streams of the Whakapapa, the Whakapapanui and Whakapapaiti, drain small glaciers and snow fields on Mt Ruapehu and are cold, swift and clear (Fig. 2). After eruptions of Mt Ruapehu, these streams are subject to floods containing volcanic debris and acidic water (lahars) from Crater Lake. The two most recent of these, in 1969 and 1975, resulted in total fish kills in the Whakapapa River (Cudby 1969, 1976). Other tributaries include the Papamanuka, Otamawairua and Piopiotea Streams. The former two are also cold and clear, while the lower Piopiotea has eroding banks and turbid water.

Approximately 80% of the mean annual flow of the Whakapapa enters an

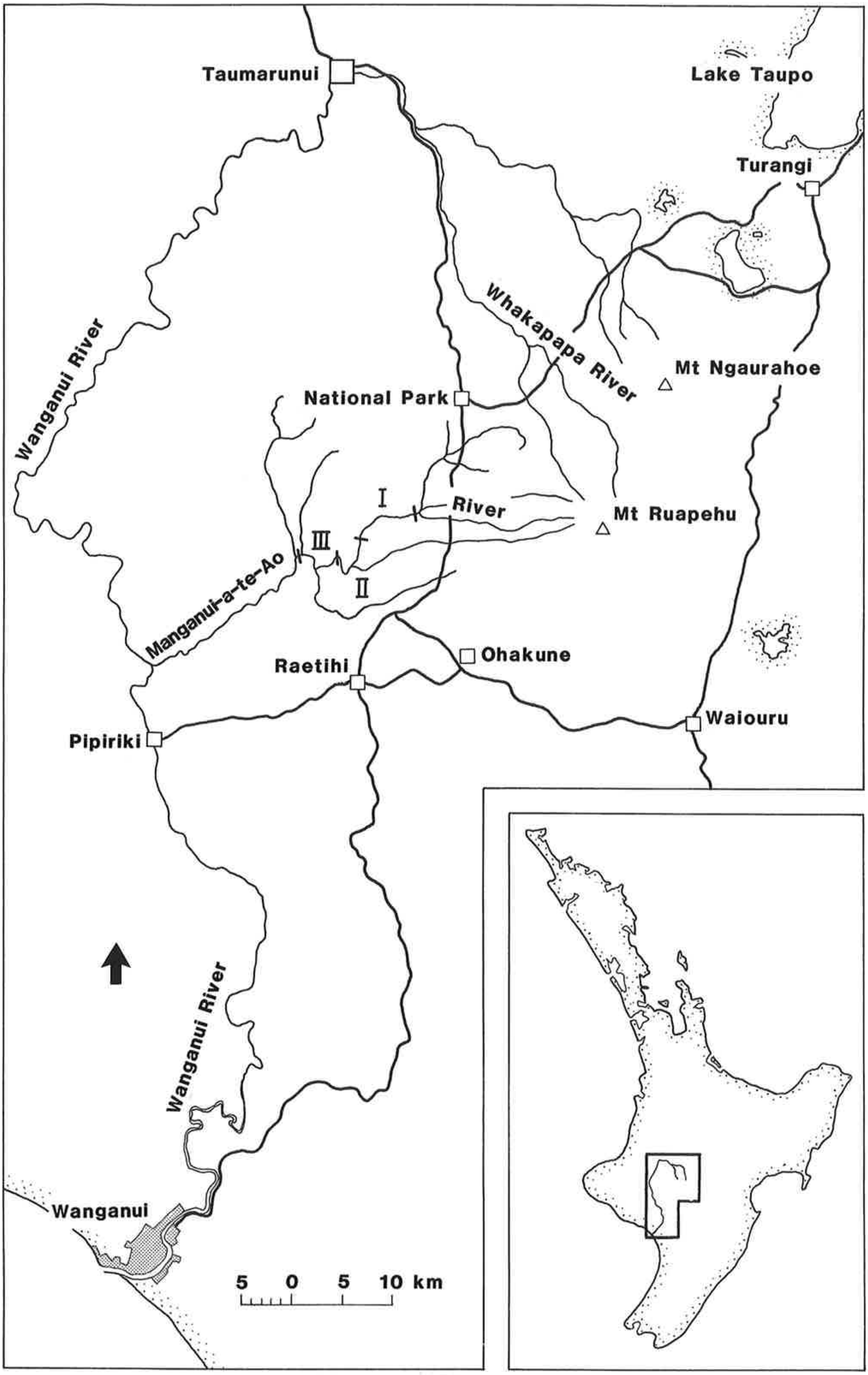

Figure 1. Locality map of Wanganui River system.

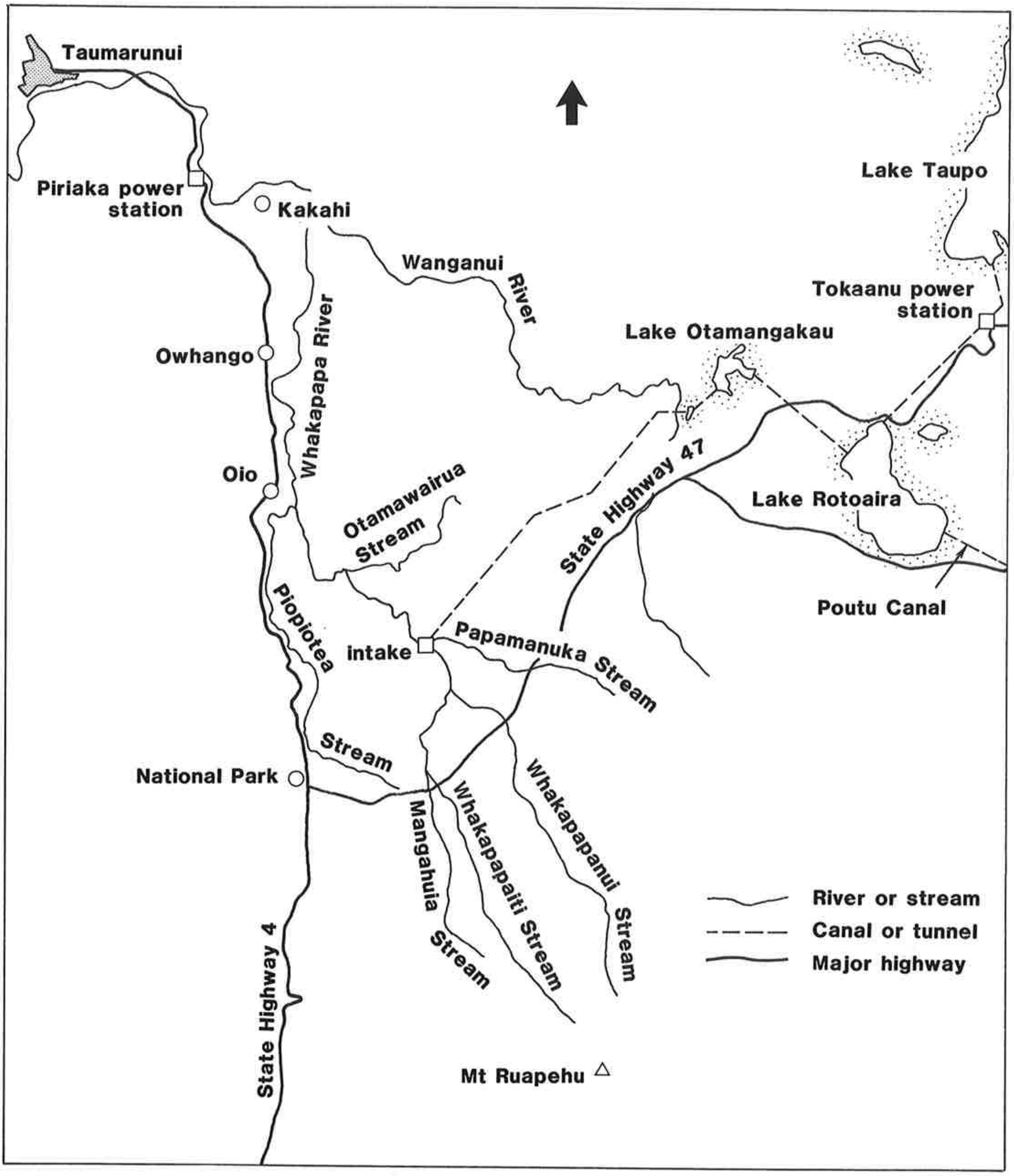

Figure 2. The Whakapapa River system showing townships, major highways and aspects of the Tongariro power scheme.

intake structure immediately below the Papamanuka Stream confluence (Plate 1). The diverted water flows via a tunnel to Lake Otamangakau, then to Lake Rotoaira and finally through the Tokaanu power station to Lake Taupo. The Waikato River, which drains Lake Taupo, has eight hydro-electric power stations with a total generating capacity of 1044 MW along its length. Water abstracted from the Whakapapa, and other streams previously outside the Taupo catchment, is available to all these stations for power generation.

The Whakapapa intake is a run-of-the-river structure with no storage capacity. Currently a minimum residual flow of 0.6 m^3/s is released at all times. The flow fluctuates depending upon water demands for the Tongariro power scheme. The capacity of the intake (approximately 30 m^3/s), is only two times the mean annual flow, so that flood water above this level continues on down the river channel. Since the intake was commissioned in 1972, these flood waters, in combination with controlled NZE releases, have actually resulted in a mean annual flow of 3.5 m^3/s below the intake. Despite this, the flow in the river below the intake is at or near the residual level (< 1 m^3/s) 53% of the time.

In addition, NZE have an agreement with the Taumarunui Borough Council (TBC) concerning the availability of water for power generation at TBC's Piriaka power station (Fig. 2). The options for NZE are:

1. Provision of > 10 m^3/s of water at the power station.

2. Provision of 7-10 m^3/s and payment of compensation to TBC for lost power generation.

3. Provision of < 7 m^3/s and payment of a higher rate of compensation.

Recently, in order to fulfill this obligation and also accommodate local pressure from other water users (jetboaters, canoeists, farmers), NZE has adopted the policy of providing 10 m^3/s. To achieve this, water is released at the Whakapapa intake so that the flow in the Wanganui River at Piriaka

PLATE 1. The Whakapapa intake under construction.

(Fig. 2) is at least 11.5 m^3/s. Fish passage past the Piriaka power station intake is maintained by provision of a small flow over the weir.

When water temperature in the Whakapapa at Kakahi reaches 23°C, NZE also has an agreement with the Wildlife Service to release additional water below the intake. Sometimes these events coincide and the extra water released serves a dual purpose for NZE, firstly to maintain a flow of at least 10 m^3/s at the Piriaka power station, and secondly, to lower the water temperature in the Whakapapa.

Trout were first introduced into the Whakapapa River in 1911 (Graynoth 1973), and at present both brown (*Salmo trutta*) and rainbow (*S. gairdnerii*) trout occur in sufficient numbers to support a recreational fishery. Other fish species found in the Whakapapa include eels, bullies and torrentfish.

Previous studies conducted on the Whakapapa River include angler diary schemes (Allen and Cunningham 1957; Graynoth 1973), a pre-power scheme investigation (Woods 1964) and a water temperature study (Hunt and Stanton undated). In the 1970's, an extensive land use study of the King Country was undertaken. Results from this study were published in the N.Z. Department of Lands and Survey Land Use Series (King Country Land Use Study Committee [KCLUSC] 1978). Useful references to the Whakapapa also appear in "Water Resources of the Wanganui River", a study carried out by Tonkin and Taylor (1978), consulting engineers for the Rangitikei-Wanganui Catchment Board.

3. METHODS AND RESULTS

Field studies on the Whakapapa River were carried out during August 1979-August 1982. Due to the inherent complexity of the questions we were attempting to answer, a wide variety of techniques was employed. Drift diving and electric fishing were used to assess species, numbers, size and distribution of fish. Spawning surveys were carried out to identify suitable spawning areas and their utilisation by trout. The density and type of invertebrate trout food organisms were assessed from bottom fauna samples. Physical habitat parameters were measured across a number of transects to determine the amount of habitat available to trout at various flows. Finally, an angler diary scheme was implemented to collect information about the recreational trout fishery.

3.1 Fish Stocks and Distribution

3.1.1 Drift diving

During the past five years, drift diving has become a standard technique for assessing trout numbers and distribution in New Zealand rivers with suitable water clarity (Hicks 1979; Teirney 1979). A team of divers clad in wet suits and snorkel gear space themselves evenly across a line perpendicular to the river banks and float with the current, counting fish which pass either under or around them. Visual contact with the river bottom is maintained by diving when necessary. In general, only pools and runs were counted as rapids were too turbulent, swift and dangerous for accurate counts.

Trout observed while drift diving were categorised as small (< 200 mm), medium (200-400 mm) or large (> 400 mm) and identified (where possible) as either rainbow or brown trout. These data were recorded after each pool/run sequence, along with other pertinent information such as unusual river features, presence of redds or observations of other aquatic fauna. A full description of the drift diving technique is given in Hicks and Watson (in prep).

