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FLOW MANAGEMENT IN THE TONGARIRO RIVER

by

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CONTENTS

Chapter Four - Features of Rainbow Trout Ecology in the Tongariro River.

Chapter Five - Flow Requirements for Trout in the Tongariro River.

Chapter Six - Recommendations for Flow and Fisheries Management.

APPENDICES

Appendix one - Previous Recommendations for Design and Operation.

Appendix Three - Effects of Scouring Rangipo Dam on Juvenile Trout in the Lower Tongariro River.

LIST OF FIGURES

Figure Short Title

LIST OF TABLES

Table Short Title

FLOW MANAGEMENT IN THE TONGARIRO RIVER

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ABSTRACT

The Tongariro River supports a world renowned trout fishery and a nationally important hydroelectric power scheme which has caused profound changes to the river's flow regime and some minor changes to its fishery. Specifications for the regulated compensation flow in the lower river, whilst originally intended to protect the fishery, constrain electricity generation and fail to address all requirements of the fishery. There is opportunity to reform the rules for flow management, both to enhance the fishery and to increase electricity generation.

The number of trout running into the Tongariro River is greatly affected by the number of juveniles which grow longer than 9cm in the river and its tributaries. Whilst diversion for power generation has increased the amount of fingerling habitat, certain artefacts in the regulated flow regime appear to prevent a corresponding increase in juvenile production. Undesirable features of the present flow regime include:

i) Artificially-induced surges.
ii) Abrupt, truncated flood recessions.
iii) Minimum flows soon after rainfall, higher flows in droughts.
iv) Absence of seasonal variation in the base flow.
v) Sandy bedloadaccumulation.

The effects of summer floods were far more damaging than undesirable features of the present flow regime. Nevertheless, numbers of trout running into the Tongariro River could be increased, particularly in years in which significant summer floods do not occur, if:

1. The minimum flow requirement at Turangi were abandoned and all flow specifications applied to the recorder site below Poutu intake.

2. A maximum surge rule were implemented such that artificially-induced water level changes never exceed

3. Conditional on "2" above, the restriction on the period for adjustment of gate and valve settings were lifted.

4. Ministry of Works and Development guidelines for scouring sediment were adopted in full.

5. The absolute minimum flow (cumecs) below Poutu intake were varied monthly to provide low flows in summer and higher flows in winter as suggested in the table below

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
13	13	14	15	16	17	18	18	17	16	15	14

These recommendations are expected to enhance angling and rafting opportunity and to increase the number of trout running into the Tongariro River. There will be more water for electricity generation during summer droughts and flows at Turangi will be lower than at present and this prospect may alarm anglers and rafters. During normal flow conditions, flows will be similar to those presently provided and when the catchment is wet, flows will be somewhat greater but there will be less water available for power generation.

CHAPTER SUMMARIES

The Tongariro Power Scheme, Fishery and River Management (Chapt. 1)

The Tongariro River supports a world famous rainbow trout fishery and is also an integral part of a nationally important hydroelectric power scheme. The power scheme diverts water from rivers draining the west and south of the volcanic plateau into Lake Taupo. Flows from the Moawhango and Whangaehu tributaries are diverted into the upper Tongariro River at Rangipo intake. This, and water from the upper Tongariro tributaries is passed through Rangipo power station and returned to the middle Tongariro at Poutu intake. The Poutu intake divides the flow and separates coarse sediment, delivering a compensation flow (i.e. flow specifically for maintenance of values) and the coarse sediment to the lower river. The remaining flow (usually a greater quantity) is diverted to Lake Rotoaira and thence to Lake Taupo via the Tokaanu power station.

Authority to build and operate the power scheme was given by Order in Council, subsequently validated by an amendment to the Water and Soil Conservation Act in 1973. This legislation does not specify provisions for maintenance of values and its authority predates the 1967 Water and Soil Conservation Act and is therefore an "existing use" which is held in perpetuity with no requirement to review. However, since the Electricity Division became a State Owned Enterprise, review is required within 35 years. Nevertheless, there are two ways to change flow management before the formal review process commences: the Waikato Catchment Board has the function of recommending, after consultation with interested parties, minimum flows in rivers; any interested statutory authority can apply for a water Conservation Order to protect existing values.

During the planning phase of the scheme, angling groups and the Wildlife Service negotiated agreement for specific minimum flow provisions, which Electricorp continues to provide. Agreed provisions for values are:

1. An absolute minimum flow of 11.3 cumecs below Poutu intake.
2. A mean daily (0800hrs to 0800hrs) minimum flow of 27.2 cumecs at Turangi.
3. An absolute minimum flow in the Poutu Stream below Poutu dam of 0.6 cumecs.
4. Flow adjustments at Poutu intake can take place only between and (when the river is closed to angling, to protect anglers from unexpected surges).

Experience gained since the scheme became fully operational in 1984 (diversion commenced in 1973) has shown that neither the design of the scheme nor present operating procedures are always sufficient to protect the fishery and specifications for the compensation flow constitute a significant constraint on generation capacity. This study, commissioned by the Wildlife Service (Department of Conservation since 1987) but funded by the Electricity Division of the Ministry of Energy (now Electricorp), assesses the impact of the power scheme on the fishery, evaluates factors affecting trout numbers, determines flow requirements for trout and, finally, recommends flow management policies to enhance angling opportunity in the lower Tongariro River.

Influence of the Power Scheme on the Hydrology of the Tongariro River (Chapt. 2)

The Poutu intake controls the amount of water diverted from the lower Tongariro and so has a major effect on flows downstream. The intake has sufficient capacity (c.a. cumecs) to divert freshes but has little impact on major floods. Consequently, its principal impact is on flows during normal flow conditions. Specific changes to the flow regime are:

1. Reduced normal flows.
2. Loss of seasonal variation in normal flows.
3. Reduced fresh frequency.
4. Truncated recessions.
5. Minimum flows soon after rain, higher flows during drought.
6. Artificially induced surges.

These artefacts in the flow regime have probably had both beneficial and detrimental impacts on the fishery. Flow diversion reduces the wetted area and therefore the living space available for aquatic life, particularly those requiring deep, fast flowing sites. However, reduced depth and current speeds have probably increased the area suitable for juvenile trout, which prefer shallower sites with moderate current speeds.

The loss of small freshes and truncation of recessions have reduced sediment transport capacity, probably detracting from the quality of the river bed as habitat for trout and their food, but have made the river fishable for more days of the year. Surges and rapid flow fluctuations at night (often caused by sudden adjustments at Poutu intake or Rangipo power station) can cause small fish and invertebrates to become stranded.

Factors Affecting Trout Numbers and Angling Success (Chapt. 3)

The number of trout running into the Tongariro River has been monitored indirectly since 1963 by trapping and counting the trout entering the Waihukahuka Stream, a spring fed tributary of the lower Tongariro River on which the Tongariro trout hatchery is located. It was assumed that numbers of trout entering this tributary would indicate the number entering the Tongariro River.

Multiple regression procedures were used to model variation in the numbers of trout to assess the influence of ten factors which might influence subsequent returns. The best fitting model accounted for 96.4% of the variation in trout numbers. The number of summer floods during the first year of juvenile life was the most important variable (-ve impact; 32.8% of variation) followed by the number of spring floods during fry emergence (+ve impact; 12.7% of variation), the number of hatchery reared fry liberated impact; +ve impact, 10.6% of variation), pollution from tunnelling wastes during the adult spawning migration (+ve impact; 6.7% of variation), the number of angling licences sold (index of angling pressure; -ve impact; 6.9% of variation), the number of winter floods during spawning (+ve impact; 4.0% of variation), the number of ova collected (-ve impact; 3.7% of variation), the number of autumn floods during the first year of juvenile life (-ve impact; 3.2% of variation), flow regulation (+ve impact; 2.0% of variation), the number of fingerlings liberated (+ve impact; 1.8% of variation). The number of trout able to spawn had no significant effect on subsequent returns.

The model suggests that:

1. Juvenile trout born in the Waihukahuka Stream spend a significant period of time in the lower Tongariro River where they are subject to the effects of floods and diversion which do not occur in the spring-fed Waihukahuka Stream.

2. Hatchery practices and diversion have influenced returns of adult trout, but floods in the Tongariro, particularly during summer, had far more influence.

3. Only a few parent trout, many fewer than occur naturally, can produce enough eggs and fry to occupy most of the nursery habitat available. There appears to be a considerable surplus of adult trout which could be harvested without impact on subsequent recruitment.

Regression modelling was also used to identify factors affecting angling success, measured in terms of individual angler's catch rates (numbers of trout caught per hour fished on the day of census). Field of some 3463 anglers between 1984 and 1988 were used to establish each angler's experience, familiarity with the river (usual number of days spent fishing the Tongariro River per annum), fishing method, reach fished and catch rate. However, despite the size of the database, the best fitting model accounted for only 10.1% of the variation in catch rates and only three variables were found to be a significant influence on angling success. These were the angler's familiarity with the river, fishing method, and the number of trout entering the Waihukahuka Stream. Neither flow, the reach fished nor years of angling experience were significant determinants of angling success.

Features of Rainbow Trout Ecology in the Tongariro River. (Chapt. 4)

The extent that juvenile trout use the Tongariro River system was examined to determine the importance for the trout population of flow provisions specifically for juvenile trout. Key questions are how long do juvenile trout live in the river before emigrating to the lake; which parts of the Tongariro system do juvenile trout use; what are the seasonal patterns of use; what are the most successful life history strategies? All but the last of these questions were addressed using a monthly electrofishing programme. Scales from adult trout were used to identify successful life history strategies.

Juvenile trout were most abundant in the Whitikau Stream, the largest natural-flow tributary of the lower Tongariro, and in the middle reaches of the lower Tongariro, between Puketarata and Turangi. Fry numbers were most variable, being scarce in winter but abundant from October until January. By contrast, there was little seasonal variation in large fingerling abundance. Reductions were associated with floods, particularly major floods and floods in summer. This indicates that juvenile trout of all sizes leave, or are displaced from the Tongariro River and enter Lake Taupo.

Scales from adult Taupo trout typically have a zone of closely spaced circuli at the centre of the scale, corresponding to slow stream growth, abruptly followed by widely spaced circuli, corresponding to faster growth in the lake. Trout size at lake entry, estimated by backcalculation, was consistent with that of large fingerlings. The minimum size (c.a. 9cm) was substantially larger than the smallest trout found in Lake Taupo. Thus, either scale analyses failed to determine the minimum size of successful emigrants, or, those less than about 9cm at lake entry do not survive. Acoustic surveys, undertaken in 1988 to estimate the number and size of trout in Lake Taupo, indicate that juvenile trout (5 to 35cm) were abundant in March (1.001 million), but declined to 161,000 by May, to 109,000 by July and to 71,000 by September. It therefore seems that considerable numbers of small juvenile trout enter the lake in autumn but few survive.

Since juvenile trout must reach at least 9cm in tributary streams before they are likely to survive and contribute to the fishery, it is clear that nursery habitat must be of central importance to the wellbeing of both the Lake Taupo and Tongariro River fisheries. It is therefore important that the flow regime in the lower Tongariro River provides suitable habitat for all the requirements of growing fry and fingerlings.

Flow Requirements for Trout in the Lower Tongariro River (Chapt. 5)

Assessments of juvenile trout abundance in the Tongariro River indicated that numbers varied from place to place and it seemed that high abundance was associated with areas of good quality habitat. Juvenile trout were reduced by ordinary floods, particularly summer floods and were decimated by major floods and these factors were key determinants of the number of trout returning to breed three years later. It therefore seems likely that the number of trout recruited to the fishery was limited by floods in some years but in good years was limited by availability of suitable nursery habitat.

Suitable habitat is a general and rather vague term embracing many variable features of a river environment. It includes physical features such as depth, current speed, light, temperature and substrate composition, chemical factors such as oxygen, carbon, nitrate and phosphate availability, qualitative factors such as cover, persistence and variability of habitat features. Two important features of physical habitat, depth and current speed, vary with flow and much of this variation can be predicted. Since the depth, current speed and substrate preferences for different trout life stages are known, it is possible to predict how habitat suitability, defined by these three aspects of habitat, varies with flow. From this, the flows which provide most physical habitat for juvenile trout, without detriment to other requirements of trout can be identified.

Four reaches, ranging from 150m to 290m in length, were selected to represent the main features of the river. Cross-sections were established along the channel at about one channel-width intervals. Substrate composition was estimated, depth and mean current speed were measured at intervals (0.5 to 2m) along each cross-section. Hydraulic modelling procedures were used to estimate depth and current velocity at different flows and published habitat preference curves were used to indicate how changes in depth and current velocity at a range of flows affect the area of suitable habitat available.

Maximum habitat area for juvenile trout was available at very low flows (< 5 cumecs) but most habitat for invertebrate food production was available at flows between 13 and 27 cumecs. This would be provided by a compensation flow of 12 to 18 cumecs measured below Poutu intake. At lower flows space suitable for juvenile trout increases but habitat suitable for invertebrate food production diminishes. At higher flows, both types of habitat decrease.