Drift diving requires a minimum visibility of 1.5 metres. Although visibility in the Whakapapa was often marginal, fish counts were obtained for all but a 2 km section of the river immediately downstream of the Piopiotea confluence. Division of the river into six sections (Fig. 3), was based on access points and the distance which could be covered by divers within a day. All sections were drifted during the summer of 1980. The exercise was repeated for all but sections A and F in the summer of 1981. Winter drifts were limited by low water temperatures to sections A (1979) and B. In addition, Section B (the intake to the Otamawairua), was surveyed at approximately three

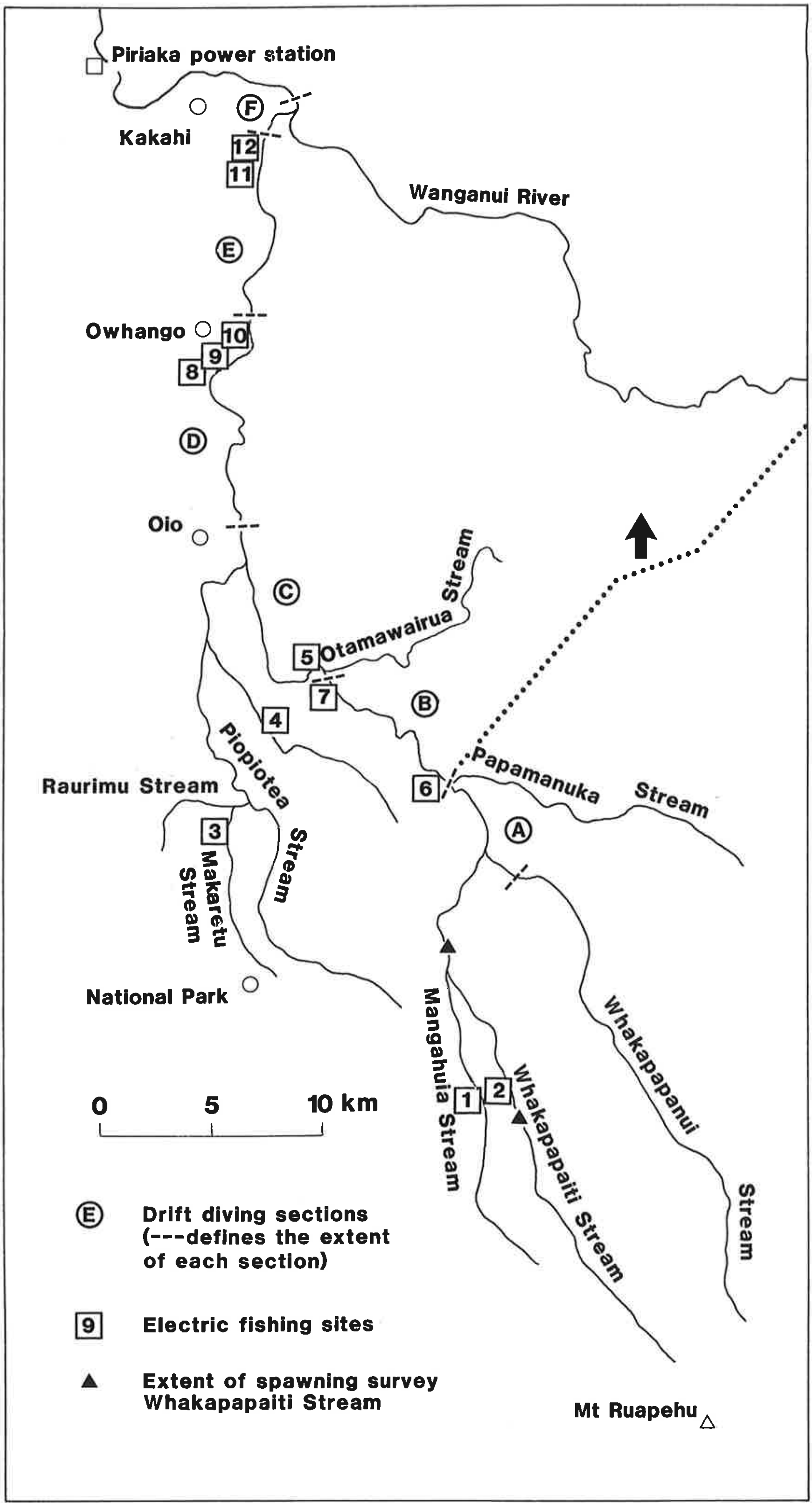

Figure 3. Drift diving sections, spawning survey streams and electric fishing sites sampled throughout the Whakapapa River system.

monthly intervals from August 1979 to July 1981, and again in August 1982, to assess its spawning and rearing potential. Results from the drift diving surveys are shown in Table 1.

Throughout the study, the difference in distribution of the two trout species and the relationship between trout numbers and river reach remained constant. Rainbow trout were distributed throughout the river system, including the headwater tributaries above the intake. In contrast, all but two of the brown trout observed during drift diving were distributed downstream of the Otamawairua confluence, and those two were less than 2 km upstream of this tributary.

Better underwater visibility and a larger, more experienced team of drift divers probably accounted for the generally higher fish counts recorded in the second year of the study. The large number of unidentified trout resulted in part from the difficulty of distinguishing browns from rainbows in the higher velocity water which characterised long stretches of run habitat. Rainbow trout are more active than browns when observed during drift diving, and therefore probably accounted for a high proportion of the unidentified trout which were recorded.

Small fish were not observed between the intake and Otamawairua Stream, because reduced flows made drift diving the runs and rapids, where these fish usually reside, impossible. A large number of small fish were observed downstream of the Piopiotea during 1981. Although 5000 fin-clipped yearling rainbows (< 200 mm) had been released at the intake the previous October, none of the small trout seen were marked. This suggests that natural recruitment in the Whakapapa may be high, at least for that year. Further, the consistent increase in numbers of medium and large rainbow trout recorded from section B during four consecutive winters indicated the existence of a spawning run.

When the numbers of trout observed during the two summer drift dives were averaged, converted to a figure of trout/km and compared between stations, the

TABLE 1. Trout counts from drift diving surveys, 1979-1982.

Section	Date	Rainbow			Brown			Unidentified			Total
		sml	med	lge	sml	med	lge	sml	med	lge	
A. Whakapapanui to intake (3.7 km)	8/79			7						1	8
	3/80	12	6	7							25
B. Intake to Otamawairua (6.9 km)	8/79		10	9							19
	3/80		1	6							7
	8/80			20			1			2	23
	10/80	*	1	9						1	11
	1/81		1	16			1				18
	4/81		1	5				1			7
	7/81	1	5	22						1	29
	8/82		4	25							29
C. Otamawairua to Piopiotea+ (5.7 km)	3/80		4	21		2	39	2	2		70
	3/81			1		4	29	2	1	7	44
D. Oio+ to Owhango (7.8 km)	3/80	1	2	3	13	26	95	5	8	8	161
	2/81	22	29	23	3	61	110	53	25	15	341
E. Owhango to Kakahi (7.5 km)	3/80	2	2	5	1	15	25	10	13	8	81
	2/81	100	32	32	18	55	62	117	17	7	440
F. Kakahi to mouth (1.2 km)	3/80	3	8	12	3	10	12	16	7	1	72
	2/81	floods prevented counts									

* Too numerous to count. 5000 fin-clipped rainbow yearlings were released at the intake one week prior to this survey. These trout were observed in the first three pools only. Fry were common along the river edges of this section during October and were also too numerous to count.

\+ The 2 km section between the Piopiotea mouth and Oio could not be counted in either 1980 or 1981 due to poor underwater visibility.

lowest number of trout/km was recorded from section B, immediately below the intake (Table 2). As distance downstream of the intake increased, so did the number of trout/km. Due to the lack of pre-diversion data, the effects which decreased flows have had on trout numbers both up and downstream of the intake could only be assessed indirectly.

TABLE 2. Average number of trout/km for each section of the Whakapapa River, from summer 1980 and 1981 counts.

Section	Date	Number of trout (all sizes)	Average no. Trout/km
A	Mar 80	25	6.8
B	Mar 80	7	1.8
	Jan 81	18	
C	Mar 80	70	10.0
	Mar 81	44	
D	Mar 80	161	32.2
	Feb 81	341	
E	Mar 80	81	34.7
	Feb 81	440	
F	Mar 80	72	60.0

In order to do this, trout counts per km were compared with those from a similar river, the Manganui-a-te-Ao. Originating close to the Whakapapa on the slopes of Mt Ruapehu (Fig. 1), this river is also a tributary of the Wanganui. Above the Ruatiti confluence, both rivers exhibit a similar rapid/pool/run formation over a comparable gradient. Flow regimes were also similar before the Whakapapa intake became operational. Both rivers support a recreational brown and rainbow trout fishery and have been the subject of fisheries investigations, including collection of fish counts by drift diving (Cudby and Strickland in prep), over the same time period.

Although these two rivers share many features in common, the amount of pool/run habitat does differ. In the Manganui-a-te-Ao, medium and large trout were observed mostly in pools, which appeared to be their predominant habitat type. By contrast, medium and large fish in the Whakapapa were observed in the longer, more extensive runs which characterise this river, as well as in the pools.

Despite this difference, counts of medium and large trout have been combined and averaged for the summers of 1980 and 1981 from the two rivers, and are compared in Table 3.

Fish per kilometer figures suggest that a 75% reduction in trout numbers may have occurred in the 3.7 km stretch (section A), surveyed above the intake. Immediately below the intake (section B), the reduction in trout numbers could have been as high as 90%, while fish numbers in section C may have decreased by approximately 60%. From the Piopiotea confluence to the mouth of the Whakapapa however, both the number of trout/km and the ratio of numbers of brown to rainbow trout coincide with those from the Manganui-a-te-Ao. This suggests that the combined flow of the two tributaries, the Otamawairua and Piopiotea, may offset to some degree the impact of reduced flows on fish numbers/km found in the 12.6 km section downstream of the intake.

3.1.2 Spawning

Spawning surveys were undertaken in the winters of 1979-1982 inclusive. These involved either walking or walking and diving to visually count trout and redds. Four areas of the Whakapapa catchment were covered: the Whakapapaiti Stream above and below S.H. 47; the Whakapapa from the intake to the Otamawairua confluence (section B); the Otamawairua Stream; and tributaries of the Piopiotea (Fig. 3). Spawning survey results are dealt with in order downstream, beginning at the headwaters.

(i) The Whakapapaiti is a clear, cold stream arising on the north-west slopes of Mt Ruapehu. Historically, it was the most important spawning tributary of

TABLE 3. Comparison of trout numbers from drift diving comparable reaches of the Whakapapa and Manganui-a-te-Ao Rivers, 1980-1981.

River Section	Whakapapa: Above the intake (Section A)	Whakapapa: Intake to Otamawairua (Section B)	Manganui-a-te-Ao: 3 streams confluence to top bridge (see Fig.1, Section I)	Whakapapa: Otamawairua to Piopiotea (Section C)	Manganui-a-te-Ao: Top bridge to Hoihenga bridge (See Fig. 1, Section II)	Whakapapa: Oio to mouth (Sections D, E & F)	Manganui-a-te-Ao: Hoihenga bridge to Ruatiti Stream (See Fig. 1, Section III)
Length (km)	3.7	6.9	8.2	5.7	6.4	16.5	9.2
Approx. gradient (m/km)	21	18	21	16	13	13	10
No. of M. and L. trout (avg of summer 1980 and 1981 counts)	13	12.5	122	55	159.5	389	215
Trout/km (M. and L.)	3.5	1.8	14.9	9.6	24.9	23.6	23.4
% Rainbow	100.0	96.7	65.4	22.7	39.2	20.3	20.2
% Brown	0.0	3.3	24.4	67.3	53.3	64.7	59.1
% Unidentified	-	-	10.2	10.0	7.5	15.0	20.7

M = medium trout (200-400 mm)

L = large trout (> 400 mm)

the Whakapapa, the majority of spawning taking place in the vicinity of S.H.47 (Cudby 1966). Since construction of the intake 3.1 km below the confluence of the Whakapapaiti and Whakapapanui Streams, access for trout, which may have moved upstream to utilise these headwater tributaries for spawning, has been prevented. Consequently, the Whakapapaiti was surveyed only once, in August 1979. Results and a comparison with historical data (Cudby 1968) are presented in Table 4.

TABLE 4. Whakapapaiti Stream spawning survey results.

Date	Number of trout	Number of redds
Aug 1966	12	41
Aug 1967	7	21
Aug 1968	4	12
Aug 1979	0	9

Intake construction activities coincided with the reduced number of trout and redds occurring between the 1967 and 1968 spawning surveys. High sediment loads downstream of the construction site and instream works during construction are believed to have disrupted the upstream migration of spawning rainbows past the intake site into the headwaters (E.J. Cudby pers. comm.). Although no fish were seen during the 1979 survey and fewer redds were counted than during the 1966-68 spawning seasons, our survey confirmed that the trout population which persists above the intake still utilises the Whakapapaiti for spawning.

(ii) During our initial survey in August 1979, several redds were observed in the section between the intake and Otamawairua Stream (Section B)(Plate 2). To determine whether this section was used consistently for spawning, surveys were continued during the following three winters. Numbers of adult trout and redds observed are presented in Table 5.

PLATE 2. Upstream of the Otamawairua confluence, showing the reduction in channel width which occurs at the residual release of 0.6 m^3/s.

TABLE 5. Whakapapa River (Section B) spawning survey results.

Date	Number of trout	Number of redds
Aug 1979	19	5
Aug 1980	23	6
Jul 1981	28	9
Aug 1982	29	17

Although suitable spawning gravel was limited, generally occurring at the tails of pools, it appeared to be under-utilised at present. Whether this area was used for spawning prior to operation of the intake is not known, and therefore the pre- and post-diversion situations could not be compared. It is likely however, that depths and velocities throughout this river reach may have been unsuitable for spawning prior to diversion. During October 1980, numerous fry were observed along the riffle margins of this section, suggesting that under the residual flow regime, this section of the Whakapapa has assumed the characteristics of a headwater area - a few large resident fish, runs of spawning fish, and a nursery area for fry.

(iii) The Otamawairua Stream enters the Whakapapa about 6.9 kms below the intake. The stream is characterised by runs 0.5 m deep, pools 1.5 m deep, and short riffle areas. A discharge of 0.89 m^3/s was recorded 400 m upstream of the mouth in February 1969 (E.J. Cudby pers. comm.). The stream is stable, clear and cold with bush growing to the edges. Good spawning gravel is abundant at the tails of pools and in some runs. Although there are several log jams in the stream, none would prohibit trout movement upstream.

Cudby (1966) found trout spawning in this tributary and estimated that the available gravel was under-used. Reduction in the number of redds between 1966-68 and 1979-81, suggest that trout utilisation of this tributary as a spawning area has declined (Table 6). The reasons for this are unclear.

Logging which took place in the headwaters in the 1960's may have affected the stream in some way, although this seems unlikely. Possibly the combination of reduced numbers of fish in the 12.6 km section below the intake and their use of the mainstem for spawning (a situation which may not have occurred at higher flows), accounts for the reduction in use of the Otamawairua Stream.

TABLE 6. Otamawairua Stream spawning survey results.

Date	Number of trout	Number of redds
Aug 1966*	9	15
Aug 1967*	18	10
Aug 1968*	8	9
Aug 1979	10	2
Aug 1980	5	0
Jul 1981	1	0

* From Cudby (1968).

(iv) The Piopiotea, the second major tributary entering the Whakapapa downstream of the intake, begins in swampy ground to the north of S.H. 47 and the water is slightly tannin-stained in colour. While much of the stream flows through second growth bush, the lower third flows through farmland, where the quality of the stream has been considerably downgraded by farm management practices which allow stock free access to the stream banks. As a result, the banks are now badly eroded, sediment has accumulated on the stream bed and the water carries a high sediment load, particularly during floods. Little is known about the trout population in the Piopiotea. Apparently rainbow trout are caught from the stream (L.R. Todd pers. comm.), and three small (< 90 mm) rainbow trout were captured by electric fishing an unnamed tributary (Fig. 3, electric fishing site 4).

Subsequent walking surveys in August 1980 did not reveal any adult fish or redds in the Piopiotea, Raurimu, or Makaretu Streams, or in the unnamed tributary. Patches of suitable spawning gravel were seen only rarely, although it was not possible to survey the entire lengths of all these streams. While spawning apparently occurs in the Piopiotea and/or its tributaries, this catchment was not used for spawning by large runs of fish from the main river.

Due to poor access and cold water temperatures, it was not possible to survey the entire Whakapapa River below the Otamawairua for spawning during winter. However, areas of suitable substrate, depth and velocity for spawning were observed and recorded during summer drift dives. These areas were distributed sporadically throughout the river, occurring mainly between the Otamawairua confluence and Owhango bridge. In March 1980, between five and ten pairs of brown trout were encountered in the vicinity of these areas, from Oio downstream. Evidence of mainstem spawning was collected in October 1979, when large numbers of fry were observed along the river edges at Owhango bridge and Kakahi. A sample of these, captured with a hand net, contained both rainbow and brown trout fry.

Results from the spawning surveys thus suggest that below the intake the majority of both rainbow and brown trout spawning takes place in the main river. By contrast, in the Rangitikei River (Hicks and Watson in prep), rainbows tend to migrate into the headwaters to spawn. Since access to the Whakapapa headwaters has been cut off, some rainbows have been utilising the most upstream section of the main river which is accessible to them.

3.1.3 Electric fishing

To augment the drift diving and spawning survey data, and to determine native fish distribution, an electric fishing survey was carried out in March 1980. Twelve sites were sampled using a portable back pack machine - five in tributaries and seven in the main stem (Fig. 3). The results are presented in Table 7. By combining the results from this method with data obtained from drift diving and spawning surveys, the following comments can be made concerning fish distribution in the Whakapapa system.

TABLE 7. Occurrence of fish species in the Whakapapa River and tributaries, March 1980 (* = present).

	Tributaries					Main Stem						
Sample Site	1	2	3	4	5	6	7	8	9	10	11	12
Salmo trutta					*			*	*	*	*	*
S. gairdnerii	*			*		*			*	*		
Anguilla spp.								*				
A. dieffenbachii	*		*	*	*	*			*			*
A. australis									*			
Cheimarrichthys fosteri									*			
Gobiomorphus basalis												*

Rainbow trout are found throughout the length of the Whakapapa and in all tributaries. Above the Otamawairua confluence, they are the dominant salmonid, comprising over 98% of the observed population. Brown trout distribution begins just upstream of the Otamawairua and extends to the mouth. No brown trout were observed above the intake or in the Piopiotea system, although Woods (1964) recorded their presence at one locality in the Piopiotea, and KCLUSC (1978) reported them in both the Piopiotea and the Papamanuka (above the intake). The latter tributary however, was not surveyed during our investigations. Juvenile brown trout were found at the mouth of the Otamawairua and at every electric fishing site below this point. From this tributary to the mouth, brown trout were the dominant salmonid species, comprising at least 66% of the observed population.

Native fish species observed in the Whakapapa were confined to eels, bullies and torrentfish. Freshwater crayfish (*Paranephrops planifrons*) have been found occasionally in the main stem, both source streams, and the

Piopiotea system. *Galaxias* has also been reported (KCLUSC 1978), but which species is not known. Torrentfish (*Cheimarrichthys fosteri*), which inhabit areas of swift broken water, were rare but extended upstream as far as Owhango.

Longfinned eels (*Anguilla dieffenbachii*) were common throughout, while shortfinned eels (*A. australis*) were rare. Occasionally the main stem and Piopiotea Stream are fished by commercial eel fishermen, but the extent of their effort and catch is unknown.

Gobiomorphus basalis (Crans's bully), was found in the lower river both by electric fishing, and with the salmonid fry hand-netted in October 1979. Woods (1964) recorded "Maui's bully" as present, but gave no specific name for the fish and KCLUSC (1978) reported *Gobiomorphus* spp. (Note: R.M. McDowall (pers. comm.) has confirmed that "Maui's bully" is synonymous with Cran's bully.) Bullies were uncommon except in the lower reach of the river where they were abundant, and possibly included *G. cotidianus* as well as *G. basalis*.

3.2 Fish Habitat

To determine reasons for the changes in trout distribution and density which appear to have taken place since water was diverted from the Whakapapa, effects of the altered flow regime on certain aspects of trout habitat were investigated. Trout habitat comprises a complex interaction of physical, chemical and biological components. Those selected for investigation and discussed in this section include: the invertebrate bottom fauna community, which forms the basis of trout diet; physical habitat measurements of depth, velocity and substrate; the nature and implication of changes in the flow regime; and water temperature.

3.2.1 Invertebrate bottom fauna

During the initial summer survey (1980), observations caused us to suspect that the invertebrate fauna, a major component in the diet of trout, may have been affected by the reduced discharge. Throughout both riffle and run areas, particularly below Oio, fine sediment was trapped in mats of algae and diatoms which had grown over the submerged rocks and boulders. In low velocity areas, accumulated sediment covered the substrate.

As invertebrate production is generally highest in riffles, and a reduction in flow has a greater effect on the depths and velocities in riffles than in pools (Kraft 1972), the invertebrate sampling programme was confined to riffle/run areas. The community structure and density of bottom fauna were compared between three locations selected for their similarity in depth, velocity and substrate type. Station a, immediately above the intake structure, station b, approximately 0.2 kms below the intake and station c, 22 kms further downstream at Owhango, were sampled at three monthly intervals for a period of one year (Fig. 4).

Three replicate samples were collected from each station on all five sampling occasions, using a circular Surber net (0.36 mm mesh) which covered a 0.1 m^2 area of substrate. Stones over 80 mm in diameter were scrubbed and removed and the remaining gravel was disturbed to a depth of approximately 150 mm.

On each sampling occasion, depths and velocities of sampling sites, river discharge and water temperatures were measured, and underwater photographs taken to aid in the assessment of algal growth and water turbidity. Samples of algae and diatoms were also collected and later identified.

A film of algae and diatoms was always present on rocks at all stations, but build-up was greatest in January. While composition of the growth varied, the alga *Ulothrix zonata* dominated at stations a and b. Diatom species of *Gomphoneis* and *Navicula* were less abundant. However, at station c, diatoms including *Cymbella, Pinnularia, Gomphoneis* and *Navicula* dominated. The alga *Oedogonium* spp. also occurred, but *Ulothrix zonata* was sparse.

Results of the invertebrate identifications, combining the three replicate samples, are presented in Appendix I. Although species composition at each

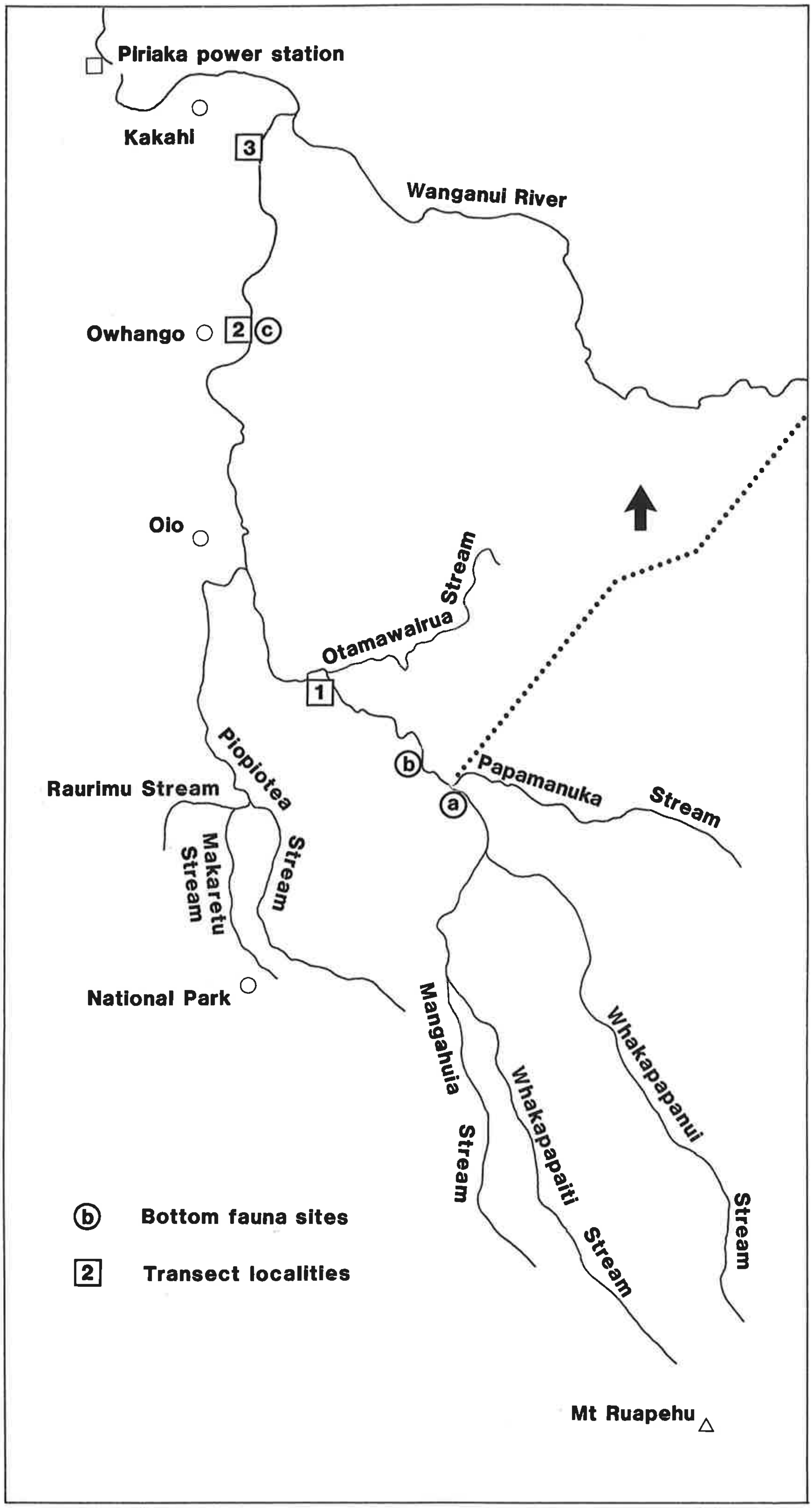

Figure 4. Bottom fauna sampling sites and transect locations in the Whakapapa River.

station varied somewhat, all the communities were typical of small New Zealand rivers which contain high quality water, with or without a small degree of organic enrichment (Winterbourn 1981).

The numbers of *Deleatidium* spp. and two other Ephemeropterans appeared to increase from the two upstream stations to station c. This trend was also apparent among the Trichoptera, particularly the cased caddis larvae. In contrast, Chironomid species (Diptera) associated with clean water were more numerous at the upstream stations. These downstream trends probably reflect a natural progression which occurs in most rivers.

When the composition of the bottom fauna communities found above the intake (station a) and below (station b) was compared, the diversity of invertebrate species was generally found to be greater above the intake. Several taxa which occurred at both stations (including the Rhyacophilidae, Elmidae, Eriopterini and *Maoridiamesa* spp.) were considerably less abundant below the intake, while the converse was true for *Deleatidium* spp. The proximity of stations a and b suggests that these differences may be attributable to the altered flow regime.

TABLE 8. Pre- and post-diversion and lahar bottom fauna densities (animals/m^2).

Station	"Pre" Aug 1966/67	"Post" July/Aug 1980/81
b	310 - 1564	623 - 963
c	667 - 3377	840 - 1743

However, the total number of animals present at these stations varied very little, indicating that the density of invertebrates/unit area was not significantly affected by the modified flow regime. In addition, E.J. Cudby (pers. comm.) sampled the bottom fauna before the diversion and lahars took place and found a greater range in the numbers of animals/m^2 at stations b and c than our study showed (Table 8). The fact that our values fell within Cudby's range again suggests that diversion of water from the Whakapapa has not had a major impact on the density of the bottom fauna.