Recommendations for Flow Management (Chapt. 6)

Flow management objectives required to maintain or enhance angling qualities of the Tongariro River are:

1. To minimize the frequency, rate and amplitude of surges.
2. To reduce the artificially abrupt rate of flood recessions.
3. To provide the flow and flow regime required for maximum production of large fingerlings.
4. To minimize sand deposition.
5. To provide a flow regime in which trout are catchable.
6. To provide enough flow to satisfy aesthetic considerations.

These objectives are not mutually compatible and some compromises will be required. Recommended changes to flow management rules are:

1. Abolish the minimum flow requirement at Turangi.
2. Change the minimum flow requirement below Poutu intake to provide a variable minimum flow (cumecs), adjusted monthly, as indicated below.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
13	13	14	15	16	17	18	18	17	16	15	14

3. Allow gate settings to be adjusted at any time of the day but instigate operating rules such that artificially induced changes in water level below Poutu intake must not exceed 2.0cm.h^{-1}
4. Implement procedures for management of sediment in Rangipo dam as recommended by Ministry of Works and Development.

These recommendations will reduce the frequency of minor surges and will provide a more natural seasonal variation in base flow. Minimum flows will be associated with dry weather and recessions will be less abrupt.

Lower compensation flows would increase generation capacity and physical habitat for juvenile trout but would probably be aesthetically unsatisfactory and would increase the likelihood of introducing new constraints on juvenile trout production. Rafting becomes difficult at flows less than about 15 cumecs below Poutu intake.

A greater compensation flow would be aesthetically more pleasing, more satisfactory for rafting and might slow upstream migrant trout, thereby making fresh run trout available to anglers for longer. However, it would further reduce generation capacity and decrease the physical habitat space available for all trout life stages. Thus, until relationships between catch rates, migration and flow are clarified, there appears to be little justification for higher flows than those proposed.

Monthly adjustments to the compensation flow have three advantages over a constant minimum flow. Firstly, the flow variation is likely to increase juvenile nursery habitat at the time when there is most demand for it. Secondly, the flow variation is likely to decrease sand and periphyton accumulation, and so improve habitat quality. Thirdly, it will give anglers higher flows during the angling season, which is what anglers seem to think they want.

Liberalization of hours for gate adjustments at Poutu intake would reduce the rate, frequency and magnitude of artificial surges and will make recessions less abrupt. It should result in more efficient use of available water for power generation by enabling operators to respond to changes in flow as they occur. However, such liberalization would expose anglers to the risk of surges caused by operator error. It is therefore recommended that operational rules and a fail-safe system are implemented to prevent artificially induced changes in the water level below Poutu intake exceeding The suggested maximum of 2.0cm.h^{-1} is based on the supposition that observed failure by juvenile trout to occupy apparently suitable habitat near Poutu intake is more a consequence of frequent minor water level fluctuations (c.a. 3 to 10 cm.h^{-1}) than the more unusual major surges.

Management of flows through Rangipo power station has to give due regard to the downstream effects of sudden cessation of tailrace discharge. At present the most dramatic surges are prevented by ensuring that tailrace discharge never exceeds the flow diverted to Lake Rotoaira. However, major surges can still happen if failure occurs when tailrace discharge is large compared with compensation flow below the intake. Further restrictions (e.g. tailrace discharge not to exceed 80% of diverted flow when the flow below Poutu intake is less than 14 cumecs) would reduce the magnitude of these surges, but the cost to generation capacity would be hard to justify as unexpected failures become less common.

Sand substrate, particularly moving sand bedload, is the poorest substrate for habitation and production of benthic food organisms and trout. Sediment scouring from Rangipo dam should therefore be undertaken in a manner which ensures that sandy does not accumulate in the lower Tongariro. It is recommended that procedures specified by the Ministry of Works and Development be adopted in full.

CHAPTER ONE

THE TONGARIRO POWER SCHEME, FISHERY AND RIVER MANAGEMENT

1.1 Introduction

The Tongariro River supports a world famous trout fishery and is also an integral part of a nationally important hydroelectric power scheme. The Government authorized construction of the power scheme with the condition that the Tongariro trout fishery must be protected and this requirement has influenced the site design and operation of many scheme components. Experience gained since the scheme became fully operational in 1984 has shown that neither the design nor present operational procedures are always sufficient to protect the interests of the fishery and specifications for the flow not used for power generation (i.e. compensation flow) constitute a significant constraint on generation capacity.

The number of anglers fishing the Tongariro River has been increasing annually, causing overcrowding problems, and the number of trout caught has also been increasing, generating concern about the possibility of overharvest. Consequently, the managers of the river and of the fishery, the Electricity Division (Ministry of Energy) and the Wildlife Service respectively need to know how the compensation flow should be managed to protect or enhance the fishery and whether more of the river could be made available for to alleviate crowding problems without undue stress on the trout population.

To answer the questions posed above, the present study of flow management of the Tongariro River was commissioned by the N.Z. Wildlife Service, Department of Internal Affairs, and funded by the Electricity Division, Ministry of Energy, to develop recommendations for fishery and flow management policies which will more effectively protect, or enhance, the fishery and still meet requirements for electricity generation. Specifically, the objectives of the study, begun in 1983, were to:

1. Describe effects of the power scheme on the flow regime in the Tongariro River and impact on the fishery.

2. Identify factors which influence the number of adult trout running into the Tongariro River.

3. Identify factors which influence numbers of trout caught by anglers.

4. Determine the most appropriate flow specifications for trout and angling in the Tongariro River.

5. Provide recommendations for flow management policies to enhance angling opportunity in the lower Tongariro River.

The study goal is to identify the most suitable flow and sediment management procedures for both the fishery and for electricity generation. Chapters 1 and 2 give the background, discuss pertinent matters raised by previous reports and describe the influence of the power scheme on the flow regime and fishery. Chapters 3 to 5 deal with the biological problems, firstly to find out what factors influence the number of trout running into the Tongariro River, what influences angling success, and finally, to determine how much compensation flow is required to provide for the needs of the trout. Recommendations for flow management policies for the lower Tongariro River are given in Chapter 6. The recommendations are based on what seems to be the most appropriate compromise between the various conflicting requirements for electricity generation, trout production and angling, consistent with reasonable operation of the control structures.

1.2 Previous Recommendations for Design and Operation

There have been five significant reports dealing with fisheries aspects of the Tongariro Power Development. These are described and discussed further in Appendix 1.

The first (Hobbs 1958) offered general predictions as to the likely consequences for the various affected fisheries. It is of interest principally because it develops the key principle of power scheme development with minimum detrimental impact on the fishery. Hobbs concluded that **"If the Hydro-electric authority shows a sympathetic appreciation of fishery needs, there is no reason why, without undue expense or serious hurt to the hydro-electric undertaking, the scheme of works should not be so developed as to prove beneficial on balance to freshwater fisheries"**

The second report (Woods 1964) based on a detailed study of these fisheries provided recommendations on fisheries management and design and operation of the power scheme. Woods calculated that the proposed reduction in the natural base flow in the lower Tongariro River from about 52 cumecs to about 27.5 cumecs would result in channel width reductions of 2-7% and shallowing by 10 to 20 cm, but he did not expect these changes to have any major effect on the fishery.

In 1973, the Power Division of M.W.D. and the Development Division of the Ministry of Energy released an Environmental Impact Statement for the Rangipo power project. No impact was expected on the lower Tongariro fishery, but it was acknowledged that unexpected shutdowns would cause shortfalls in the compensation flow followed 2 to 3 hours later by a rapid increase in flow.

The Commission for the Environment released their audit of this statement in 1973 and expressed concern regarding the effects of siltation and artificial fluctuations in the compensation flow, which had received scant attention in the Impact Statement.

In 1980, the M.W.D. released a series of papers by Dawson, Riddell, Jowett and Jones which examined flood and sediment management to develop guidelines for operation of the power scheme. The procedures recommended for flushing Rangipo dam are of particular interest.

1.3 The Power Scheme

The Tongariro River is the largest tributary of Lake Taupo, draining the eastern flanks of the volcanoes to the south-west and the Kaimanawa ranges to the south-east (Fig. 1). The catchment has recently been extended further south to increase the river's potential for hydroelectric power generation and now includes the headwaters of the Moawhango river and upper tributaries of the Whangaehu River. These waters enter the Tongariro River via the Moawhango tunnel (Fig. 2) and the flow is controlled by a valve located at the tunnel outlet where the water enters Rangipo dam. The latter is a small impoundment in the Tongariro River channel designed to separate sediment from the water, which is then diverted to the Rangipo power station via the Rangipo tunnel. Typically a high proportion, and sometimes all, of the

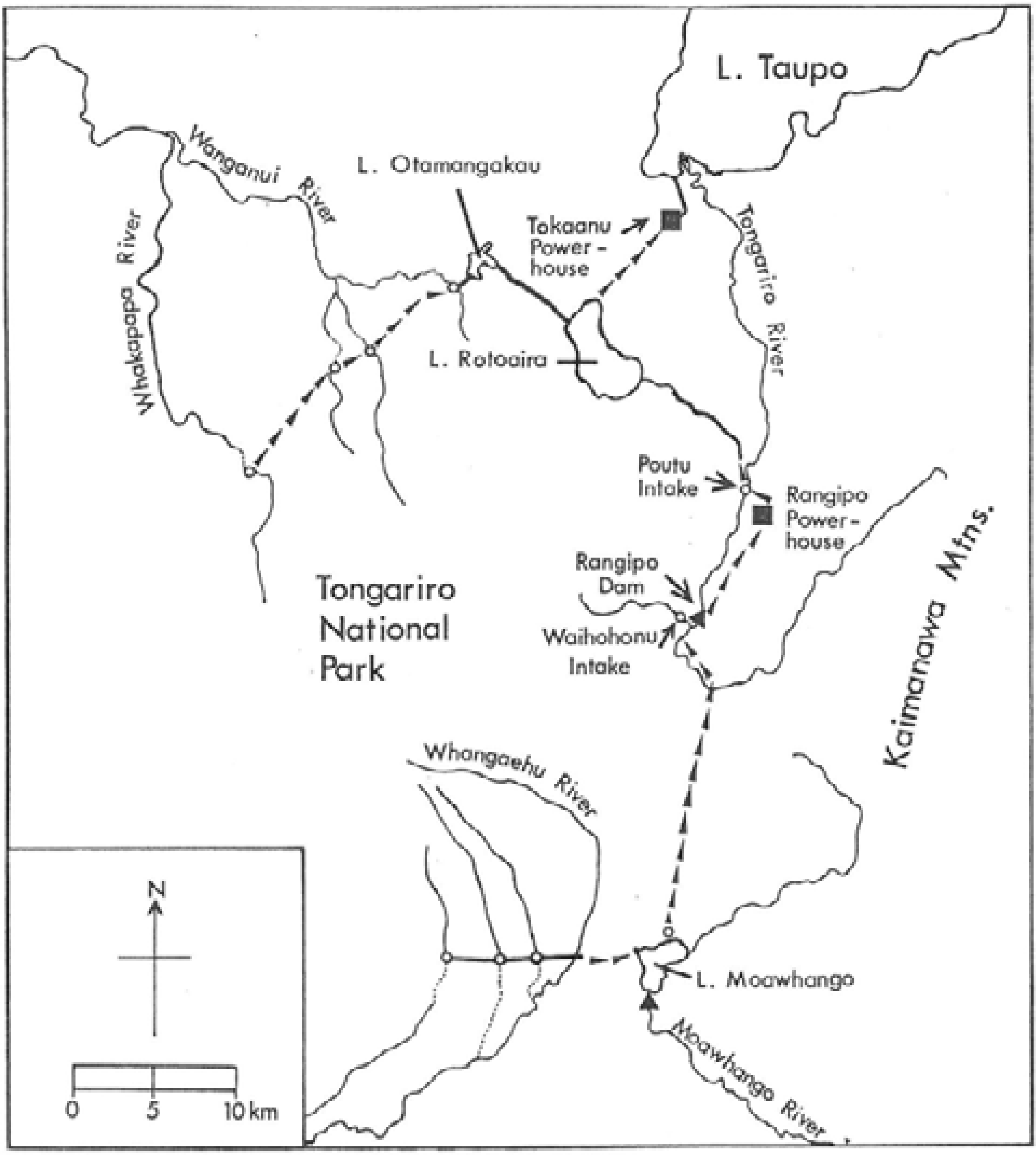


Figure 1. The Tongariro hydro-electric power scheme showing major diversions, intake structures, dams and power stations.

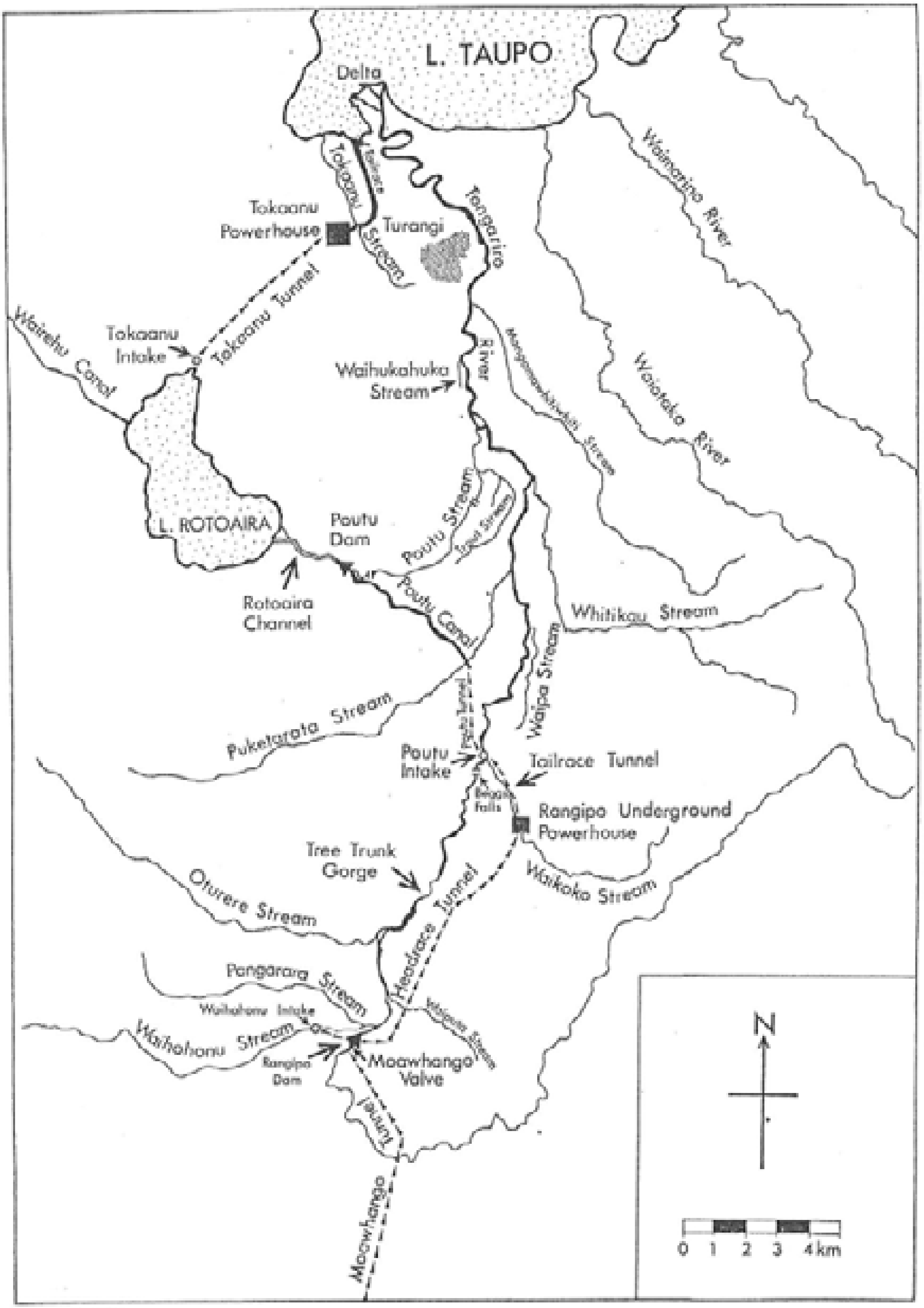


Figure 2. The Tongariro River catchment showing major tributaries and flow control structures.

flow entering Rangipo dam is diverted for power generation. After passing through Rangipo power station, either via the turbines or through the bypass system, the water re-enters the Tongariro River just upstream of the Poutu intake. Here a large proportion is again diverted, via the Poutu tunnel, to Lake Rotoaira at the Poutu dam. The remaining compensation flow continues down the Tongariro River to Lake Taupo. It is this section of river, about 30 kilometres long, between Poutu intake and Lake Taupo, known as the lower Tongariro River, which supports the famous Tongariro trout fishery. Thus, the management and operation of the upstream control structures (e.g. Moawhango valve, Rangipo dam, Waihohonu intake, Rangipo power station, Poutu intake and the Poutu dam) influence the compensation flow and sediment in the lower Tongariro River and so might also influence the fishery in the lower river.

1.4 Administrative Responsibilities

An Order in Council, gazetted on 29 October 1958 under section 311 of the Public Works Act 1928 (subsequently validated by an amendment to the Water and Soil Conservation Act in was issued. This authorized the Minister of Electricity "**inter alia, to erect, construct, provide, and use works in connection with utilisation of water power from the Wanganui, Tokaanu, Tongariro, Rangitikei, and Whangaehu Rivers and all their tributary lakes, rivers and streams in the land districts of South Auckland, Taranaki and Wellington for the generation and storage of electrical energy and to raise or lower the level of all or any of such rivers and their tributary lakes, rivers, and streams, and impound or divert the waters thereof:**" Under this authority, the Tongariro Power Scheme was built and the headwaters of the Moawhango, Whangaehu and Tongariro were diverted to flow into the power scheme.

This authority predates the 1967 Water and Soil Conservation Act and is therefore an "existing use" which is held in perpetuity with no requirement to review. However, since the Electricity Division became a State Owned Enterprise, review is required within 35 years. Furthermore, authority to exercise some control is vested in the National Water and Soil Conservation Authority (NWASCA) under the Water and Soil Conservation Act. Thus, independent of formal review, NWASCA has authority to fix, after consultation with interested parties, maximum and minimum levels, minimum acceptable flows and minimum standards of water quality. The Waikato Catchment Board has the function of recommending, after consultation, minimum flows in rivers. Recommendations are subject to direction from NWASCA and there is provision for the right of appeal to the Planning Tribunal.

Protection or preservation of valued natural features can also be achieved by a Water Conservation Order. Any statutory body with a function affected by water and soil conservation may apply to the Minister for the Environment for a Conservation Order.

Thus, the Department of Conservation has no statutory authority to compel Electricorp to modify aspects of flow management in the Tongariro River. It is merely an interested party, in the case of setting minimum flows, or a potential applicant for a Conservation Order.

During the planning and construction phases of the power scheme, angler groups, the Wildlife Service and the Marine Department negotiated agreement for a minimum daily mean flow for the Tongariro River at Turangi. This was the first of six assurances given by the Minister of Electricity listed in what has become known as the Shand agreement (see Appendix 2). The most important assurances given were:

1. **Sufficient water will be spilled at the Poutu canal intake to provide the recommended mean flow of approximately 1000 cubic feet per second in the Tongariro River at Turangi bridge.**

2. **The contaminated Whangaehu water will be entirely excluded from the scheme.**

3. **Collaboration between the New Zealand Electricity Department and the Departments concerned with fishing will continue into the future and operating procedures will be modified where necessary in the light of experience.**

The first assurance was based on observed low flows in the Tongariro and on the belief that angling became difficult at lower flows. It was assumed that if the minimum flow was never less than that which occurred naturally then the trout population would not be detrimentally affected. However, the Electricity Department subsequently realized that, within the terms of this agreement, major diel flow fluctuations were permissible and continuous flow below Poutu intake was not guaranteed. When flows in the lower tributaries were high, the flow requirement at Turangi could be met without any release of water from Poutu intake which left several kilometres of river channel below the intake virtually dry. This finding prompted further negotiation to take place between the Wildlife Service and the Electricity Department for a small reduction in the mean daily flow at Turangi and an absolute minimum compensation flow below Poutu intake, both of which requirements were soon agreed to.

Thus, whilst the Department of Conservation is responsible for management of the fishery, Electricorp controls much of the Tongariro River's flow characteristics but is under no statutory obligation to protect or enhance the trout fishery. All flow specifications have been established through negotiation and the only penalty which might be used to discourage non-compliance is uncomplimentary publicity presented in the light of assurances given in the Shand agreement. Despite this, transgressions have been rare and the scheme's operators have been receptive to advice and requests from the managers of the fishery when these do not cost significant generation capacity. However, the effectiveness of the various compensation flow criteria for protection of fisheries interests has never been critically examined.

1.4.1 Present Management Policies

The goal for flow management is to maximize electricity generation without compromising the quality of the fishery. Therefore, the principal objective for operation of the scheme is to divert as much water as possible through the Rangipo and Tokaanu power stations whilst also both leaving enough water in the river to comply with the minimum flow requirements (at Poutu intake, Poutu Stream, and at Turangi) and avoiding sudden surges which could pose a safety hazard. Sediment management is also necessary to achieve the flow management goal, in part to prevent accumulations at control structures which impede their function or efficiency and in part to protect trout habitat. It appears that policies for electricity generation and angler safety are well developed, but those required to manage sediment and to ensure that the quality of trout habitat is maintained or enhanced are only partially developed.

Fisheries management goals associated with the Tongariro power scheme are to prevent fish species spreading into waters where they were not previously present and to protect or enhance habitats of existing populations, particularly those with significant angling value.

1.5 Fishery Usage and Economic Values

The Taupo fishery is used intensively and considerable economic activity is generated by angling. Shaw (1985) found that during the 1982/83 fishing season 45,113 anglers came fishing; they owned $112.5M in assets associated only with angling in the Taupo District; they spent $16.7M on consumable item; generated some 244 full time jobs in the Taupo area; businesses had a value of $23M attributable to fishing; and the total harvest for the year was 626,000 trout (870 tonnes). Some 13,923 (30.9%) anglers fished the Tongariro River for an average for 7.3 days over the season and caught an average of 7.2 trout each. From these figures, total harvest was estimated to be 100,082 trout and the average catch rate was 0.22 fish caught per hour fished. This intense usage confirms the river's international standing, its reputation as the most important recreational river trout fishery in New Zealand and the importance of protecting or enhancing the exceptional angling qualities of the Tongariro River.

Note: Recent (1989) estimates of the size of the Lake Taupo trout population (Cryer in prep.) suggest that Shaw over-estimated the size of the 1982/83 harvest, possibly by one order of magnitude. The sources of bias in Shaw's estimates have not been identified.

1.6 Fisheries Management

The Tongariro River supports one brown trout population and at least two rainbow trout populations. Upstream of Poutu intake, rainbow trout are present and these are river resident because Rangipo dam, Tree Trunk Gorge, Begg's Falls (also known as Waikato Falls) and Poutu intake are all insurmountable barriers to upstream migration. The populations downstream of each of these barriers may be supplemented from above, but upstream movement past these barriers is not possible.

The trout stock which supports the famous Tongariro Fishery comprises migratory populations of rainbow and brown trout which occur downstream of Poutu intake. The trout live as juveniles in the river for varying periods, some being carried to the lake as fry whilst others live and grow for an unknown period before emigrating to Lake Taupo where they live until maturity when they return to the river to breed; adults which survive spawning then move back to Lake Taupo. Rainbow trout penetrate upstream to Poutu intake but brown trout are rarely seen upstream of the Puketarata Stream confluence. The fishery is based principally on the migratory adult rainbow trout which are abundant in the river between May and October. Between November and June, some anglers fish for the rainbow trout remaining in the river and for the brown trout which are most numerous downstream of the Mangamawhitiwhiti Stream confluence (near Turangi). Thus, whilst most angling activity takes place during the winter months, there is opportunity for angling in the Tongariro River throughout the year.

Eels are present in the Moawhango and Wanganui river systems and, despite Woods' (1964) recommendation that no action was required to prevent eels entering Lake Taupo, it was considered necessary to install a velocity barrier below Moawhango dam and fish screens in the top of the Wairehu canal to prevent possible movement into the Tongariro River, Lake Rotoaira or Lake Taupo. Eels have not been found in the Tongariro River but have occasionally been found in Lakes Taupo and Rotoaira, both before and after development of the power scheme. Brook trout from the Moawhango system have been found below Rangipo dam and brown trout seen in the Wairehu canal. However, whilst individuals of all three species have been seen, there is no evidence to suggest that new populations of eels, brown trout or brook trout have developed following construction of the power scheme.

Angling regulations have been developed, largely at the request of angler groups, to encourage sporting aspects of angling, to protect fish stocks and to assist with logistic aspects of enforcement. In general, the regulations are intended to ensure equitable distribution of both the catch and angling opportunity as well as to encourage sporting and conservationist ethics. However, since it is not known how large the total catch must be before angling values become threatened, functional angling restrictions to protect angling opportunity must await development. Appropriate bag limits, size limits, duration and timing of closed seasons, boundaries for closed waters and definition of appropriate angling methods are based more on conservative tradition than on objective assessment.

At present, angling on the Lower Tongariro River is restricted to fly fishing, the bag limit is eight trout, the size limit is 35cm and angling is prohibited between midnight and 0500 hrs. There is no closed season downstream of the Whitikau confluence, but angling is not permitted upstream between June and December. Angling is prohibited in all tributaries except the Poutu Stream. Angling groups frequently promote further angling restrictions, but in the absence of evidence indicating a need for additional regulation, the fishery managers have recently been unwilling to pursue such promotions.