Measurements of species diversity were calculated for each station using Margalef's (1951) index (Appendix I). With the exception of January, the unmodified station above the intake (a), had the highest diversity values, while b, 0.2 km below the intake, had the lowest, suggesting that the diversion may have had some impact on the diversity of the bottom fauna.

Thus, while the modified flow regime has not had a major impact on the density of the invertebrate fauna, species composition and diversity may have altered somewhat. In addition, because the total area of submerged river bed below the intake is much smaller under the reduced flow regime, the total biomass (at least in the first 6.9 km reach) would have decreased since diversion of water commenced in 1972.

3.2.2 Physical habitat

The habitat of trout comprises a complex interaction between physical, chemical and biological components. Physical habitat parameters include such things as water depth, velocity, and substrate composition; chemical parameters include dissolved oxygen concentration, water temperature and other aspects of water quality; biological parameters include interactions with other living organisms, such as feeding, competition and parasitism.

The effect of a flow reduction on the physical habitat of trout can often be assessed visually. Immediately below the Whakapapa intake, for instance, the area of submerged river channel is greatly reduced at times when the residual flow of 0.6 m^3/s is being released. Changes in certain aspects of physical habitat which result from flow manipulations can be quantified using the recently developed Instream Flow Incremental Methodology (IFIM) described by Bovee and Cochnauer (1977), Bovee and Milhous (1978), and Milhous, Wegner and Waddle (1981). For the purposes of this discussion, physical habitat is used to distinguish depth, velocity and substrate components from the other parameters which make up total trout habitat.

Briefly, two of the major components of physical habitat (depth and velocity), were measured across transects located through habitat types which represented the river reach under investigation. If this information is collected at several different discharges, a hydraulic model can be used to predict the array of depths and velocities that will occur at flows outside the range for which measurements were taken. Since our transect measurements were made at a wide range of different release flows in the Whakapapa, it was not necessary to use the hydraulic modelling capacity of the IFIM. Substrate composition was also assessed at 2 m intervals across each transect.

The physical habitat information was combined with information about the depth, velocity and substrate preferences of each life stage of the fish species of interest. Suitability functions which have been developed for the life stages of both brown and rainbow trout (Bovee 1978) were used in this investigation. The resultant measure of weighted usable area (WUA) represented the amount of physical habitat at a particular flow which supported a suitable combination of depth, velocity and substrate for the life stage of the fish species being considered.

To assess the effect of various discharges on WUA, physical habitat measurements were collected from three river reaches (Fig. 4) with the co-operation of NZE, who released four flows from the intake: 13.0 m^3/s (the full flow), 5.2, 3.4, and 0.9 m^3/s. Initially, transects were located across run/riffle type habitats at all three stations. The placement of transects was based on the assumption that alterations in flow would have a greater effect on these habitat types than on pools. Also, the size of pools in the lower reaches of the river and the lack of appropriate equipment precluded collection of depth and velocity data from them. However, during the full flow release of 13 m^3/s, access to station 1 (which was located in the most severely affected section of the Whakapapa below the intake), was prevented by the landowner. As a result, gauging was not possible at this release and transects were relocated to an accessible pool/slow run habitat a short distance upstream of Otamawairua Stream.

Transects at station 2 were located across a long, fast run upstream of Owhango bridge. All four release flows were gauged through this run, which was typical of the type of run encountered below Oio. Habitat data collected from station 3, located upstream of Kakahi, were not converted to WUA for the following reasons. The slow run which comprised part of the station contained very little fish cover and was not generally representative of the lower reaches. Measurements from a side channel where yearling brown trout were located could not be incorporated into the IFIM because the hydraulics of this channel could not be related to the main channel.

In addition to the limitations already described, the following points should be mentioned. The brown and rainbow trout suitability functions used were developed in the USA and have yet to be ratified for the salmonid species in New Zealand. Due to the difficulty of accurately quantifying cover, substrate measures have been incorporated in the IFIM as a substitute. Cover was generally abundant in the Whakapapa and no doubt played an important role in providing shelter for trout at high velocities, an aspect which could not adequately be taken into account using the IFIM. The calculation of WUA was carried out in the USA by the second author, using the IFIM computer package, since the programme had not been adapted to New Zealand computer hardware. Unfortunately, time limitations prevented a detailed analysis of the data.

(i) At station 1, discharges of 1.4, 3.8, and 6.2 m^3/s resulted respectively from flows of 0.9, 3.4, and 5.2 m^3/s released at the intake. Over this range of discharges (1.4-6.2 m^3/s), water depth increased about 100 mm, and water velocity increased 2.7 times to 0.3 m/s. The surface area of submerged river channel increased by less than 10% from the lowest to the highest discharge. This was not unexpected in the pool/slow run habitat confined by the river channel.

As discharge increased from the residual flow to 6.2 m^3/s, physical habitat available to adult rainbow trout increased by approximately 40% (Fig. 5). Although this relationship would be reversed at some higher discharge when velocities exceeded those preferred by rainbow trout, this result suggested that the significant decrease in numbers of adult rainbow trout in the section below the intake may have been related to a reduction in velocities through pools, the major habitat type utilised by adult fish. Brown trout physical habitat altered by less than 10% over the same range of discharges. However, this fact is somewhat academic as brown trout were rarely observed in this section. Therefore, this suggests that some other aspect of habitat excludes brown trout from this reach of the Whakapapa.

Physical habitat suitable for fry and juveniles of both rainbow and brown trout changed very little with increasing discharge. Sub-adult rainbow trout have a much smaller optimum range of depth and substrate than browns, which probably accounted for the smaller percentage of rainbow fry and juvenile WUA at this station.

(ii) At station 2, data were collected at all four release flows (0.9, 3.4, 5.2 and 13.0 m^3/s), which resulted in measured discharges of 9.4, 8.3, 10.7 and 17.4 m^3/s respectively. The decrease in discharge (from 9.4 to 8.3 m^3/s), which occurred simultaneously with an increase in the release flow, was due to the natural discharge from the catchment decreasing after a rain storm. The effect of this natural flow reduction outweighed the effect of the increased release flow. To extend the range of measured flows, the transects were regauged at a natural low flow of 6.4 m^3/s.

Over the range of measured flows, average depth increased 210 mm and average velocity increased 2.1 times to 0.6 m/s. However, as at station 1, the submerged area of river channel only increased by 10%.

Within the range of measured flows, the percentage of adult habitat available to both rainbow and brown trout remained virtually unchanged

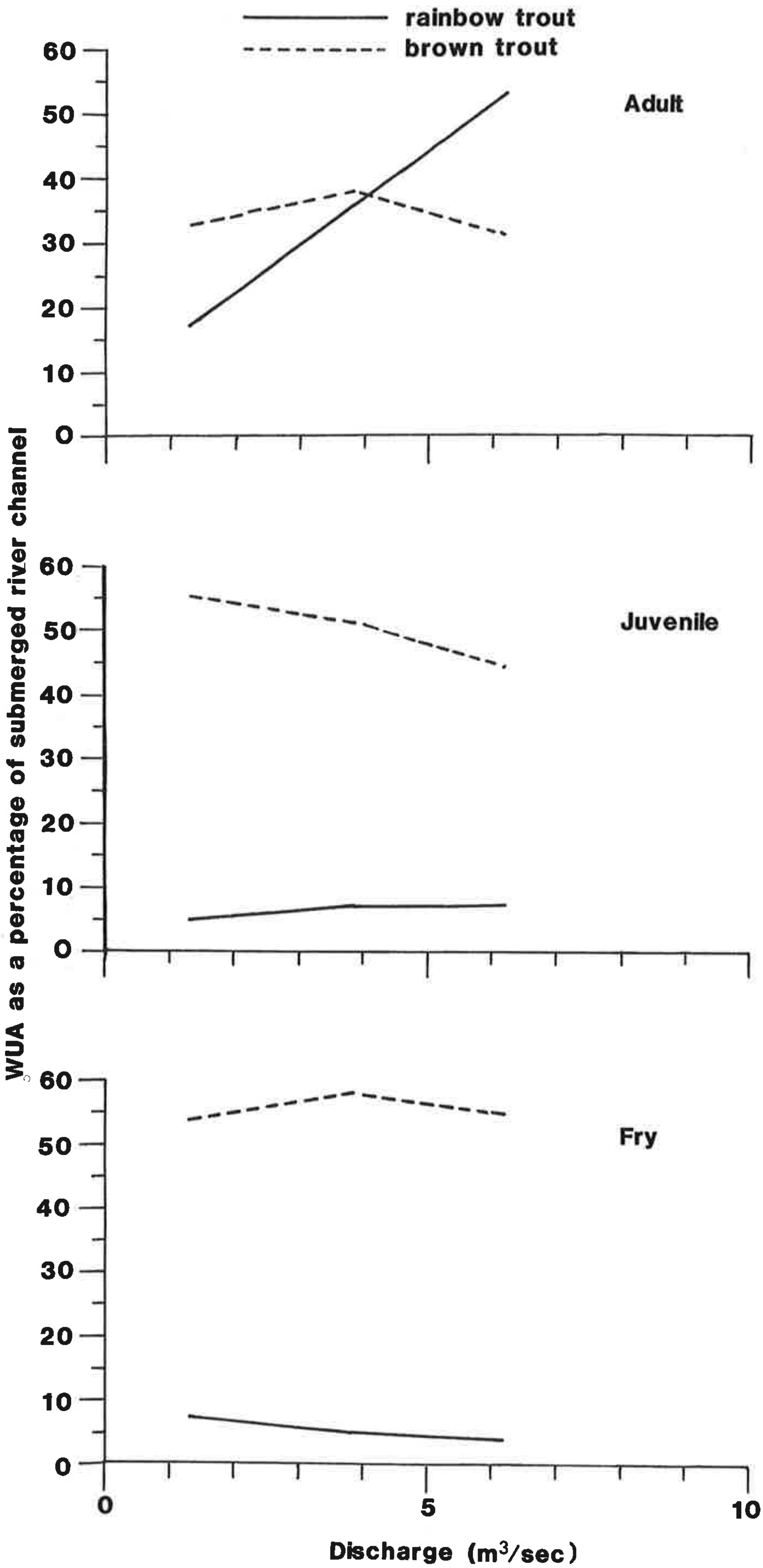

Figure 5. The relationship between WUA (as a percentage of the total area of submerged river channel) and discharge for three life stages of rainbow and brown trout at station 1.

(Fig. 6). Although juvenile and fry WUA values showed an increase at lower flows, this increase may not have been as marked if cover had been adequately assessed. Neither substrate composition nor measurements of bottom profile made at 2 m intervals could quantify the cover provided by numerous boulders throughout this section. At increasing velocities, trout were observed sheltering behind these boulders.

These results were not unexpected, and again confirmed our visual observations. As discharge increased, depths and velocities increased and the flow, being confined to a single channel, could not spread out and inundate additional areas of river bed. The fact that changes in physical habitat measurements were generally likely to be less than 15% throughout runs below Oio reinforced our view that the Otamawairua and Piopiotea Streams offset to some degree the effects of diversion of water at the intake. However, these results only apply to run habitats, as measurements were not taken from pools in the lower reaches. While the relationship between a 15% change in physical habitat and trout stocks could not be measured directly, fish numbers/km were comparable with those from the Manganui-a-te-Ao, suggesting that increases or decreases of this magnitude were not critical in those reaches of the Whakapapa below the major tributaries.

3.2.3 Flow regime

During drift diving, the accumulation of fine sediment, which was observed in pools and slow runs below the intake, was not apparent in comparable habitats above the intake. The 2.7 times difference in average velocity, measured through the pool at station 1 between discharges of 6.2 and 1.4 m^3/s, indicated that the sediment carrying capacity of the river may have been altered by diversion of water from the intake. Sediment accumulation in pools inhabited by adult trout may have contributed in some way to the reduction in numbers of adult rainbow trout in this section of the river.

Diversion of water from the Whakapapa has altered the natural flow regime in a number of ways. From the flow duration curves (Fig. 7), a flow

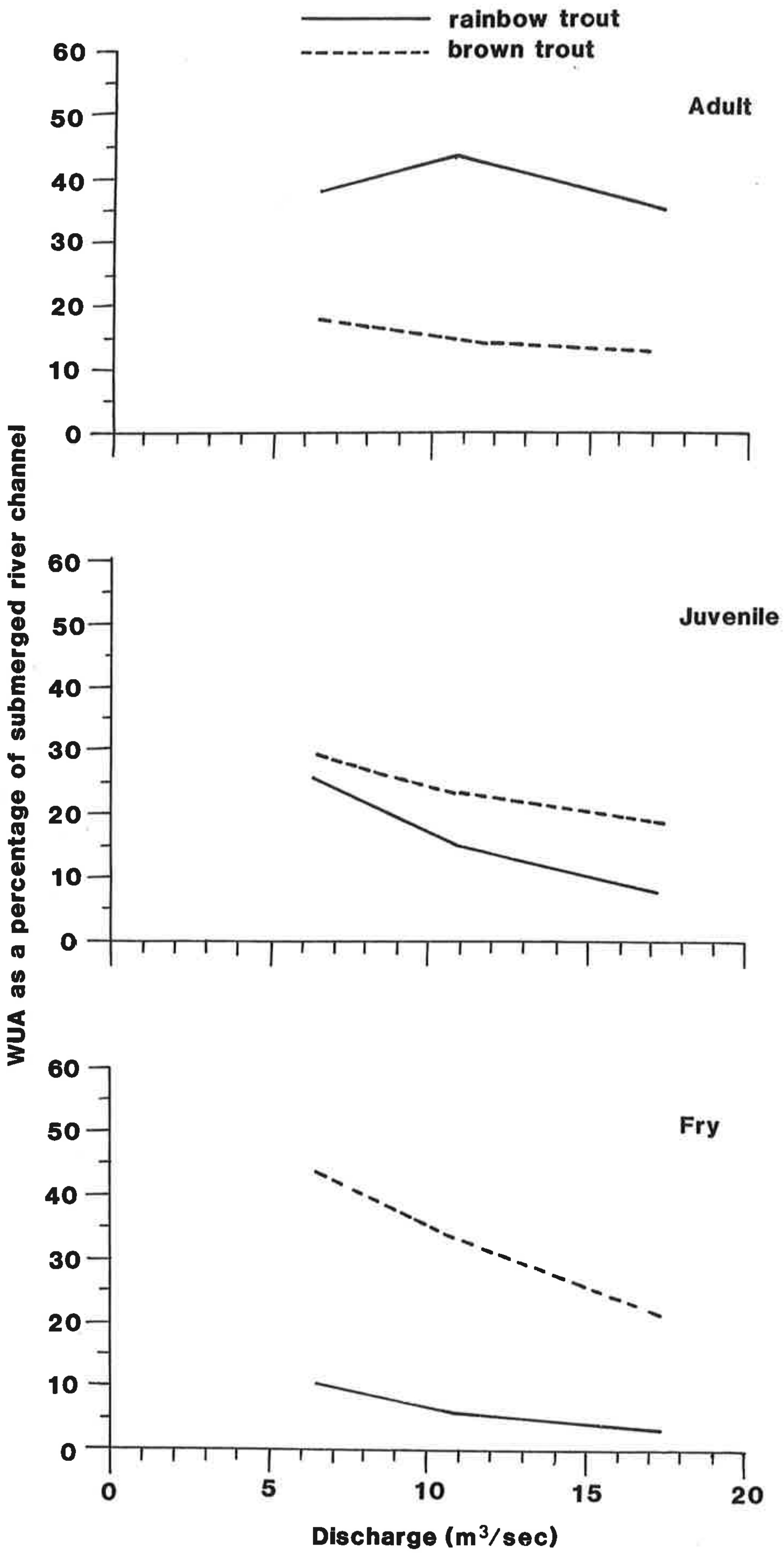

Figure 6. The relationship between WUA (as a percentage of the total area of submerged river channel) and discharge for three life stages of rainbow and brown trout at station 2.

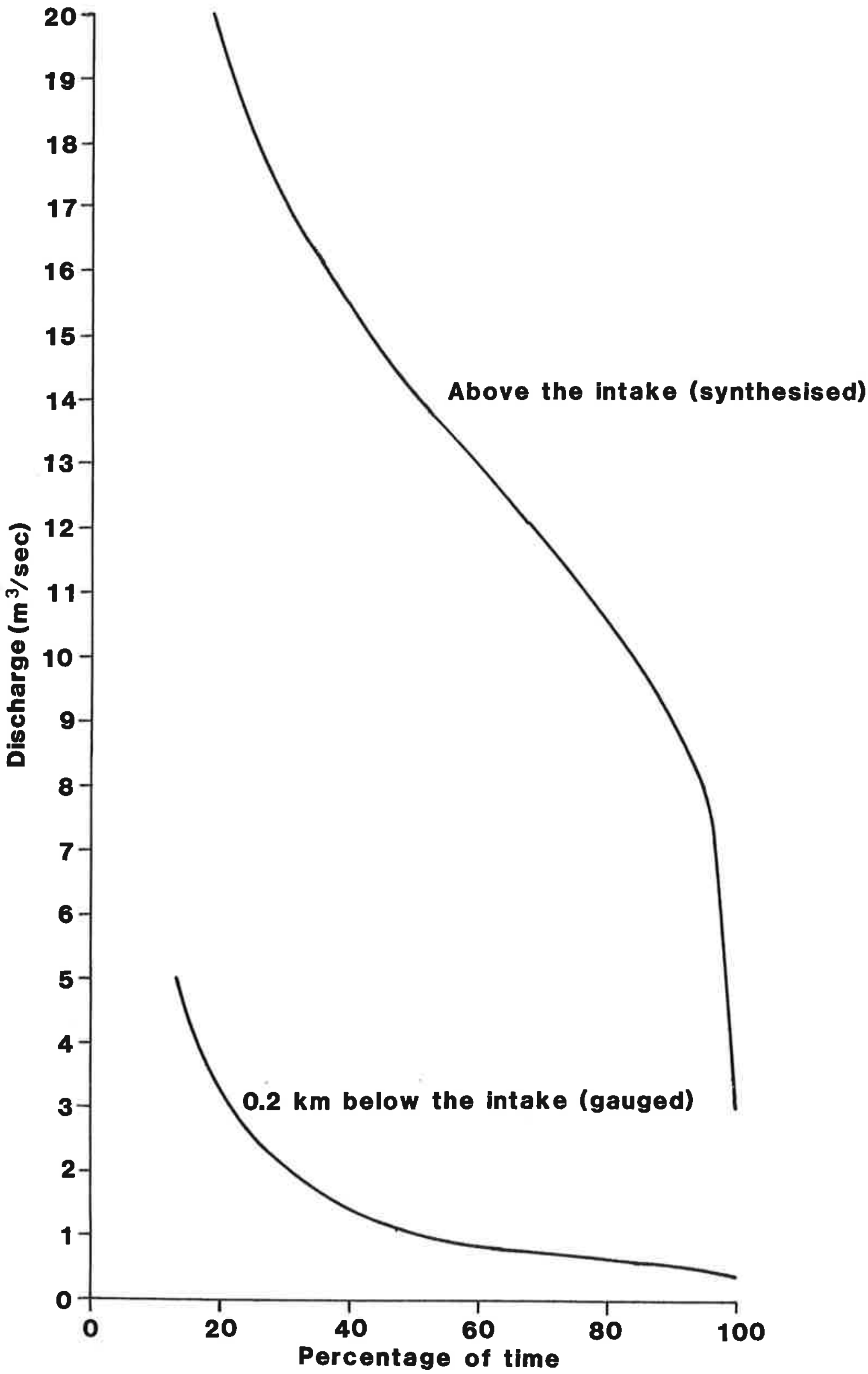

Figure 7. **Post-diversion flow duration curves above and below the Whakapapa intake.**

of 14 m^3/s (which would have characterised section B for approximately 50% of the time) has been reduced by more than 90% to a flow of less than 1 m^3/s. Apart from release of additional water, either in excess of NZE requirements or to satisfy agreements with downstream water users, freshes and floods exceeding the intake capacity of 30 m^3/s continue to pass down the main river channel. The magnitude of flow fluctuations, particularly in the section immediately below the intake, has therefore been increased by operation of the intake.

The attenuation of flood flows has also been affected. In Appendix II, data are tabulated for 15 floods which occurred in the Whakapapa before the intake was commissioned. Each flood can be interpreted as an initial peak discharge which decays exponentially over a period of several days, the flow eventually stabilising at a level determined by the prevailing environmental conditions. The rate of recession is a characteristic of the Whakapapa system, and represents the capacity of the catchment to attenuate flood peaks. A generalised "recession curve" (derived from the flood data - see Appendix II for details), can be used to predict the naturally occurring attenuation to be expected after a flood of any given magnitude.

In Figure 8, this curve has been used to compare, for the section of the Whakapapa below the intake, the recession of a 100 m^3/s flood both before and after completion of the diversion. Clearly, the present situation is highly artificial, in that as soon as the flood discharge falls below 30.6 m^3/s, the residual flow below the intake drops immediately to 0.6 m^3/s. Consequently, there is an abrupt reduction in water velocities, without a corresponding decrease in sediment load - a situation that would not occur naturally. Assuming that the ability of floods to carry sediment from the Whakapapa headwaters has not changed since the intake was commissioned, it can be inferred that under the present flow regime, deposition of sediment occurs in low velocity areas downstream of the intake.

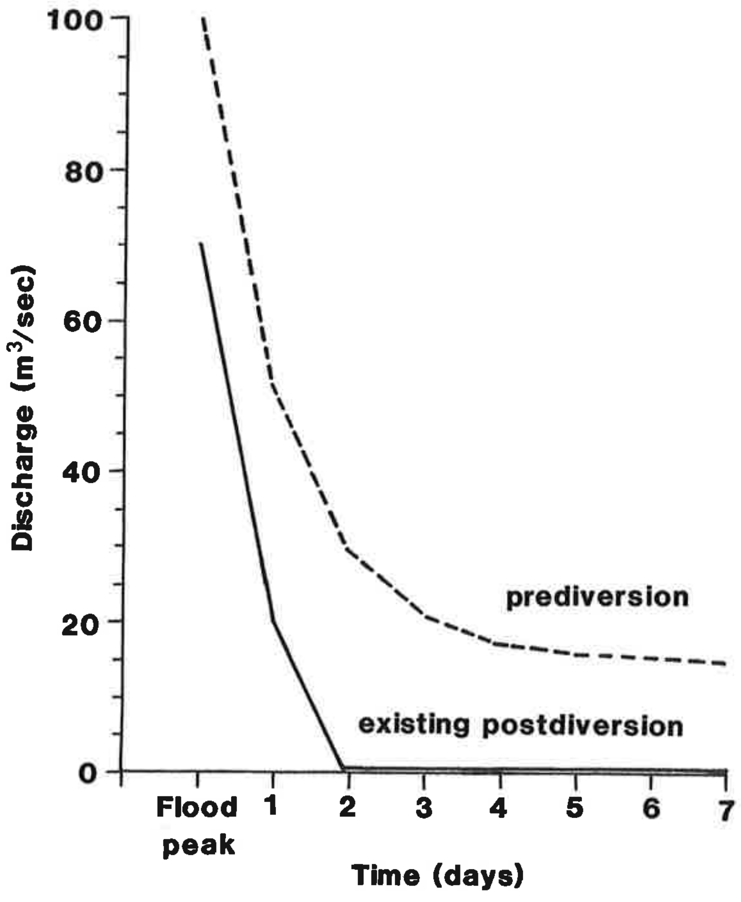

Figure 8. **Prediversion and existing post-diversion attenuation of a 100m^3/sec flood below the intake.**

In addition, a rapid decrease in the flow is likely to result in stranding of fish and invertebrates. Such an effect was observed in 1972, when all but the residual flow was initially diverted (E.J. Cudby pers. comm.). Further downstream, the modified flow regime may have affected the movement of fine sediment transported down the Whakapapa from the Piopiotea. This, however, could not be verified one way or the other.

3.2.4 Temperature

One other important aspect of trout habitat which has been the subject of negotiations since the intake became operational is water temperature. In 1964, the Minister of Electricity, Mr T.P. Shand, stated in a letter to the Wellington, Waimarino and Auckland Acclimatisation Societies: "in dry spells the flow in the Whakapapa and Wanganui Rivers would not be allowed to fall so low that the safety of the fish is endangered, even if this means that the diversion has to be discontinued" (Shand 1964). After commissioning of the intake in November 1972, the Waimarino Acclimatisation Society expressed concern about the possible effects of increased water temperatures under low flow conditions and also about whether the Minister's promise would be honoured by NZE.

A seven week study was initiated in January 1973 to investigate the relationship between discharge and water temperature in the Whakapapa. The results of this study did not demonstrate any consistent relationship between releases of up to 6.6 m^3/s from the intake and changes in water temperature downstream of the intake to Kakahi (Hunt and Stanton undated). However, the authors recognised the limitations inherant in this study, and from information about the upper lethal temperature limits of brown trout (22.5 - 25.3°C) and the slightly higher reported tolerance of rainbows, they recommended that in conditions of extreme hot weather, an additional discharge of water be released.

In December 1974 a fish kill occurred in the Whakapapa. Dead trout, eels and bullies were first noticed in the lower reaches of the river and later, large numbers of dead fish (mostly eels) collected on the trash screens at Piriaka power station (Cudby 1975). Although the specific cause of the fish kill was never determined, following discussions with the Waimarino Society and CNIWC, NZE agreed to release extra water when the water temperature in the Whakapapa at Kakahi reached 25°C, the upper-most lethal limit for trout. For the past three years, releases have been occurring when the water temperature reached 23°C.

From a literature review of trout temperature tolerances (Table 9), there is general agreement with the upper lethal limits quoted by Hunt and Stanton (undated). However, the optimum temperature for trout growth and that which is preferred by trout, is considerably less than 22°C. In fact, most workers who have investigated trout growth (Bell 1973, Brown 1946, Frost and Brown 1967, Gardner 1926 and Spaas 1960) agree that temperatures over 20°C are stressful to trout. Growth ceases, the fish become excitable, and mortality can occur if the water is not fully saturated with oxygen.

TABLE 10. Number of days on which water temperature reached or exceeded 20°C at two locations in the Whakapapa River, December-March 1974-1982.

Year	No. of days temperature ≥ 20°C		Total days measured (max. = 90 [91*])
	Intake	Kakahi	
1974*	0	47	67
1975	0	47	90
1976	0	9	86
1977*	0	28	91
1978	0	22	80
1979	0	31	90
1980*	0	18	91
1981	0	24	90
1982	0	23	90
Average	0	28	-

* Leap years

TABLE 9. Lower lethal, optimum and upper lethal temperatures (°C) for brown and rainbow trout.