1.7 Flow Rules and Flow Management

There are now three minimum flow requirements and a restriction on the hours during which gate settings at Poutu intake may be adjusted. Two minimum flow requirements apply to the Tongariro River and one applies to the Poutu Stream. Below Poutu intake the flow must never be less than 11.3 cumecs and at Turangi the mean daily flow (0800 hrs to 0800 hrs) must not be less than 27.2 cumecs, except when a lower flow would occur naturally. In the Poutu Stream, below Poutu dam, the minimum flow is 0.6 cumecs. Flow adjustments at Poutu intake can take place only between 2300 hrs and 0200 hrs so that surges associated with flow manipulation will occur outside legal angling hours and so will not he a hazard to legitimate anglers. These rules were developed through negotiations between representatives of angler groups, the Wildlife Service and the Electricity Division. Considerable effort is made to comply with these requirements and the few transgressions which have occurred were caused either by operator error or unexpected failures at Rangipo power station. In deference to the goal of not compromising either the fishery or angler safety, Electricorp have a policy of minimizing surges in the river during legal angling hours. Procedures which ensure compliance with the flow rules and the policy of minimizing surges have been developed (Interim Operating Rules 1979) and these are the procedural rules which guide decisions made by the operators in the Tokaanu control room. Thus, all adjustments of flow control structures which could influence flows in the lower river are made outside legal angling hours. Furthermore, the effects downstream of unpredictable surges caused by load rejections at Rangipo power station are minimized by ensuring that the flow through the power station never exceeds that diverted into the Poutu tunnel. This requirement costs significant generation potential, because generally water must be spilt from Rangipo dam to meet this requirement, instead of being diverted through the power station to generate electricity. However, this rule for flow management cannot prevent surges in the lower Tongariro, it only reduces their magnitude.

1.7.1 Sediment Management

Procedures for sediment management are still being developed, largely through experience; the M.W.D. recommendations for sediment management both at Rangipo dam and at Poutu intake were largely ignored prior to 1986. Rangipo dam has been flushed three times; twice during the annual maintenance shutdown (March 1984 and March 1985) and during a flood in January 1986. In March 1984, the normal lake level was maintained, although spilling was not over the spillway but via the sluice gates, which removed about 2040 cubic metres of sediment. This operation conformed to M.W.D. guidelines in that scouring took place during a fresh (although peak flows reached only about 85 cumecs - not the recommended 120 cumecs) and the Poutu tunnel was closed for the period. However, the lake level was not lowered, the sluice gates were only partially opened and Moawhango valve was closed for most of the operation.

In March 1985, the lake was partially lowered and some 3,300 cubic metres of sediment were mechanically excavated but, following an accidental further lowering of the lake, about 12,000 cubic metres were sluiced down the river. The Moawhango valve was closed and there were no significant freshes during the scouring operation. The turbid discharge, occurring at a weekend during low flow conditions, and consequent sediment deposition caused considerable dismay amongst recreational users of the river, but the event had little demonstrable effect on the trout population, probably because a small fresh on 15-16/3/85 removed much of the sediment so that heavy deposits persisted for only a week (Appendix 3). Following concerns expressed by the Wildlife Service, the Electricity Division agreed to abide by the procedures recommended by M.W.D. for sediment management in Rangipo dam. In January 1986, a major flood occurred and the Electricity Division partially lowered the lake to scour the accumulated sediment. Procedures recommended by M.W.D. were followed and the effects of the scouring operation were not noticed. Nevertheless, experience gained from these two events demonstrate that procedural rules based on M.W.D. guidelines for sediment management are required to protect the interests of both the trout and the recreational users of the river.

CHAPTER TWO

INFLUENCE OF THE POWER SCHEME ON THE OF THE TONGARIRO RIVER

2.1 Background

The major changes to the flow in the lower Tongariro River commenced in 1973 when the Poutu intake became operational. This structure controls the amount of water diverted from the river and so has a major effect on flows downstream. The intake has little influence on major flood flows but has capacity (c.a. 80 cumecs) to intercept most freshes. Consequently, its principal influence is to alter natural flows during normal flow conditions (Figs. 3 and 4). Changes include reduced modal, median, mean and minimum flows, elimination of seasonal flow variation, reduced frequency of freshes, truncated recessions, minimum flows early in the flood recession, artificially induced surges and a reduction in sediment transport capacity. Consequently, the form of the flood hydrograph for the lower Tongariro changed dramatically after 1973 (Fig. 3). Further developments (southern diversions and Rangipo power station) had comparatively little influence on flows below Poutu intake, although they were another source of interruptions to the natural flood recession.

In contrast, these later developments substantially altered the flow regime further upstream, between Rangipo dam and Poutu intake, reducing normal flows and increasing their variability. The Poutu Stream, formerly the outlet to Lake Rotoaira, has been severely affected by the power scheme and now has much less flow, a different water source and a substantially greater sediment load. The Waipakihi River (i.e. Tongariro River headwaters) is unaffected by the power scheme.

2.2 Average Flows in the Lower Tongariro River.

Diversion has reduced the usual flow in the lower Tongariro River. Before 1973, the mean flow at Puketarata was 38.3 cumecs and 53.6 cumecs at Turangi. Since 1973, the mean flow at Puketarata has been 22.8 cumecs and 31.9 cumecs at Turangi. However, the change to the normal or modal flow range has been more dramatic (Fig. 4). Flows at Puketarata ranging from 16 to 26 cumecs occurred for 35% of the time before diversion and for 79% of the time since diversion. At Turangi, flows between 24 and 32 cumecs occurred for 13% of the time but since diversion have occurred for 80% of the time. Thus, diversion has reduced both the range and magnitude of usual flows in the lower Tongariro River.

The Poutu intake has the capacity to divert all of the available flow during normal flow conditions. Consequently, for most of the time the flow discharged into the lower river is only enough to ensure that the 27.2 cumecs daily minimum is provided at Turangi and therefore, the average flow at Turangi is only marginally more (31.9 cumecs c.f. 27.2 cumecs; modal flow 26 to 28 cumecs). In contrast, the minimum flow required below Poutu intake is only 11.3 cumecs, the annual mean flow (1982 to 1988) is 18.5 cumecs and the modal flow is between 16 and 18 cumecs. This difference between the minimum permissible flow and the usual or modal flow occurs because, under normal conditions, tributary flow between Poutu intake and Turangi is only about 10 cumecs. Therefore, a minimum of about 17.2 cumecs must be split

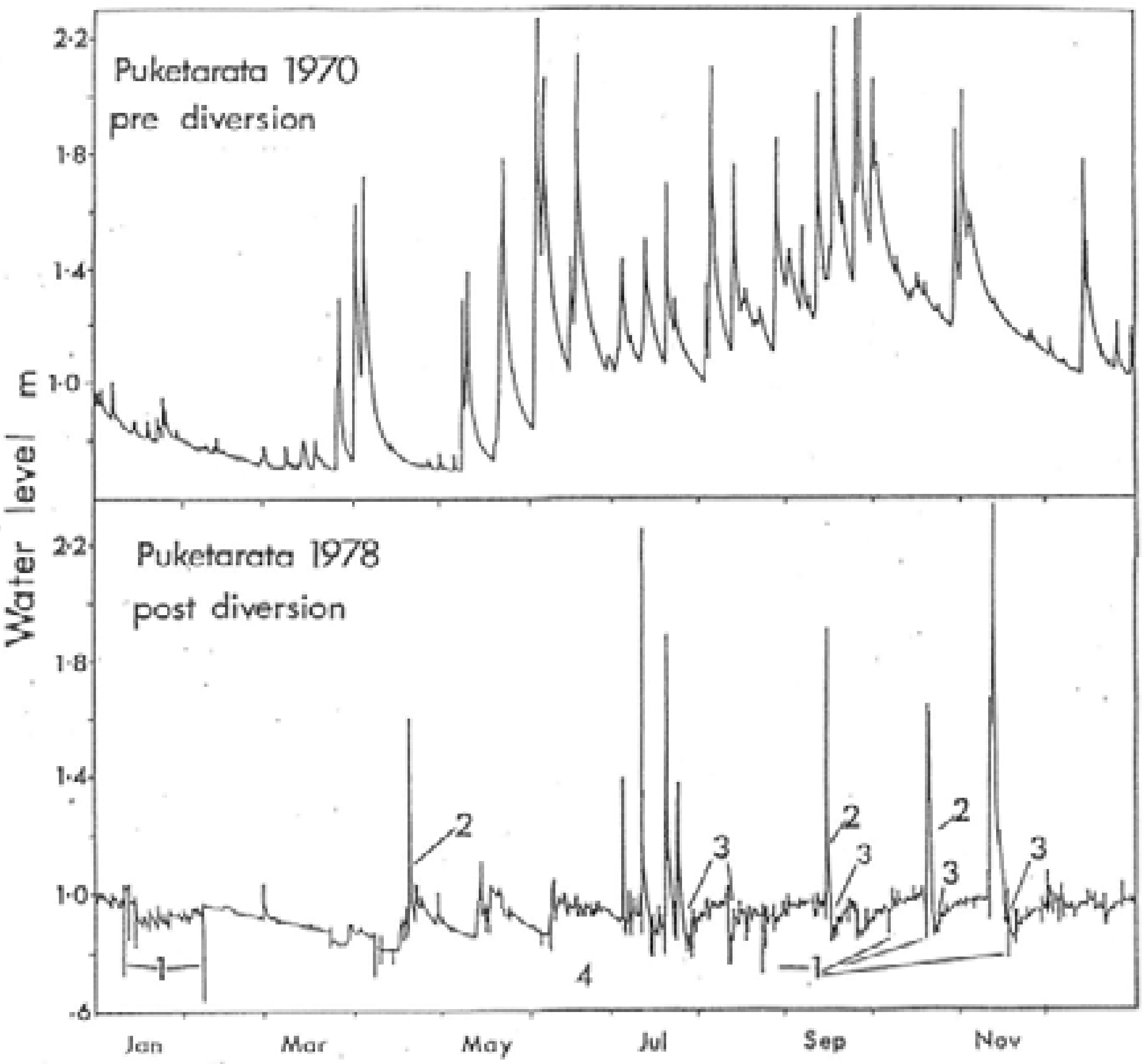


Figure 3. Tongariro River stage hydrographs at Puketarata before and after diversion showing negative surges (1), truncated recessions (2), periods of particularly low flow following floods (3) and absence of seasonal variation in the base flow (4). (Data supplied by Water & Soil Division of M.W.D.)

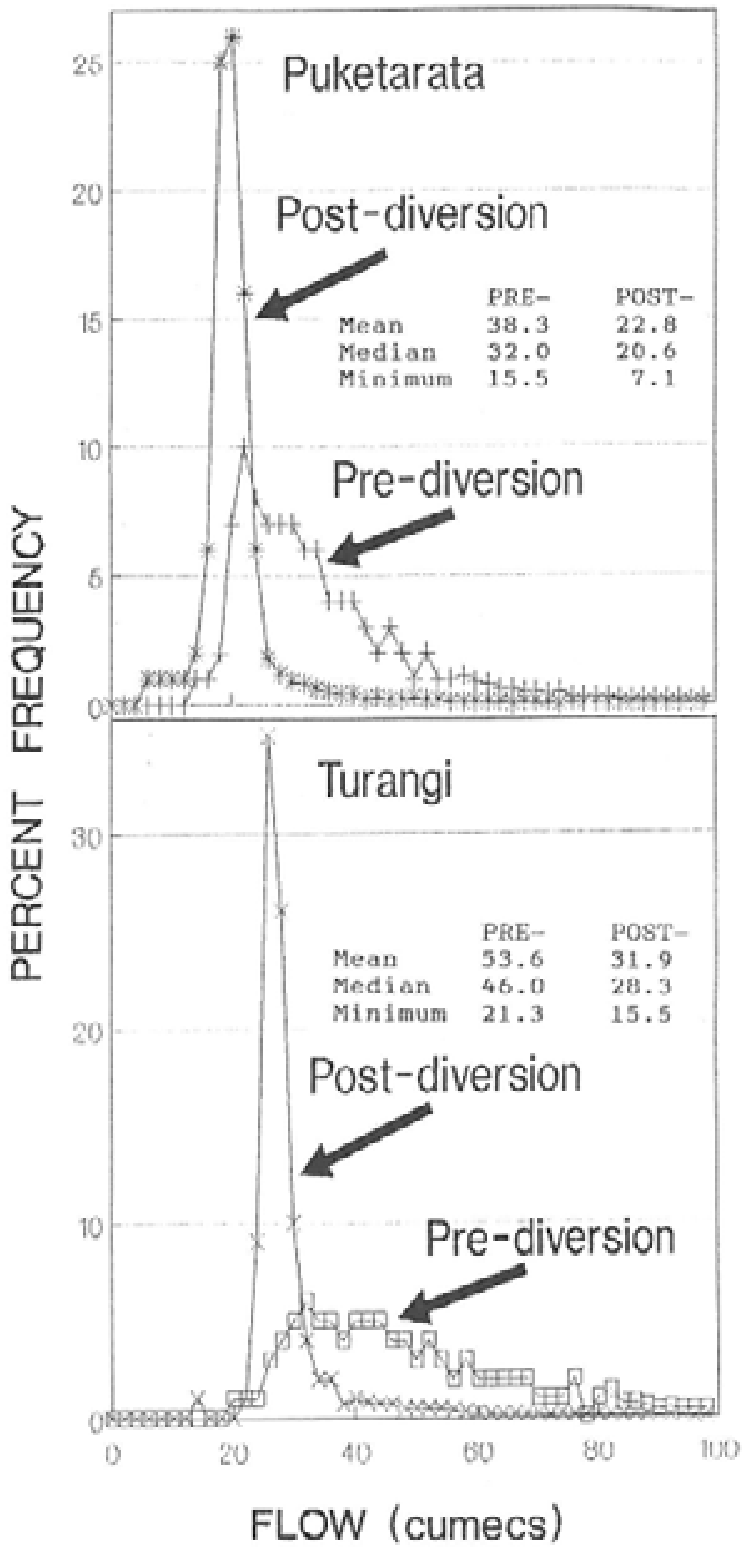


Figure 4. The distribution of flows at two sites in the lower Tongariro River from 1960 to 1971 (pre-diversion) and from 1973 to 1988 (post-diversion). Data are the percentage of time that flows are within each 2 cumec flow interval. (Data supplied by Water Resources Division of DSIR).

from Poutu intake to provide 27.2 cumecs at Turangi. In practice, up to about 22 cumecs are spilt when the catchment is dry and less (about 12 cumecs) when tributaries downstream of Poutu intake supply more than 16 cumecs. Consequently, minimum flows occur when above average flows would occur naturally.