Source	Lower lethal		Preferred or growth optimum		Upper lethal	
	B	R	B	R	B	R
Alabaster & Downing (1966)					26.4	26.6
Bell (1973)	2.2	0	3.8-21.1	12.2-18.8	23.8	29.4 (avoid at 21.7)
Black (1953)						25.7
Brown (1946)	3		7-19		25	
Cherry et al. (1975)		5 (avoid)		11.6-22		25
Craigie (1963)						27
Frost & Brown (1967)			7-19		22.5-25.3	
Gardner (1926)			< 18-20		25	
Garside & Tait (1958)				11.6-15.7		
Hobbs (1948)					> 25	
Hunt & Jones (1972)			10-13			
Javaid & Anderson (1967)				15.8-22		
Jones (1964)					22.5-29	
Kwain & McCauley (1978)				11 - 18		
McCauley et al. (1977)				9.8-12.7		
Peterson et al. (1979)				14.7		
Phillips (1929)					> 25.6	
Platts (1981)				18.3		
Spaas (1960)			< 18-20		25.5	
USEPA (1976)				19		24

B = Brown trout

R = Rainbow trout

Since 1974, water temperatures have been recorded at both the intake and Kakahi during the months of December, January and February. The number of days on which temperatures exceeded 20°C is presented in Table 10. Temperatures at the intake never exceeded 20°C and were usually below 15°C. However, at Kakahi, the temperature reached 20°C or more on an average of 28 days during these months. Recorder breakdowns commonly occurred during hot weather, with the result that water temperatures could have exceeded 20°C for up to 71 days during the 1973/74 summer. In most years though, this value remained close to the average. Days on which temperatures exceeded 20°C were not necessarily consecutive, nor was the water temperature necessarily above 20°C for a 24 hour period.

3.3 Angling

Records from previous angler diary schemes have enabled us to compare aspects of the Whakapapa trout fishery before and after the diversion and lahars affected the river. Two reports have been published, one by Allen and Cunningham (1957) covering the years 1947-52, and a later one by Graynoth (1973) which discussed the continuation of the earlier diary scheme carried out in the 1960's. In comparison with other rivers in what used to be the Waimarino Acclimatisation District, the Whakapapa fishery was rated very highly. Allen and Cunningham reported the catch rate to be one of the best in the district (along with the Makotuku River), and the mean length of fish was second only to the Manganui-a-te-Ao. Graynoth (1973) rated the Whakapapa as "the best fishery in the Waimarino District", and said the majority of fish over 2.5 kg in weight caught in the Waimarino District came from the Whakapapa.

Since a good return to the angler is an essential aspect of a viable fishery, an angler diary scheme was incorporated into our study to document catches, and assess changes in catch which may have occurred as a result of diversion of water and the two lahars in 1969 and 1975. A list of anglers who regularly fished the Whakapapa was obtained from the Waimarino Ward and these anglers were asked to record the time spent and results of each visit to the river during the 1979/80 and 1980/81 fishing seasons. An example of the diary is included as Appendix III.

Although diaries could not be sent to every angler who fished the Whakapapa, considerable data were collected from the regular fishermen. In 1979/80, 29 diaries were distributed and 20 were returned. Of those returned, three anglers (15%) indicated they had not fished the Whakapapa that season. In 1980/81, 24 diaries were sent out and 18 (75%) were returned. Seven of the 18 anglers had not visited the Whakapapa that season. Results of our angler diary scheme are presented in Table 11, and compared with historical data collected by Allen and Cunningham (1957) and Graynoth (1973).

In some respects, pre-diversion and lahar, and post-diversion and lahar data appear quite similar. Graynoth (1973) reported that angling in the Whakapapa mainly occured at Kakahi. This remained true and 50% of the visits in the present study were to the lower section of the river. Over 80% of the regular anglers' visits occurred between Oio and the mouth. With the exception of the 1967/68 season, when only six diaries were returned, the percentage of rainbow to brown trout in the catch has remained the same, with between two and three times more rainbows being landed.

Mean lengths and weights of takeable rainbow and brown trout caught show small increases, the statistical significance of which cannot be tested, because of deficiencies in historical data. In contrast, catch rates appear to have declined, though again the significance of this cannot be statistically tested. However, some anglers have stated that they caught many more trout in the Owhango/Kakahi area prior to abstraction of water (H.H. Brown pers. comm.). Nevertheless, our results indicate that the Whakapapa still supports a viable recreational trout fishery.

Using the 1979/80 and 1980/81 diaries, it was possible to compare anglers' results from two reaches of the Whakapapa, above and below the Piopiotea confluence. From the average lengths and weights of brown and

TABLE 11. Pre- and post-lahar and diversion angling diary information.

Season	1947-52[1]	1962/63[2]	1967/68[2]	1979/80	1980/81
No. of diarists	unknown	16	6	18	10
No. of trout caught by diarists	247	165	81	141	131
% rainbow	66	67.8	28.4	75.6	68.9
% brown	34	32.2	71.6	24.4	31.1
Takeable rainbow	99	unknown *		64	54
Avg. length (mm)	466	456 *		500	487
Avg. weight (g)	-	1100 *		1534	1442
Takeable brown	41	unknown *		21	22
Avg. length (mm)	436	482 *		500	529
Avg. weight (g)	-	1400 *		1510	1818
Catch rate (fish/hr)	0.69	0.62 *		0.35	0.50

1. From Allen and Cunningham (1957)

2. From Graynoth (1973)

* Results from 1962/63 and 1967/68 seasons combined by Graynoth (1973).

rainbow trout presented in Table 12, fish of both species landed above the Piopiotea were larger than those landed below the confluence of this tributary. The differences were found to be significant at P = 0.001, using Student's t-test.

TABLE 12. Average lengths and weights of rainbow and brown trout landed from two reaches of the Whakapapa River.

Species		Above Piopiotea	Below Piopiotea
Rainbow	Number	17	104
	Length (mm)	578	479
	Weight (g)	2192	1349
Brown	Number	7	37
	Length (mm)	612	499
	Weight (g)	2360	1533
Both	Catch rate (fish/hr)	0.34	0.45

However, the number of regular anglers who indicated they no longer fished the Whakapapa River was of some concern. These anglers' comments gave some insight into three factors which have contributed to this change in fishing behaviour. The lahars of 1969 and 1975, which depleted the fish stocks throughout the Whakapapa main stem, no doubt discouraged anglers from visiting the river. Despite the fact that fish populations recover from such events, some local anglers may not have returned to fish the river. Between the lahars, works associated with construction of the intake and the effects of diversion of water (which were quite apparent to those who fished the upper reaches), probably compounded the feelings of local anglers that the Whakapapa was no longer worth fishing.

One further event which may have contributed to a change in fishing habits involves amalgamation of the Waimarino Society with the Central North Island Wildlife Conservancy, Department of Internal Affairs. Prior to 1977, local anglers required only one licence to fish the following rivers: Whakapapa, Wanganui, Manganui-a-te-Ao, Mangawhero, Waipa, Ongarue, Ohura and others. Since amalgamation, a Department of Internal Affairs Rotorua licence must be purchased (at a current cost of $18) to fish the Whakapapa, Wanganui, Manganui-a-te-Ao and Mangawhero Rivers. An Auckland (or other) ordinary acclimatisation society fishing licence is required to fish the Waipa, Ongarue and Ohura, while anglers wishing to fish any of the Lake Taupo tributaries must purchase an additional Department of Internal Affairs Taupo licence. The three licences required to fish all the rivers in this area therefore cost $45 in 1981/82, a fact which may deter some anglers.

Provisional data from the National River Angling survey (Teirney 1980), which was recently undertaken by FRD in conjunction with each acclimatisation society and the CNIWC, suggests that the Whakapapa is still relatively highly valued as a recreational fishery (Teirney, Richardson and Unwin in prep.). Of the 15 609 adult anglers who purchased whole season CNIWC licences during the 1980/81 fishing season, 1500 (9.6%) were included in the survey sample. To date, information about the angling habits of 931 (62%) of those sampled has been received. Information about rivers throughout the CNIWC district fished by 368 (40%) of these licence holders has been provided by the respondents, so far.

Table 13 shows the number of respondents who fished each river in the Waimarino Ward, the number of visits they made each year and the average number of visits/angler. Also included is a 1-5 importance grade which was assigned to anglers' ratings of importance, or value, of each river, taking into account the whole angling experience.

TABLE 13. Measures of angler use and importance grade, or value, of rivers in the Waimarino district.

River	No. of respondents	No. of visits	Visits/ angler	Importance grade
Wanganui	22	268	12.2	5
Whakapapa	26	253	9.7	4
Retaruke	5	40	-	*
Manganui-a-te-Ao	23	217	9.4	5
Orautoha	5	47	-	*
Mangawhero	17	298	17.5	4
Taonui	13	154	11.8	4
Waitaiki	11	79	7.2	3

Scale of importance: 1 = not highly valued

5 = very highly valued

* = too few responses to analyse.

The Whakapapa attracted a similar number of anglers and angling effort to the neighbouring Manganui-a-te-Ao River. However, the angling experience afforded by the unmodified Manganui-a-te-Ao was more highly valued than that associated with the Whakapapa, a reversal of the pre-lahar and diversion situation. The Whakapapa was fished both by local anglers who lived in close proximity to the river, and by others who had to travel a considerable distance to reach the river. Access to the middle and lower reaches, where the majority of angling took place, was not considered to be easy. Once at the river though, anglers appreciated the extensive areas of fishable water which were available. Both scenic beauty and the opportunity of fishing in peace and solitude were very highly valued. Dry fly, wet fly, nymph and spinner were equally popular methods used by anglers. Fishing was often combined with a range of other recreational activities including picnicking, swimming, shooting, tramping and camping. Anglers were attracted to the Whakapapa from six other North Island acclimatisation society districts - Auckland, Tauranga, Hawkes Bay, Wellington, Wanganui and Stratford. Although a slightly higher percentage of visiting anglers fished the headwaters, their responses about the angling experience afforded by this river were very similar to those of the CNIWC anglers.

4. DISCUSSION AND RECOMMENDATIONS

Results of our studies show that some sections of the Whakapapa have been affected more than others by the residual flow regime. In order to summarise these effects, the river has been divided into the following four sections: above the intake, the intake to the Otamawairua confluence, the Otamawairua to the Piopiotea confluence, and Oio to the mouth (Fig. 3). The section between the Piopiotea and Oio (2 kms) was always too turbid to observe fish by drift diving and has not been included. Where appropriate the following discussion gives consideration to ways in which the existing situation could be improved.

4.1 Above the Intake

While most of our survey effort was directed downstream of the intake, drift diving and spawning survey results indicated that the rainbow trout population and fishery in this headwater section have been adversely affected by the intake. Trout numbers were lower than would have been expected in a river of this size and character. Although the swift and turbulent nature of the water made accurate counting difficult, an average of only 2.8 fish/km* were seen. Use of the Whakapapaiti as a rainbow trout spawning area also has declined.

Although this section of the river was characterised by high water quality, abundant invertebrate fauna and a range of habitat types suitable for all life stages of trout, it appeared to be under-utilised. Water

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* Note: In this discussion, all "fish/km" figures refer only to medium and large trout.

temperatures, which may approach the lower lethal limit during winter, remained below the optimum feeding and growth temperature for much of the year. While this may limit the size of the rainbow population, it does not explain the apparent decline in numbers which has occurred since water was diverted from the Whakapapa.

Upstream movements of trout, including migration of spawning rainbows into the headwaters, has been prevented by construction of the intake. A proportion of the fry, juvenile and adult trout moving downstream are now diverted by the intake into Lake Otamangakau and lost to the Whakapapa altogether. Those which are carried over the intake during floods or through the intake during release of water, cannot return upstream.

Loss of fish from the Whakapapa could be prevented by provision of screens at the intake, and upstream migration encouraged by construction of a fish pass. However, although the headwaters were very highly valued by anglers who knew how to gain access to this reach of river, construction of these facilities is not recommended, because their success under the current residual flow regime cannot be guaranteed.

4.2 The Intake to the Otamawairua

This 6.9 km section of the Whakapapa (Plate 3) has been the most severely affected by the modified flow regime. A fish salvage operation conducted in 1972, immediately after the intake became operational, gave an estimate of 20 medium and large fish/km, all of which were rainbow trout (E.J. Cudby pers. comm.). While rainbow trout still predominate, an average of only 1.8 fish/km currently reside in this section during the summer months. This reduction in trout numbers by over 90% has been caused by the effects of modifying the natural flow regime in three important respects:

(i) A reduction in flow from 14 m^3/s to a flow of less than 1 m^3/s for approximately 50% of the time, has adversely affected several aspects of trout habitat. Decreased velocities through pools may have reduced the amount of

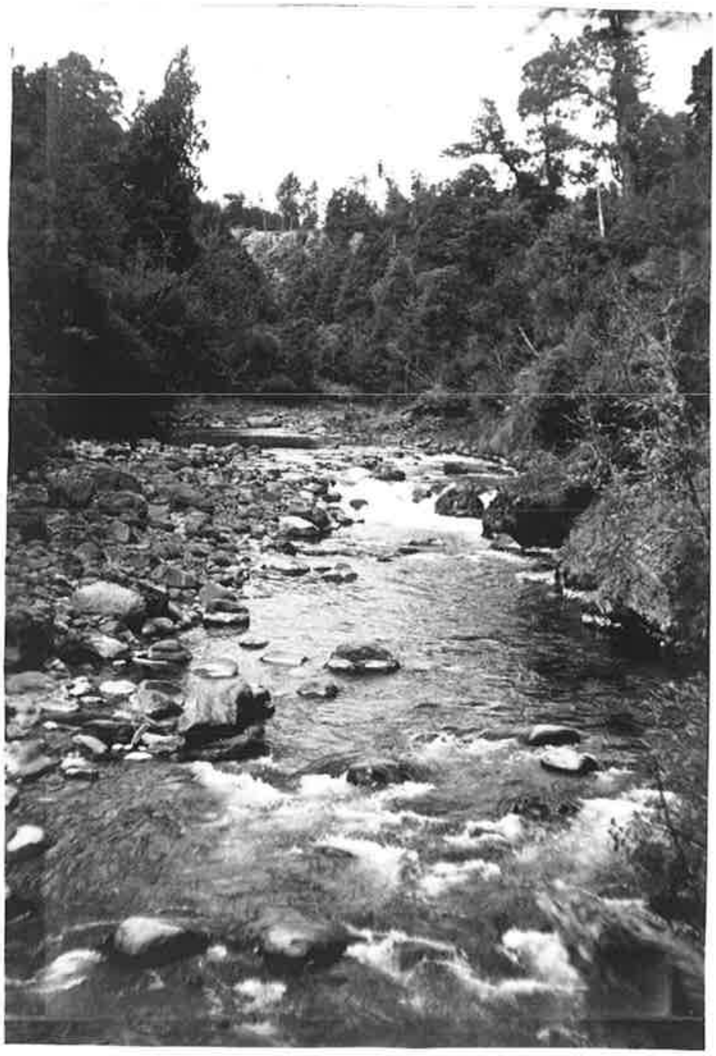

PLATE 3. Whakapapa River (Section B), between the intake and Otamawairua confluence at the residual release flow of 0.6 m^3/s.

suitable adult rainbow habitat quite substantially. Our studies showed that an increase in residual flow from 0.9 to 5.2 m^3/s increased available habitat by 40%.