2.3 Seasonal Flow Variations.

Before the power scheme was built, there was, in most years (e.g. Fig. 3), a seasonal pattern in base flow whereby flows were minimal in April (c.a. 25 cumecs at Puketarata) and maximal in September (c.a. 40 cumecs at Puketarata). However, because the Tongariro flow is now managed to provide as much water as possible for power generation, flows throughout the year are generally close to the minimum permissible mean daily flow at Turangi. The greater flows available in early spring are diverted at Poutu intake to Lake Rotoaira via the Poutu canal. Thus, seasonal flow patterns persist in the upper Tongariro and in the Poutu canal, but the average compensation flow in the lower Tongariro is constant throughout the year.

2.4 Reduced Fresh Frequency.

Minor freshes (< 80 cumecs) are intercepted by Poutu intake. In practice, not all the water is intercepted but the number of flood peaks observed in the upper river is substantially greater than the number occurring in the lower river (Fig. 5).

2.5 Truncated Recessions.

Flows now return to normal generally within two days after a flood, where previously flows remained high for nearly a week (Fig. 3). This happens because as much water as possible is diverted. The intake's capacity is sufficient that flows below Poutu intake must exceed the minimum compensation flow only when the flow arriving at the intake exceeds about 90 cumecs. This situation rarely persists for more than 48 hours.

Recessions are particularly abrupt when the Poutu tunnel gate (at Poutu intake) is opened from a near-closed position to maximize the diverted flow. This is because the power scheme operation rules confine all artificial flow adjustments to a daily three hour time slot and therefore adjustment has to be completed rapidly rather than in a stepwise, incremental manner.

2.6 Low Flows.

The natural relationship between flow and rainfall has been reversed for at least 12 below Poutu intake. After a period of significant rainfall, tributaries entering the lower Tongariro supply more than 16 cumecs, which is sufficient to meet the minimum flow requirement at Turangi when only 11.3 cumecs are released from Poutu intake. Consequently, the flow between Poutu intake and the Whitikau confluence is often minimal (i.e. a little over 11.3 cumecs) soon after a flood (Fig. 3). However, as the catchment dries out, tributary flow falls to about 10 cumecs so that more water has to be released, either from Poutu intake or down the Poutu Stream. Thus, in contrast with the natural situation, flows in the upper river increase as the catchment dries out.

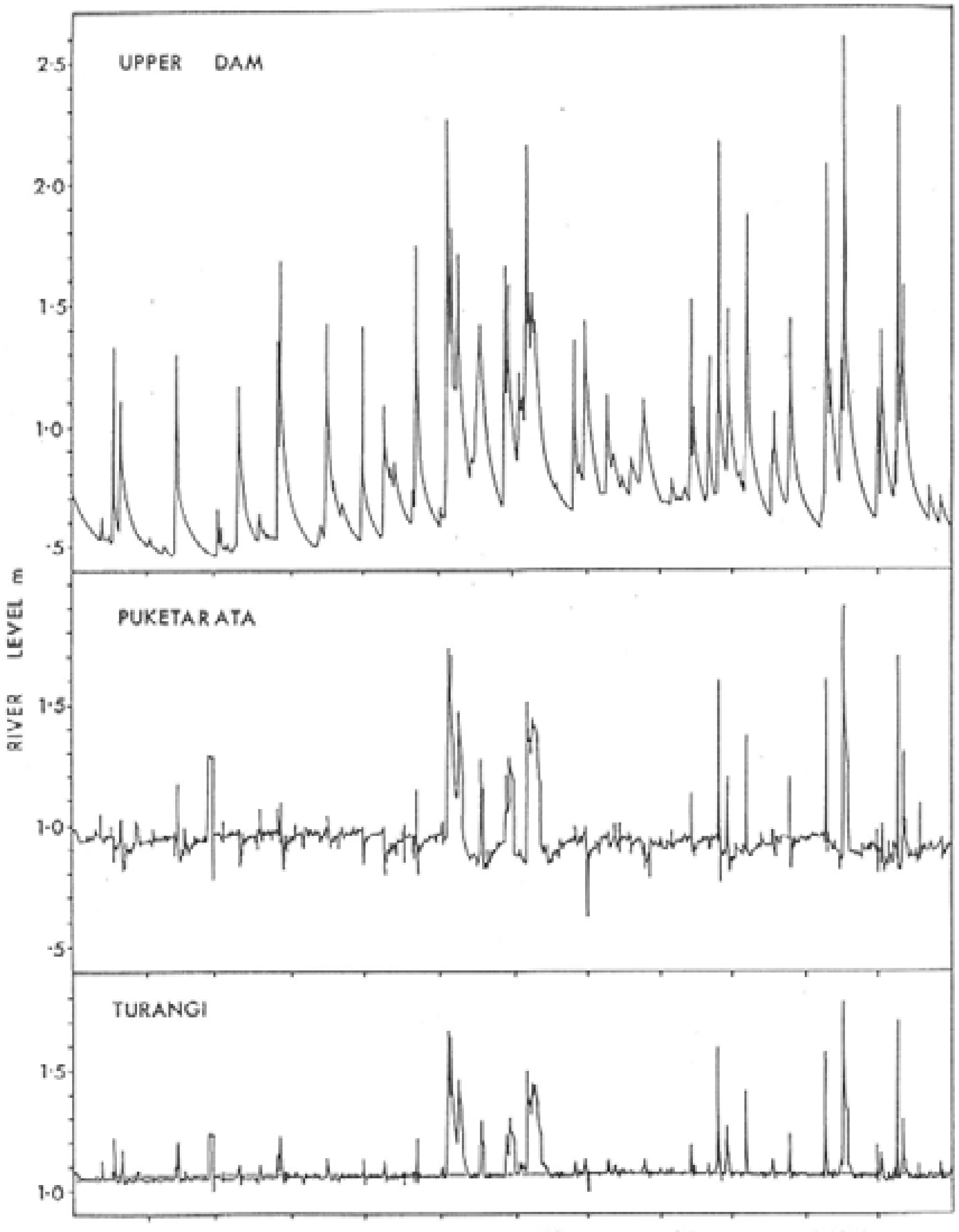


Figure 5. Tongariro River stage hydrographs for the upper, mid and lower river, showing differences in flood frequency and river level variation associated with each event. (Data supplied by Water & Soil Division of M.W.D.)

During dry conditions the compensation flow in the Poutu Stream may be increased to maximize the flow through Rangipo power station whilst still complying with both the minimum mean daily flow rule at Turangi and the "Interim Operating Rule" governing Rangipo tailrace discharge. The effect of this is to reduce the flow below Poutu intake with little effect on flows at Turangi.

The 11.3 cumecs instantaneous minimum flow rule was instigated because it was realized that without this, flows below Poutu intake could be very low, perhaps ceasing altogether if tributary flows were sufficiently high, without breach of the mean daily minimum flow rule at Turangi. In practice, this situation could arise several times every year. Thus, the 11.3 cumecs instantaneous minimum provides a compromise between protection from excessively low flows and maintenance of a natural flood recession in the lower river.

2.7 Surges.

Recessions now rarely follow the smooth exponential decay curves which characterize natural recessions (Figs. 3 and 5) because frequent artificially-induced flow variations interrupt the recession. These variations are typically caused by adjustment of Poutu intake or Moawhango valve and by load changes at Rangipo power station. Other, less common, sources of flow variation include failure of the Rangipo bypass and valves and closure of the Waihohonu intake.

Stage hydrographs (M.W.D. unpublished data) indicated that at Puketarata, from 1981 to 1983, artificial reductions in water level of about 5cm.h^{-1} occurred 2 to 3 times per month and rates of over 10 cm.h^{-1} occurred 4 to 6 times each year. Maximum rates were 30 to 35 cm.h^{-1}. Artificial rises of over 30cm in 15 minutes have occurred and these would be particularly hazardous for anglers if they occurred during normal angling hours.

The most dramatic surges occur when the flow through Rangipo power station ceases unexpectedly. When this happens, there is initially a rapid flow reduction (negative surge) followed about 1.5 hrs later by a positive surge when the water arrives at Poutu intake via the upper Tongariro River after spilling over Rangipo dam. There is, however, an operating rule designed to minimize the consequences of these unexpected shutdowns, which dictates that the flow through the power station is never less than that diverted into the Poutu tunnel. Operation according to this rule does not prevent surges occurring in the lower river when the flow through Rangipo power station is disrupted and it may not even prevent flows falling below the agreed instantaneous minimum flow below Poutu intake. This is because the flow remaining when the Rangipo tailrace discharge ceases is that which arrives over Beggs Falls. Some of this is diverted into Poutu tunnel and the rest passes down the lower river. A breach of the minimum flow requirement below Poutu intake will occur if the compensation flow is near the minimum flow when the Rangipo tailrace discharge is unexpectedly reduced.

A particularly common, but generally less severe, source of surges stems from the necessity to adjust the Poutu intake gates to meet the minimum flow requirements at Turangi. As there is only a three hour time slot available for flow manipulation, gate adjustment has to be made in anticipation of likely flow conditions during the next 24 hour period. If a faster recession or a smaller fresh than was anticipated occurs, additional water is released at Poutu intake on the following night to ensure that the minimum requirement at Turangi is met on the second day. A typical case is occurred on 17 Dec 1985 (Fig. 6) when the operator overestimated the size

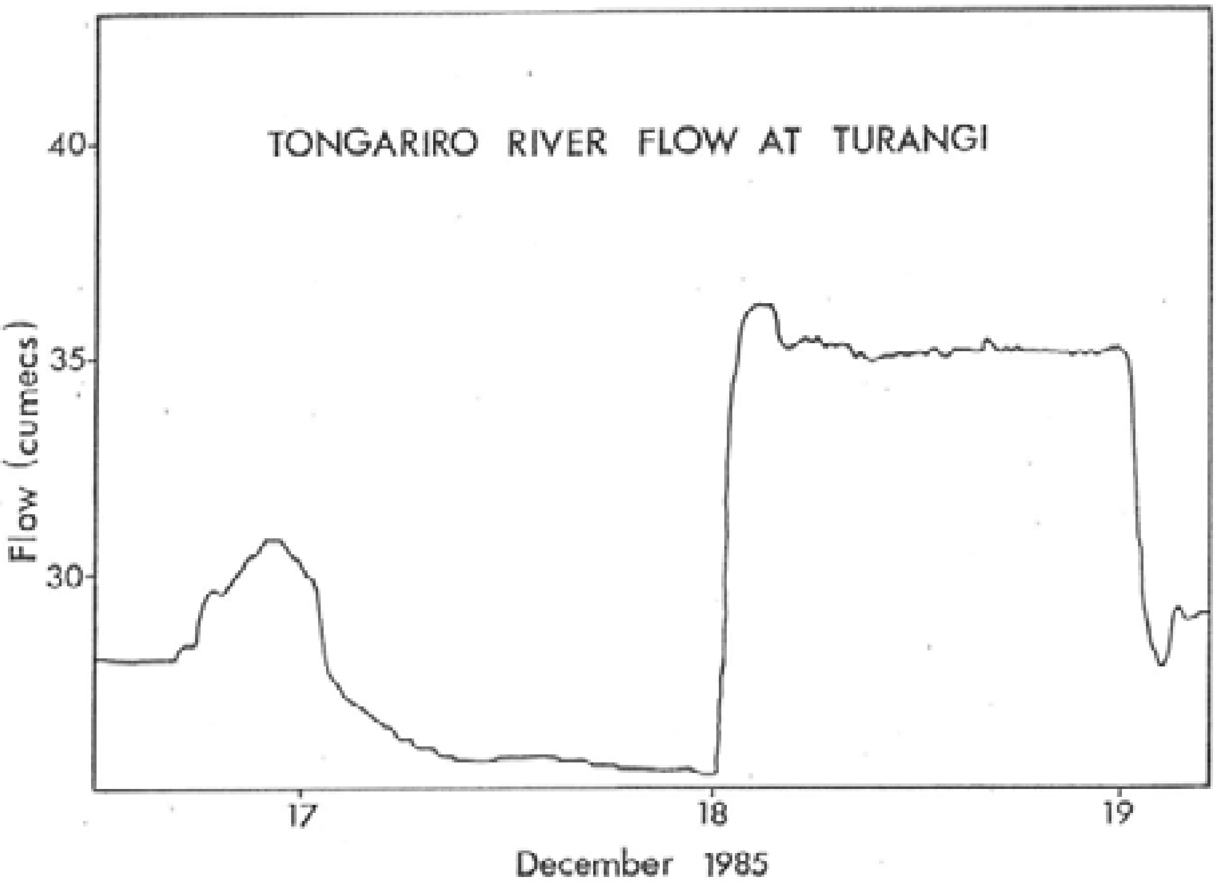


Figure 6. Flow variations following inappropriate gate adjustment at Poutu Intake on 17 December, 1985. (Data supplied by Water & Soil Division of M.W.D.)