While species composition, diversity and density of invertebrate fauna do not appear to have altered significantly, there has been a reduction in the amount of continually submerged riffle and run habitat. As a result, the total biomass of potential trout food organisms will have decreased.

Release of a higher residual flow, in combination with a more natural attenuation of floods, could improve the transport of fine sediment through this section. Hynes (1970) stated that fine material (silt and mud), would settle out at mean current speeds of up to approximately 0.2 m/s. Sediment accumulation through pools could therefore be reduced if the mean velocity was maintained at 0.2 m/s after floods. From examination of the velocity data from transects through the pool/slow run at station 1, an average velocity of 0.2 m/s is provided by release of 3.4 m^3/s at the intake.

Spawning survey results from four consecutive winters show that increasing numbers of rainbow trout are moving into this river section to spawn. Abundant fry observed along the riffle margins indicate that spawning is not only successful, but that suitable rearing habitat also occurs throughout this section. For some time prior to the 1982 spawning survey, a stable flow of 3 m^3/s was being released from the intake. Before this was reduced to 0.6 m^3/s in mid July, two pairs of rainbow trout were observed spawning immediately below the intake (E.J. Cudby pers. comm.). Neither this, nor the occurrence of five redds in the immediate vicinity of the intake had been observed in previous years when a residual flow of 0.6 m^3/s was released during the spawning period (Table 5 does not include these results). Spawning conditions throughout this section could therefore be improved by an increase in the residual flow to 3 m^3/s. Since successful spawning and rearing depend on the existence of relatively stable flows during winter and early spring, between July and October, water in excess of the recommended residual flow and hydro-electric generating requirements at Piriaka should be released at some other point along the Western Diversion.

For the combination of reasons outlined above, release of a 3 m^3/s residual flow is recommended, to partially compensate for the loss of trout habitat and resultant reduction in trout stocks and fishery values throughout this reach of the Whakapapa.

(ii) The natural flow regime has been modified by the operation of the intake which has increased the magnitude of flow fluctuations (from the residual flow to flood flows). The resultant decrease in habitat stability would be partially offset also by provision of a higher residual flow.

(iii) Abrupt attenuation of flood flows may result in a reduction in the biomass of potential trout food, stranding of both invertebrates and fish, and a disruption in the movement of fine sediment. A more natural attenuation of floods, in combination with a higher residual flow, would further stabilise trout habitat, particularly spawning habitat, throughout this section. There is however, merit in attenuating floods below the intake according to the method described in Appendix II and Figure 9, irrespective of size of the residual release. In an unmodified situation, the reduction in flow during the falling phase of a flood is a continual process, which enables mobile aquatic fauna to avoid being stranded. While a stepwise reduction in flow below the intake is unavoidable, the changes from day to day generally will not be large. In particular, it is important that immediately after a flood, sufficient flow is available below the intake to provide adequate transport for flood-borne sediments. The flood attenuation procedure described in Appendix II would ensure this, by restricting the amount of water available for diversion until flows had stabilised.

4.3 The Otamawairua to the Piopiotea

With addition of water from Otamawairua Stream, the discharge of the

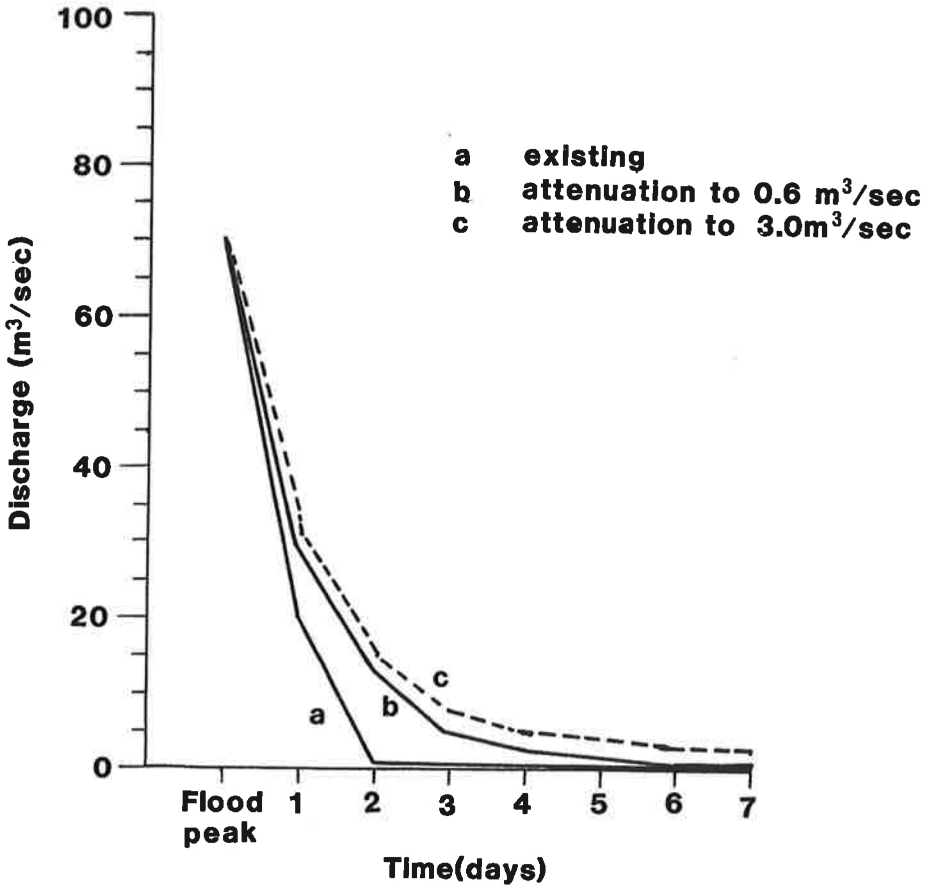

Figure 9. Recommended attenuation of a $100 m^3/sec$ flood to a residual flow of 3.0 or 0.6 m^3/sec.

Whakapapa is increased by at least one third. No other major tributaries enter the main stem until the Piopiotea Stream, a further 5.7 kms downstream. This section of the Whakapapa is characterised by steep shallow rapids, deep pools and areas of run. The true left bank of the river is currently in pastureland.

Unfortunately, no pre-diversion data are available on fish numbers in this section. Although an average of 9.6 fish/km were recorded during our drift diving surveys, trout numbers were probably underestimated due to marginal visibility in this section. The increase from 1.8 trout/km in section B to 9.6 trout/km in this section, where the effect of the residual flow regime was offset to some degree by the addition of the Otamawairua flow, indicates a positive relationship between trout numbers and the amount and stability of discharge. This relationship is further reinforced by the increase in fish numbers to 23.6/km which occurs after the flow of the Piopiotea is added to the Whakapapa. It is possible, therefore, that a residual release of 3.0 m^3/s and a more natural attenuation of floods, could result in a substantial increase in the trout carrying capacity of this section.

Anglers' access to this section of the Whakapapa is difficult. On the true right bank, steep terrain and dense bush make access almost impossible. The owner of farmland on the true left bank allows very few anglers through his property to the river. Anglers who were able to fish in this section landed trout at a rate of 0.34 fish/hour (Table 12). Below the Piopiotea, this rate increased to 0.45 fish/hour. However, the mean lengths and weights of both brown and rainbow trout caught above the Piopiotea mouth were significantly larger than those caught below. Despite the fact that brown trout dominated, 72% of the trout caught in this section were rainbows. Should the landowner assume a more flexible attitude towards access, angling could increase in popularity throughout this reach.

4.4 Oio to the Mouth

Addition of water from the Piopiotea increases the flow of the Whakapapa by approximately one third. Badly eroded stream banks, a partly developed catchment, sawdust heaps and a rubbish dump have downgraded the water quality of the Piopiotea. During drift diving, the turbid conditions created by addition of this warmer water, with its higher sediment and nutrient load, prevented the counting of fish for at least 2 km in the Whakapapa. Accumulations of sediment transported into the mainstem by the Piopiotea were observed in both pools and runs downstream. How much the transport of this sediment out of the river system has been affected by diversion of water at the intake was not investigated.

Although a more natural attenuation of floods may improve sediment transport below the Piopiotea, reducing the amount of sediment which is eroded from the catchment is very important. Erosion of stream banks could be reduced by a combination of revegetation and fencing to control stock access. The beneficial effects of riparian vegetation include lowering of water temperature, reduction in sediment load, addition of fish cover and terrestrial food input, and an increase in the aesthetic quality of the catchment. As the Rangitikei-Wanganui Catchment and Regional Water Board has some responsibility for catchment management practices which affect the quality and quantity of water, we recommend that discussions about both fencing and riparian revegetation take place between the fisheries managers and the regional water board.

Below the Piopiotea, long runs are the predominant habitat type (Plate 4). Rapids are short and steep, spilling into large, deep, sedimented pools. Although most pools held fish, more trout were observed in runs. As in section C, brown trout predominated, comprising approximately two thirds of the population. Numbers of medium and large trout/km, and the ratio of browns to rainbows throughout this section of the Whakapapa were almost identical to figures for a comparable reach of the Manganui-a-te-Ao.

Although the aquatic invertebrate community structure differed somewhat between the headwaters and this reach, the animals were mobile, non-burrowers and therefore potentially available as trout food. Transect measurements

PLATE 4. Whakapapa River between Owhango and Kakahi, at the full release of 17 m^3/s.

of depth, velocity and substrate did not indicate a significant reduction in the amount of physical trout habitat through runs in this section under the existing flow regime. However, water temperatures in the lower reaches exceed 20°C on an average of 28 days each summer. While the degree to which this stresses the trout population was not investigated,the adverse effects of such temperatures are well documented in the literature.

The few pre-diversion summer water temperature records available (E.J. Cudby pers. comm.), suggest that temperatures in the lower Whakapapa and Wanganui River downstream of the confluence, did not reach 20°C, remaining within the optimum temperature range for trout. It can be assumed therefore, that diversion of water has caused an increase in summer water temperatures throughout the Whakapapa, downstream of the intake. Despite the importance of meteorological conditions in determining water temperature, an inverse relationship was demonstrated between discharge and summer water temperature in the recent Hurunui River water temperature study (Hockey 1981). To make recommendations regarding the discharge required to lower summer water temperatures in the Whakapapa, the relationship between discharge and water temperature needs to be determined for this system. Although post-diversion water temperature, intake release and meteorological data will be useful, the lack of detailed pre-diversion temperature data necessitates a modelling approach. The most appropriate water temperature model is one recently developed by the US Fish and Wildlife, Instream Flow Group (I.G. Jowett pers. comm.). We recommend therefore, that this model be applied to the Whakapapa situation by I.G. Jowett (Ministry of Works and Development, Wellington). Specific recommendations about the discharge required to reduce summer water temperatures will not be possible until results of the modelling exercise are available.

Several public roads, part of the main trunk railway line and a more amenable attitude on the part of property owners make access to this river reach easier than further upstream. Once at the river, reduced flows have allowed anglers to ford the river more easily, and fish long stretches by walking along the river bed (Plate 5). Historically and currently, most angling takes place in this section of the river. As mentioned previously, the catch rate is higher than upstream of the Piopiotea, although the trout landed are smaller. Again rainbow trout predominate, making up 70% of the catch. Although catch rates from the current investigation are lower than those recorded by Allen and Cunningham (1957) and Graynoth (1973), from pre-lahar and diversion times, the significance of this decrease could not be tested.

Provisional results from the national river angling survey showed that anglers expend a similar amount of effort on both the Whakapapa and neighbouring Manganui-a-te-Ao Rivers. Before being modified, however, the Whakapapa was regarded as the best river fishery in the Waimarino Acclimatisation District. While it continues to support a viable fishery and is still highly regarded by those anglers who visit it, the Whakapapa has been replaced by the unmodified Manganui-a-te-Ao as the most highly valued river in the district.

5. SUMMARY OF RECOMMENDATIONS

1. This study has investigated the trout stocks, habitat and fishery supported by the existing flow regime of the Whakapapa, which includes additional releases of water made to satisfy agreements with TBC. Any renegotiations of these agreements which result in a reduction in the releases could therefore alter the existing fishery values and should not be implemented without consultation with the regional fisheries managers.