of a developing fresh. He adjusted the gates in anticipation of a significant fresh causing a rapid 4 cumecs drop in the compensation flow. However, the fresh did not develop and for most of 17 Dec 1985 the flow at Turangi was less than 27.2 cumecs. At 2300 hrs on 17/12, in compliance with the flow rules, the operator readjusted the gates to increase the compensation flow by about 10.5 cumecs to ensure that the daily mean minimum flow requirement was met. On 18 Dec at 2300 hrs, the gates were readjusted, to reduce the flow by about 8 cumecs, thereby diverting as much water as possible through both power stations without contravening any minimum flow requirement. The need to maintain a minimum flow at Turangi was the cause of two large and rapid changes in the flow and both of these were larger than the 4 cumec change caused by the operator's initial misjudgment. Thus the mean daily minimum flow requirement at Turangi is the cause of unnecessary surges.

2.8 Sediment Transport.

The power scheme has reduced both the frequency and duration of the high flows which carry the sediment through the lower Tongariro River. However, whilst anglers often assert that the power scheme is causing the river to 'silt up', there are no data to indicate whether the composition of the substrate in the lower Tongariro River has changed since the power scheme began operation.

The Rangipo dam and Poutu intake, are designed to separate sediment from the diverted water. Rangipo dam is a settling pond designed to also remove much of the suspended sediment. This remains in the impoundment until the sluice gates in the base of the dam are opened, when accumulated sediment is washed into the river below. At Poutu intake, only sediment is separated from the diverted water and this is continuously passed into the lower river. The power scheme has reduced the sediment transport capacity of the lower river and has altered patterns of sediment movement, so that sediment movement now occurs in pulses, when Rangipo dam is scoured.

The reversal of the natural relationship between flow and rainfall in the river below Poutu intake has probably increased fine sediment deposition. Soon after rain the water arriving at Poutu intake is generally turbid with suspended sediment but, during these conditions, the compensation flow is typically minimal. Consequently, transport capacity is minimal when the sediment load is quite high and this causes sand deposition in areas of low current velocity.

2.9 The Poutu Stream.

The Poutu Stream has been severely affected by the power scheme. It was the outlet to Lake Rotoaira and had a sediment free, fairly stable flow of 4 to 6 cumecs (Fig. 7). After completion of the Poutu dam a minimum compensation flow of 0.6 cumecs was provided. Since completion of Rangipo power station, the Poutu Stream flow has become more variable as operation rules allow for its manipulation to maintain the required flow at Turangi whilst also maximizing flow through Rangipo power station. The flow variations are rapid, being caused by manual adjustment of the valve used to provide the compensation flow. Moreover, the water used is derived from the Tongariro River and contains considerable quantities of sand. Sediment accumulates in the forebay area of the Poutu canal and some of this is carried into the Poutu Stream. Thus the power scheme has changed the source of water for the stream, lowered the average flow, made the flow more variable and increased the sediment load, but reduced the stream's capacity to transport it.

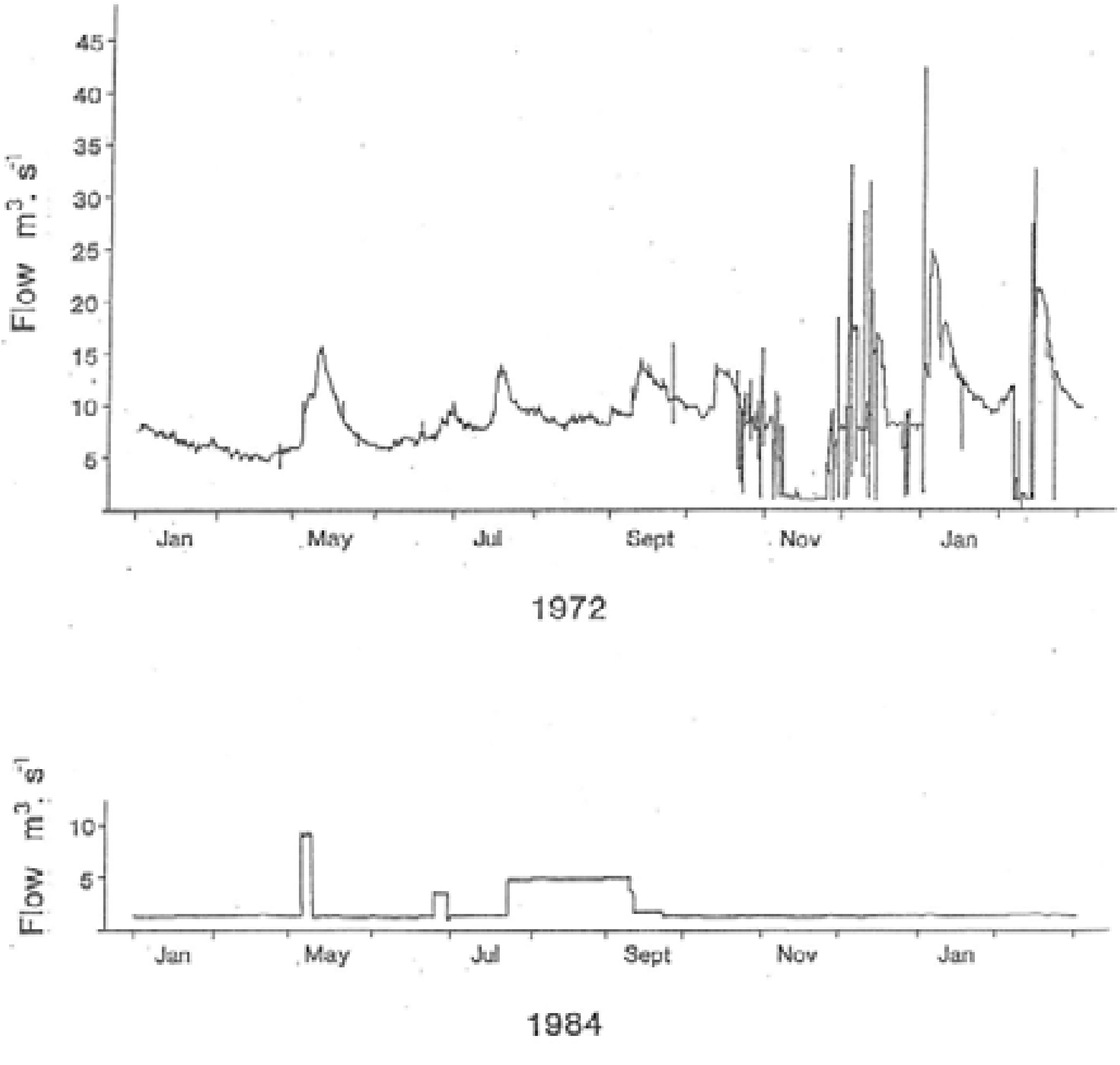


Figure 7. Flows in the Poutu Stream below the Poutu dam in 1972, before diversion and in 1984, after diversion. The unnatural flows during the latter part of 1972 were caused by construction work. (Data supplied by Water & Soil Division of M.W.D.)

The Poutu Stream was formerly used by Lake Rotoaira trout for spawning and anglers fished for these trout up to 300m downstream. This area has since been replaced by the canal, resulting in an increase in the fishable area but a loss of breeding habitat.

2.10 Discussion

Surges, truncated recessions, reduced sediment transport capacity and reversal of the natural relationship between rainfall and flow are all likely to adversely affect the quality of the river as habitat for trout. Surges displace stream invertebrates (Irvine 1985) and salmonoid fry (Irvine 1986, Ottaway and Clarke 1981, Cushman 1985, Unwin 1986). Truncated recessions cause young trout to become stranded and reduced sediment transport capacity causes fine sediment accumulation which reduce invertebrate and fish production (Cushman 1985, Hynes 1970, Alexander and Hansen 1986). The minimum flows early in a flood recession expose reeds created during prolonged periods of higher compensation flow. It seems reasonable to expect some benefit to the fishery if these undesirable features of the regulated flow could be ameliorated.

Other aspects of the regulated flow have probably had beneficial consequences for the fishery. Reduced fresh frequency probably enhanced habitat stability and, in combination with truncated recessions, made the river fishable for more days of the year. The flow reduction probably increased the extent of physical habitat suitable for use by juvenile trout (Bovee 1978) but may have reduced the quality of resting habitat for adult trout. Assessment of the combined effects on the fishery of the changes to the hydrology of the Lower Tongariro River await further investigation.

CHAPTER THREE

FACTORS AFFECTING TROUT NUMBERS AND ANGLING SUCCESS

3.1 Introduction

Effects of the power development on the Tongariro trout fishery have been the subject of speculation (Hobbs 1958, Woods 1964, M.W.D. 1973) and remain of interest to both anglers and those responsible for managing the river. Changes in the fishery have occurred and although these have been attributed to the power development (Richmond 1981), there has been no attempt to identify key factors influencing the fishery and assess their relative importance. An understanding of factors which cause variations in trout numbers and angler catch rates could offer some guidance for setting flow management objectives intended to protect or enhance the fishery. It therefore seems relevant to describe historical information on trout and angling, to examine factors which influence the angler's catch and to identify those which can be manipulated in pursuit of management objectives.

Two measures of the Tongariro fishery are available for periods before and after the power development. These are angler catch rates (numbers of trout caught per hour fished) and numbers of trout running into the Waihukahuka Stream. Both parameters are presumed to be related to the number of trout present in the Tongariro River but the nature of this relationship is unknown and factors which might influence it await identification.

3.1.1 The Waihukahuka Trap

The Waihukahuka Stream is a small, stable, spring fed tributary of the lower Tongariro River and is the source of water used by the Tongariro Trout Hatchery. Trout running into the stream have been used to supply the hatchery with ova and varying numbers of hatchery reared fry and fingerlings have been released into the stream. Numbers of trout spawning in the Waihukahuka Stream vary from 1000 to 3000. Spawning takes place throughout the length (c.a. 500m) of the stream and redd superimposition is common at the height of the winter spawning season.

The number of trout entering the Waihukahuka Stream has been counted since 1962, after a trap was installed about 50m upstream of the confluence with the Tongariro River. In most years, trap operation commenced on April 1 and continued until October 31, when the bars were removed so that there is no impediment to fish movement outside this period. When operational, the trap is checked and cleared almost every morning, and every trout present is measured, weighed, sexed and examined for any previous fin-clips. The trout are then fin-clipped and released upstream. Until 1986, when a new trap was built, there was a bypass which allowed free downstream passage of trout.

The data used in the following analyses are counts of wild, adult rainbow trout, from May 1 until September 30. April and October data was excluded because in some years the trap was not operated until late April and in 1981, was not operated in October. Hatchery reared trout, released as finclipped fingerlings, returning to the Waihukahuka Stream were excluded from the data.

3.1.2 Creel surveys

Historical catch rate estimates were obtained from creel census data obtained by Wildlife Service field staff. In the absence of many of the original survey records, data presented by Richmond (1981) are used. It is unclear how these catch rate data were calculated. Two likely approaches are:

Catch Per Unit Effort (CPUE) = ΣCATCH/ΣHOURS

and,

Arithmetic Mean Catch Rate (AMCR) = $(\Sigma (CATCH_i/HOURS_i))/N$

For a given data set, the CPUE is usually smaller than the AMCR (see Table 3). Measures of variance are easily obtained for the latter.

As the catch rates would have been calculated manually, it seems likely that the historical data are estimates of CPUE. After 1979, estimates of CPUE were determined directly from creel survey data. The method used in creel surveys since 1984 is described in section 3.4.1.

3.2 Changes in the Fishery since Diversion

Before diversion commenced, it seems that both trout numbers and the catch rate were declining (Fig. 8). After diversions began in late 1972, trout numbers increased whilst the catch rate continued to decline until 1978. Average catch rates have fallen from 0.46 to 0.29 fish per hour ($t = 4.00$; $p < 0.001$) but the average number of trout running into the Waihukahuka Stream (between May & September) has increased, but not significantly, from 1522 to 1769 ($t = 1.27$; $p > 0.2$). Therefore, it cannot be inferred that catch rates declined because diversion caused a reduction in the number of trout returning to the river. This finding is the basis for the working hypothesis that diversion was not associated with significant changes in numbers of trout using the Tongariro River. During construction, silt from tunnelling operations often polluted the river and both large numbers of trout in the Waihukahuka Stream and low catch rates in the Tongariro River were associated with tunnelling discharges. Low catch rates would be expected, at least in part because anglers' lures would be less visible to the trout. Unusually large numbers of trout running into the Waihukahuka Stream might have occurred because this tributary would have been one of the first sources of high quality water encountered by upstream migrants.

This change in the relationship between trout numbers and catch rate coincides with the start of diversion in late 1972 and it seems likely that it was associated with reduction in the flow of the lower Tongariro River. There is statistically significant correlation between the catch rate and the numbers of fish trapped before diversion ($r = 0.59$; $.05 > p > .025$) and somewhat weaker correlation after diversion (all post-diversion data: $r = 0.40$; $.05 > p > .025$; data removed for 1.976 and 1982 to eliminate variation associated with tunnelling waste discharges: $r = .74$; $.001 > p > .0025$). However, the relationship between these parameters (as manifested by the distance separating the two lines) changed when diversion commenced (comparison of elevations for pre-and post-diversion regressions of catch rate on trout numbers: $t = 5.71$; $p < .001$). Since trout were apparently no less numerous after the diversion, it seems that they became less catchable.

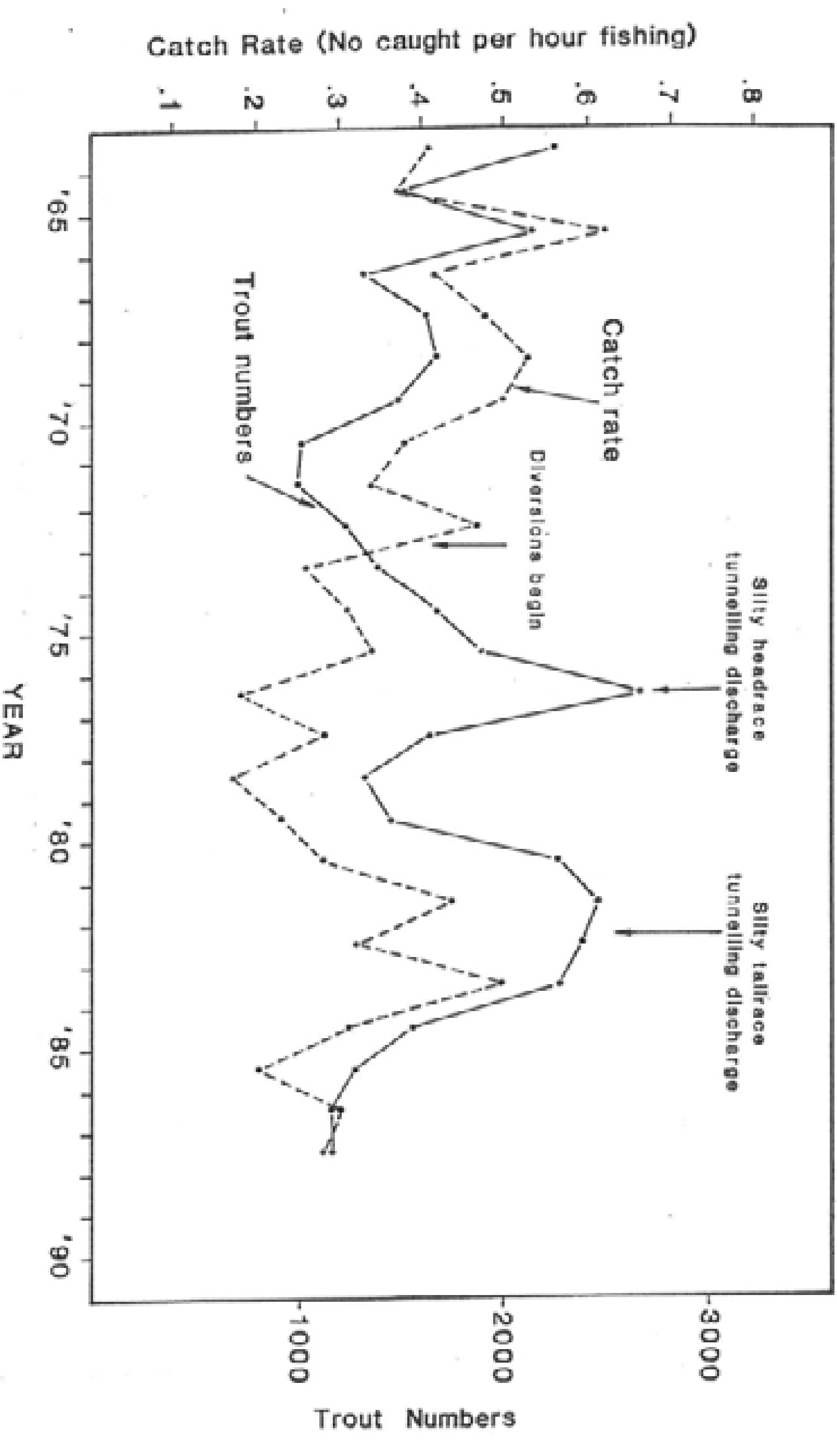


Figure 8. Annual variation in numbers of trout trapped (May 1 to Sept. 30) in the Waihukahuka Stream and catch rates in the lower Tongariro River. (Data reproduced, with modifications from Richmond 1981 and McLay 1984.)

The correlation between catch rates in the Tongariro River and numbers of trout entering the Waihukahuka Stream suggests that the number of trout available to anglers in the Tongariro River is related to the number entering the Waihukahuka Stream. Thus, the Waihukahuka Stream run may be a useful index of the run into the Tongariro River. However, until the annual run into the Tongariro River can be routinely measured and compared with the Waihukahuka run, the nature of relationships between catch rates, the Tongariro run and the Waihukahuka run will remain obscure.

3.3 Variations in Trout Numbers

The number of trout entering the Waihukahuka Stream between May and September is variable, ranging from 999 to 2657. Several factors may have caused this variability, including hatchery management practices (ova collection, fry and fingerling liberations), angling pressure, the power scheme and flood events. Hatchery management practices may have influenced the number of adults returning to breed because trout generally return to breed in their natal stream. Ova collection would reduce the number of trout left to spawn in the wild and hence the number of eggs spawned. Fry and fingerling liberations would increase the number of trout which would regard the Waihukahuka as their natal stream. Thus, ova collection might diminish subsequent returns of adult trout whilst fry or fingerling liberations might increase returns. Environmental influences such as the power scheme and floods would be influential if young trout born in the Waihukahuka Stream live for a while in the Tongariro River before moving downstream to Lake Taupo. Fishing pressure, both in Lake Taupo and in the Tongariro River might also influence the number of returning adults. Clearly, the impact of each of these factors on returns to the Waihukahuka Stream needs to be assessed to justify confidence in the hypothesis that diversion was not associated with reduced trout numbers.

3.3.1 Methods

Multiple regression procedures were used to identify factors associated with variations in the number of trout entering the Waihukahuka Stream. However, the first problem was to estimate the year class composition of the run in order to determine the year in which hatchery practices, floods or other factors would affect spawning and/or the juveniles and the subsequent run of adult trout. The only estimate of age composition of the run is from returns of 10,000 marked one year old fingerlings, reared in the hatchery and released in the hatchery stream in August 1981 (Fig. 9). Some 72% returned as 3 year olds in 1983 (McLay unpublished data) and so it seems likely that 3 year olds would dominate the wild trout run. Therefore, events three years before the year under consideration seem likely to be most strongly correlated with the number of trout trapped in that year.

Flood frequency data were obtained from hydrographs (Water & Soil Division of M.W.D). The criterion for flood identification was an event in which flow exceeded twice the mean annual flow. Thus before diversion, floods were counted if they exceeded 100 cumecs but after diversion floods exceeding 55 cumecs were counted.

Numbers of ova collected, fry and fingerling liberation data were obtained from hatchery records. Licence sales records were used as a surrogate for fishing pressure and a dummy

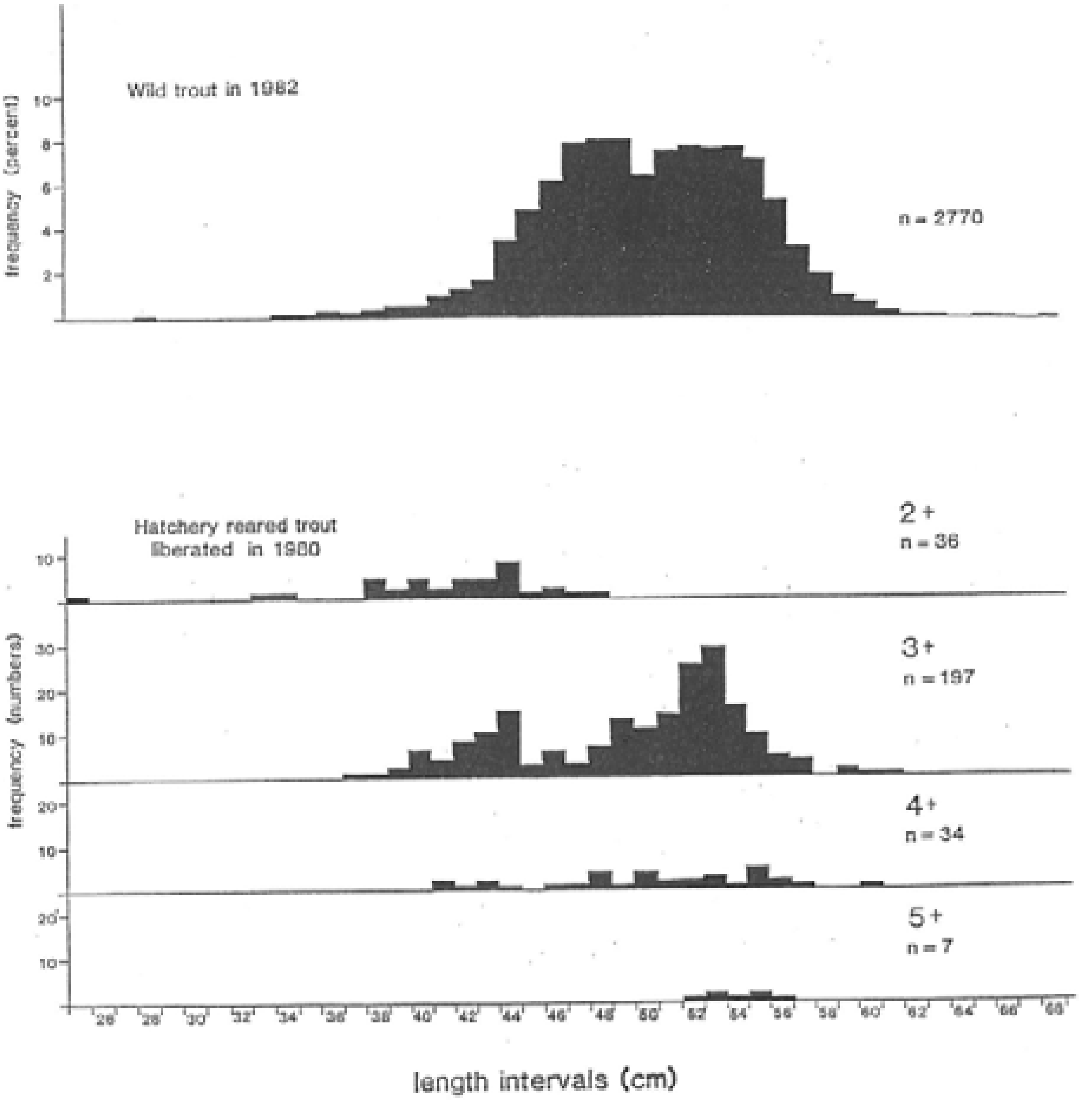


Figure 9. The and age composition of hatchery-reared trout running into the Waihukahuka Stream between 1982 and 1985. The hatchery-reared trout are progeny of adults stripped in 1980. The juveniles were reared to one year old fingerlings (c.a. 15 cm FL) in the hatchery and released into the Waihukahuka Stream in August 1981. The length frequency distribution of all wild trout trapped in 1982 is given for comparison. (Adapted and updated from McLay 1983.)

variable (0 or 1) was used to index diversion and pollution by tunnelling wastes. The parent stock was estimated by subtracting the number of trout stripped (for ova collection) from the total run:

$$\text{PARENT STOCK} = \text{RUN} - [\text{OVA}/3000 + (0.8 * \text{OVA}/3000)]$$

From hatchery records, it was apparent that about 40% of those stripped were male and on average, about 3000 ova were collected from each female.