2. An increase in the flow released at the intake, from 0.6 m^3/s to 3.0 m^3/s, would partially compensate for the reduction in habitat values and trout stocks which has occurred in the Whakapapa (particularly between the intake and Piopiotea Stream), since diversion of water began in 1972.

PLATE 5. Whakapapa River at Owhango Bridge, at the full release flow of 17 m^3/s.

3. A more natural attenuation of flood and NZE releases below the intake would reduce habitat instability caused by diversion of water, and therefore improve habitat values and trout stocks throughout the Whakapapa River.

4. Gauging of water temperatures by NZE during December - February (and March if hot dry weather persists), should continue. The recently acquired Instream Flow Group water temperature model should be applied by I.G. Jowett (Ministry of Works and Development, Wellington), to determine the relationship between discharge and water temperature for the Whakapapa system. Until these results are available, the discharge required to reduce summer water temperatures which are stressful to trout, cannot be specified.

5. A reduction in the amount of eroded sediment transported by the Piopiotea Stream would improve fish habitat both in this stream and in the Whakapapa downstream of the Piopiotea confluence. Landowners should be encouraged by the regional water managers (in consultation with the fisheries managers), to restrict stock access to the eroded stream banks and promote revegetation.

6. The regional fisheries managers could encourage greater angling use of the Whakapapa by negotiating better access with landowners, sign-posting access routes and publicising the trout fishery supported by this river.

7. Further stocking of hatchery-reared rainbow trout would only be recommended in the event of a catastrophy, such as the occurrence of a lahar. If the hatchery liberations are to continue, all released trout should be tagged to determine whether the return of these fish to the angler justifies this current practice by the fisheries managers.

While we consider that implementation of these recommendations would reduce the adverse impact the diversion of water has had on the fish stocks, habitat and fishery supported by the Whakapapa, the necessary negotiations are the responsibility of the Wildlife Service, Department of Internal Affairs who are the freshwater fisheries managers in this district.

6. ACKNOWLEDGEMENTS

The authors would like to thank E.J. Cudby for use of his historical field records and helpful suggestions during the Whakapapa investigation, and M.J. Winterbourn, J.D. Stark, R.M. Ogilvie and P.M. Sagar for assistance with invertebrate identification and analyses. E.J. Cudby and M.J. Unwin made constructive contributions during drafting of this manuscript. In addition, members of the Waimarino Ward committee and staff of Wildlife Service, Department of Internal Affairs, are thanked for their assistance with data collection.

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APPENDIX I. Invertebrate bottom fauna sampling results (replicate samples combined for each sampling date).

	Station a					Station b					Station c				
Date	8/80	10/80	1/81	4/81	7/81	8/80	10/80	1/81	4/81	7/81	8/80	10/80	1/81	4/81	7/81
TAXA															
Megaloptera															
Archichauliodes diversus				1									2	1	1
Ephemeroptera															
Coloburiscus humeralis				1	1				1	1	2		10	32	21
Nesameletus spp.		3	2	31	3	1	1		12	6	18	13	36	42	3
Deleatidium spp.	192	232	145	240	87	203	269	484	294	149	409	567	537	492	176
Austroclima sepia	1	9						1							
Plecoptera															
Austroperla cyrene				2	1						1				
Megaleptoperla grandis	1		2	1					2	2					
Zelandoperla decorata	12	4						1	3		21				1
Zelandobius furcillatus	1	1			1										3
Trichoptera															
Aoteapsyche tepoka	1	2		1	1				2				2	5	1
A. colonica													1	6	1
Oxyethira albiceps				3										1	
Paroxyethira sp.				1											
Psilochorema spp.	2	5		8	1	3	5	2	9	9	5	10	6	14	20
Costachorema callista		1													
C. psaroptera	12	7	12	1					7		7			1	

APPENDIX I. (Cont'd)

Date	Station a					Station b					Station c				
	8/80	10/80	1/81	4/81	7/81	8/80	10/80	1/81	4/81	7/81	8/80	10/80	1/81	4/81	7/81
Trichoptera (Cont'd)															
C. xanthoptera	2	1	1									2			
Hydrobiosis parumbripennis	4	4				1		2	2			2	7	13	
H. clavigera												1			1
H. charadraea		1						1			2		2	4	
H. spatulata	2				1										
H. harpidiosa													2		
Hydrobiosis spp.	7	3	1						2						
Neurochorema confusum														1	
Other Rhyacophilidae	4	1	5	2	1	1	3	1	5	2	3	6	4	7	1
Polycentropodidae								2				2	2		
Pycnocentrodes aureola				2									1		
Beraeoptera roria	3	3		14	8	1				2	35	11	10	62	5
Olinga feredayi		1	1	2				3	2	1	4		5	138	9
Coleoptera															
Elmidae	17	46	38	58		8	11	19	49	1	2	8	29	113	2
Hydrophilidae								1							
Diptera															
Aphrophila neozelandica	7	6	1		5			1	7	2	3	1	6	5	2
Eriopterini	21	43	23	53	74	7	12	1	18	8	6	10		34	5
Paralimophila skusei					1										
Muscidae			9	5	1										

APPENDIX I. (Cont'd)

	Station a					Station b					Station c				
Date	8/80	10/80	1/81	4/81	7/81	8/80	10/80	1/81	4/81	7/81	8/80	10/80	1/81	4/81	7/81
Diptera (Cont'd)															
Orthocladiinae	185	619	343	18	5	57	740	227	5	1	2	2	11		
Podonominae	2		1												
Tanypodinae				1				1				1			
Lobodiamesa spp.													14		
Maoridiamesa spp.	81	55	12			7	19	1	3		1		5		
Tanytarsus vespertinus		4	13				1	1					5		
Polypedilum spp.			1										1		
Other Chironomidae a.	1										1	1			
b.					18					1					
c.		2			3						1				
Ceratopogonidae								1						1	
Others	1						1			2*		1*	1*	2	
<u>SUMMARY</u>															
Total animals/0.3m²	559	1053	610	445	212	289	1062	750	423	187	523	638	699	974	252
Animals/m²	1863	3510	2033	1483	707	963	3540	2500	1410	623	1743	2127	2330	3247	840
Number of "species" (taxa)	22	23	17	20	17	10	10	18	17	13	18	15	22	20	16
"Species" diversity	3.3	3.2	2.5	3.1	3.0	1.6	1.3	2.6	2.6	2.3	2.7	2.2	3.2	2.8	2.7

* Terrestrial animals not included in calculations of "species" diversity

APPENDIX II. Suggested method for attenuating flood flows below the Whakapapa intake.

Assume that each flood event can be described by an equation of the form:

$$Q_t = Q_B + Q_P e^{-Kt}, \quad t = 0, \ldots N \qquad = \text{(A1)}$$

where Q_t = discharge on day t

Q_B = base discharge

Q_P = peak discharge

and k is a constant to be determined.

Q_B and Q_t need to be determined for any particular flood, but can be estimated easily from the data. For each of the 15 events in Table A1, the last recorded value of Q_t (six or seven days after peak discharge) has been used as an approximation to Q_B. Therefore, for each flood:

$$Q_B = Q_N$$

and $$Q_P = Q_0 - Q_B$$

To estimate the value of k, equation A1 can be expressed in the equivalent form:

$$- Kt = \log \left(\frac{Q_t - Q_B}{Q_P}\right)$$

Comparing the observed and predicted values of Q_t, (t = 1, ... N - 1), minimisation of the squared deviations leads directly to the estimate k = 0.863. Equation A1 can therefore be written:

$$Q_t = Q_B + Q_P e^{-0.863t} \qquad = \text{(A2)}$$

Using the appropriate values of Q_B and Q_P for each event, this equation agrees well with the observed values for Q_t (correlation coefficient r = 0.89).

TABLE A1. Attenuation of 15 pre-diversion flood events (m^3/s) in the Whakapapa River.

Flood	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Start Date	5.7.60	13.9.60	17.7.61	15.4.62	5.11.62	21.6.63	11.3.64	18.2.65	8.7.66	3.7.67	30.8.68	7.12.68	27.10.69	14.12.70	14.5.71
Day 0	106.4	-	-	-	81.6	-	236.3	-	94.3	-	-	166.7	-	-	-
1	66.6	51.1	43.7	54.6	41.4	45.6	77.2	79.6	43.5	45.6	51.3	36.2	39.5	77.4	39.9
2	21.8	47.2	21.2	26.1	32.3	31.8	38.6	20.0	21.5	17.0	20.9	22.9	21.2	31.6	20.9
3	17.3	27.0	15.6	16.7	28.3	26.4	28.3	17.2	19.9	15.3	16.4	18.9	13.5	21.2	14.1
4	15.3	24.0	14.1	13.9	27.7	24.3	22.6	16.2	16.9	11.4	14.7	16.9	11.3	15.4	11.5
5	14.4	23.1	13.1	13.1	21.5	19.9	18.2	15.6	16.1	10.4	14.8	16.0	10.5	12.6	10.4
6	14.4	22.3	12.6	12.2	19.3	18.2	15.2	14.4	15.0	9.8	13.5	15.3	10.0	11.5	9.8
7	13.7	21.4	11.4	11.8	18.1	15.1	13.7	14.1	13.8	9.5	12.8	15.2	9.7	-	-

TABLE A2 Effect of two residual flows and natural attenuation of floods on diversion of water into the Whakapapa intake. (Figures shown are the percentage of total river flow taken by the diversion.)

Year	Management Option			
	Residual Flow: 0.6 m^3/s		Residual Flow: 3.0 m^3/s	
	No Attenuation	Attenuation	No Attenuation	Attenuation
1964	84.2	79.4	73.3	69.9
1969	92.4	91.0	74.3	73.8

The value of this relationship is that it provides a rational basis for setting residual flows so that, below the intake, recession of floods proceeds in a relatively natural manner. In particular, by requiring that the same recession constant apply to discharges both above and below the intake, appropriate discharges can be calculated for the days immediately following a flood of any given magnitude Q_P.

For practical purposes, calculation of residual flows can be simplified as follows: From equation A2, the ratio of the discharges Q_t and Q_{t+1} on two successive days is given by:

$$\frac{Q_{t+1}}{Q_t} = \frac{Q_B + Q_P e^{-0.873(t+1)}}{Q_B + Q_P e^{-0.873t}}$$

Since Q_B below the intake will always be small in relation to Q_P, the above ratio can be approximated by ignoring Q_B. This gives:

$$\frac{Q_{t+1}}{Q_t} \doteqdot \frac{Q_P e^{-0.873(t+1)}}{Q_P e^{-0.873t}}$$

$$\doteqdot e^{-0.873}$$

$$\doteqdot 0.42, \quad Q_B << Q_t.$$

Adopting this ratio as the guideline for setting flows (after rounding off to 0.40, or 40%), the general requirement is that on any one day, the residual flow should not be less than 40% of the discharge on the previous day.

To evaluate what this requirement would mean in terms of water lost to NZE, computer simulations were conducted to calculate the total amount of water abstracted during one year under various management options. Two years of flow data were selected for investigation, a high flow year (1964 : $\bar{Q}$ = 20.1 m^3/s) and a low flow year (1969 : $\bar{Q}$ = 12.8 m^3/s). Four runs were made for each year, assuming residual flows of 0.6 m^3/s and 3.0 m^3/s with and without attenuation of floods (Table A2).

When compared to the existing situation (0.6 m^3/s and no attenuation), the results show that the annual reduction in the volume of water diverted ranges from 4.8% to 1.4% (0.6 m^3/s residual flow), and from 3.4% to 0.5% (3.0 m^3/s residual flow). Most of this reduction comes about in the two days immediately after each flood peak, when most (or in some cases all) of the flow is required to produce a natural attenuation of flows below the intake. For example, after the flood of 11 March 1964 (Table A1), all of the 77.2 m^3/s recorded on 12 March would have been required below the intake, leaving no water available for diversion.

APPENDIX III. The Whakapapa River angler diary.

Please help your Acclimatisation Society and the Ministry of Agriculture and Fisheries to help you to better fishing by keeping a record of your fishing in this diary.

Tagged Fish: have either a plastic or metal tag about 5 mm diameter attached in front or behind the dorsal fin. Please attach tag to diary.

Marked Fish: have one or more of their fins removed i.e. Adipose, Adipose and Pectoral (right or left), Adipose and Pelvic (right or left), Pelvic (right or left), Pectoral (right or left). Please check your fish for such markings and record in your diary.

Comments record any changes in the state of the river i.e. discoloured, in flood, also weather conditions, raining, overcast, bright sun etc. Note condition of the fish you catch or see. You may observe distressed fish, particularly if the weather is very hot and the river is low.

WHAKAPAPA RIVER FISHING DIARY

NAME: ______________________________

ADDRESS: ___________________________

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IMPORTANT

Please record EVERY fishing trip you make even those that are unsuccessful.

All diaries will be treated as confidential and no information as to what any individual caught or where he fished will be disclosed.

Please send completed diaries to:

J. Richardson
Fisheries Research Division
P.O. Box 19062
WELLINGTON.

Diaries will be returned on completion of the study if desired.

REMEMBER THIS DIARY IS FOR THE WHAKAPAPA RIVER ONLY.

Date	Location Fished	* Method	Time Fished		Number and Species of Fish*			Fork length* of each fish kept	Weight of each fish kept	Comments
			start	finish	under-sized	legal size returned	kept			
example	kakahi	DF	0630	0830	1R		1B	40 cm	792 gm	good Fish

* Method DF = dry fly
WF = wet fly
Spr= spinner

*Species of fish R = Rainbow trout
B = Brown Trout

*