The model was refined by weighting events in each year according to the proportion of any one year class in the run. Whilst the proportions are likely to vary between years, the first approximation was based on the 1981 liberation from which it was inferred that in any run, the proportions of 2+, 3+, 4+ and 5+ trout were .131, .719, .124 and .026 respectively. Thus all independent variables (X_w) except licence sales data were weighted by:

$$X_w = \Sigma P_i (X_i)$$

where Pi is the proportion of age group i (2+ to 5+) in the run and X_i is the independent variable i years before the return of adult trout to the Waihukahuka Stream.

Since trout are subject to continuous angling pressure after reaching about one year of age, successive year classes were considered to have been subjected to increasing angling pressure in a cumulative manner. Thus licence sales data (L_i) were weighted by:

$$L_w = \Sigma P_i (\Sigma L_i)$$

An iterative procedure was used to identify transformations of independent variables and to determine the weighting for age structure which resulted in the best fitting regression model. Logarithmic $\log(X + 1)$, exponential X, reciprocal $1/((X + 1)^b)$ and normal $\mathrm{EXP}(-((X - b)^2)/c)$ transformations were tested and selected if the fit of the model was improved. The weighted, transformed independent variables were calculated thus:

$$X'_w = \Sigma P_i \, f(X_i)$$

and $$L'_w = \Sigma P_i (f(\Sigma L_i)$$

where f was the transformation function.

The database to which the model was fitted is listed in Appendix 4, followed by the program used to fit the model.

3.3.2 Results and Discussion

The best fitting regression model (Table 1) describing associations between numbers of trout entering the Waihukahuka Stream and events occurring 2 to 5 years earlier accounted for 96.4% of the variation in trout numbers. Stepwise regression analysis (Table 2) indicated that seasonal flood frequencies accounted for 52.8% of the variation, whilst diversion and pollution during construction accounted for 20.7% of variation. Hatchery management practices had less influence, accounting for 16.1% and angling pressure accounted for 6.9% of variation.

Parent stock size (i.e. the number of fish left to spawn) accounted for only 1.1% of variation and since the coefficient was not significantly different from zero ($p > 0.5$) variable was removed from the model in the final trials.

The model was used to predict the number of trout entering the Waihukahuka Stream between May and September 1988 and 1989 (Fig. 10). The predicted run in 1988 was 552 but the actual run was 902 trout. The model correctly predicted that the 1988 run would be the smallest recorded although the residual variation was substantial, probably because two influential variables (summer flood frequency and licence sales) as well as actual trout numbers were outside the range of values to which the model was fitted. These sources of error are also likely to cause the 1989 prediction to be biased low. A better prediction of the 1989 run could be obtained by adding the 1988 data to the database to which the model was fitted and then further refining the fit of the model.

Table 1. Coefficients and Student's t values for the multiple regression model describing variation in numbers of trout returning to breed in the Waihukahuka Stream. The coefficients differ significantly ($p < 0.5$) from zero if t exceeds 2.13. Variables (for years preceding the run by 2 to 5 years) were weighted according to the age structure of the run and transformed if this improved the fit of the model.

Variable	Coefficient	t	Transformation	Scaling terms
Intercept	398.2	-	-	-
Winter floods	758.1	3.94	Exponential	0.12
Spring floods	2.41E-7	6.01	Exponential	9.8
Summer floods	1300.6	11.01	Normal Mean = .98	S.Dev = .88
Autumn floods	-70.76	-3.56	Exponential	1.22
Ova collections	1031.2	4.28	Normal Mean = 0	S.Dev = 254
Fry liberations	5.75E-12	4.92	Exponential	5.0
Fingerling lib's	3.14E-16	2.41	Exponential	18.0
Licence sales	-2.6E-11	-4.98	Exponential	9.5
Diversion	-662.5	-5.19	None	
Silt pollution	809.0	8.07	None	
	$R^2 = 0.964$	F = 37.86		

Table 2. Variables ranked according to their contribution to the regression model as determined by a stepwise procedure. The R^2 values indicate the variation accounted for by the addition to the model of each variable.

VARIABLE	F-Prime	R^2
Summer floods	11.24	.328
Silt pollution	8.45	.515
Spring floods	7.45	.642
Fry liberations	8.41	.748
Winter floods	3.57	.788
Fingerling liberations	1.66	.806
Licence sales	9.37	.875
Diversion	3.07	.895
Ova collections	8.19	.932
Autumn floods	12.68	.964

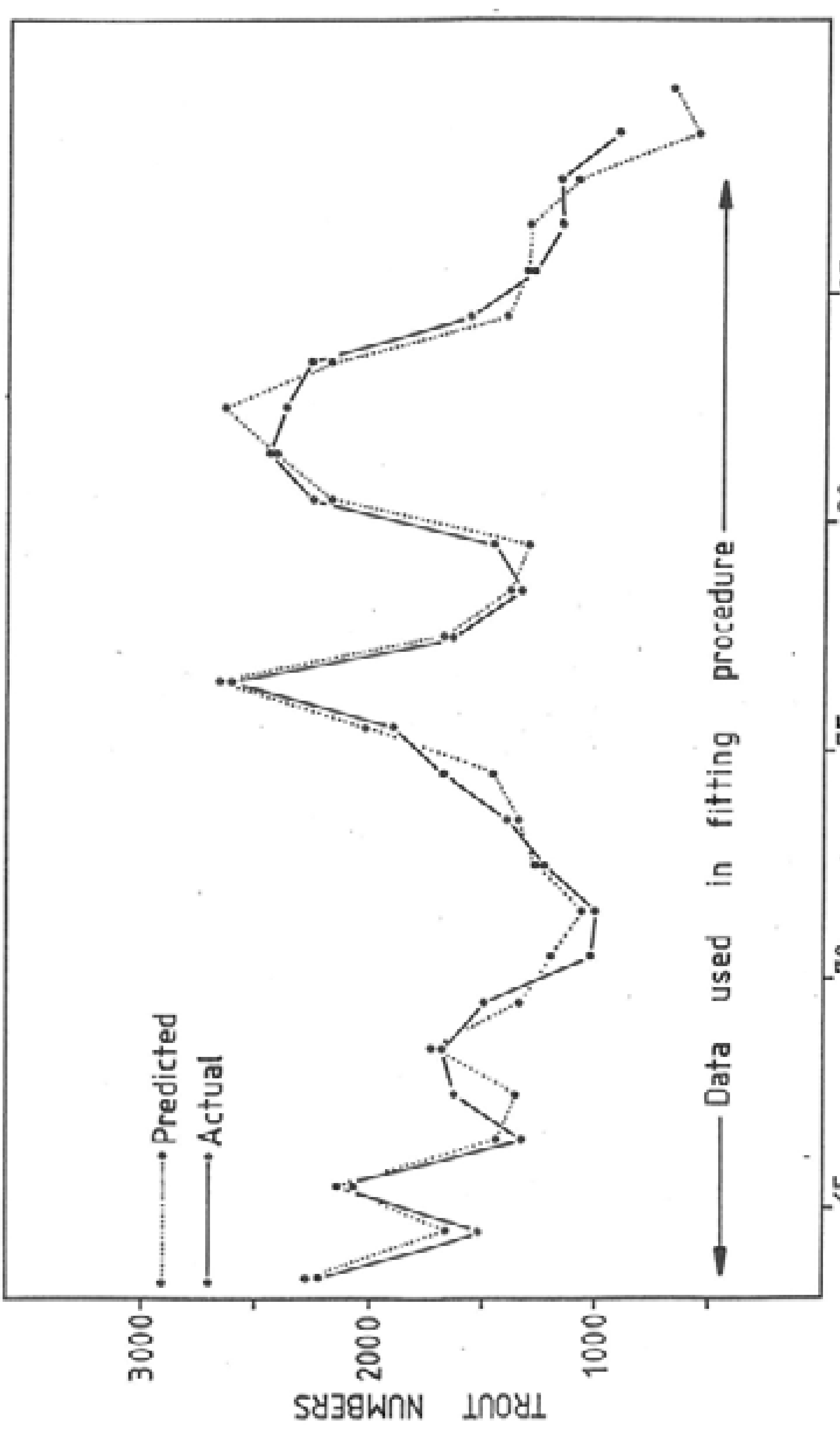


Figure 10. Actual and predicted variation in numbers of trout entering the Waihukahuka Stream.

3.4 Factor affecting Catch Rates

There have been changes in the number of trout running into the Waihukahuka Stream, in the angler's catch rate and in the relationship between these parameters (Fig. 8). The changes in the catch rate and in the relationship between catch rate and numbers of trout entering the Waihukahuka Stream seem to be associated with flow diversion. Thus, it is relevant to find out what factors influence catch rates and to consider how the diversion might have reduced trout catchability, and in particular, whether variation in flow is associated with variations in angler catch rates.

3.4.1 Methods used for Collection of Angling Data

Between May and October 1984, and also in August 1985, 1986, 1987 and 1988, anglers were interviewed in the field to establish, on the day of census, how many trout they had caught, how long they had been fishing, the area fished, method used and how much experience they had.

Some 3463 anglers were interviewed over a total of 45 days; 25 days in 1984; 2 days in 1985; and six days in August 1986 to 1988. The survey dates since 1986 were randomly chosen, using a random number generator. On survey days, each angler encountered was first asked "How's the fishing" or "Have you caught any trout" to provide an informal introduction and commence the interview. After this, each angler was asked how long they had been fishing that day. If the angler had been fishing for less than 15 minutes, then no data were recorded as catch rate data based on such a short time fished, would be excessively biased; low for those with no fish and high for successful anglers.

Only two angling methods were recognised. These were fly fishing with a floating line and fly fishing with a sinking line. Both methods can be used to imitate insects and trout roe, but fishermen using floating lines generally cast upstream and their lures imitate inert, drifting food items, whereas fishermen using sinking lines generally cast across the river so that their lures imitate active food organisms swimming across the current. Thus, separation of floating and sinking line fishing methods distinguishes the way a lure is presented rather than the type of lure used.

The lower river was arbitrarily divided into three reaches to identify the area fished by each angler. The lower reach extended from the lake to the S.H.l road bridge, the middle reach extended upstream to the Red Hutt footbridge and the upper reach ended at the Fence Pool, just upstream of the Whitikau Stream confluence. Little angling takes place upstream of the Fence Pool and none of the anglers interviewed had fished above this point.

Two measures of experience were obtained to account for two different kinds of experience, one being a measure of general experience with trout fishing, the other being a measure of familiarity with angling in the Tongariro River. Thus, each angler was first asked “How many years have you been a trout fisherman" and then "On average, how many days per year do you spend fishing the Tongariro River".

On each day that field interviews were undertaken, mean flows for the twelve hour period, 0600 hrs to 1800 hrs, were obtained from Water Resouces Division, DSIR and numbers of trout passing through the Waihukahuka trap during previous days were recorded.

3.4.2 Features of Catch Rate Data.

Catch rate data had a skewed, bimodal distribution, with large numbers of anglers having caught no trout, forming the first mode in the distribution, and somewhat fewer anglers having catch rates ranging up to six trout caught per hour fished (Fig. 11). The geometric mean was found to be a more precise measure of central tendency than the arithmetic mean (Table 3). However, both of these measures of mean catch rate were biased because all data received equal weighting, whether the angler had been fishing all day or for only an hour. Clearly, an angler who fishes all day is less likely to have a zero catch rate than one who has fished for only a few minutes. The CPUE is unbiased in this respect but precludes identification of variation associated with individual anglers experience, fishing method and site fished). However, CPUE can be used to assess the influence of factors which are likely to have a similar effect on all anglers (e.g. flow and trout numbers).

3.4.3 Influence of Angling Method and Site Fished

Anglers using floating lines had higher catch rates in all three river reaches. Catch rates were highest in the middle reach and lowest in the lower reach. Floating lines were preferred in the upper river reach, whereas sinking lines were preferred in the lower reach. Thus, catch rates were influenced by both angling the method used and the river reach fished.

Table 3. Average catch rates for the two fishing methods (floating and sinking lines) and the three reaches of the Tongariro River (lower reach = lake to S.H.1 road bridge, middle reach = S.H.1 road bridge to Red Hut footbridge, upper reach = Red Hut footbridge to Fence Pool).

	CPUE	Arithmetic Mean	SE	Geometric Mean	SE	% Anglers who caught no fish	Number of Anglers
Floating Lines	.307	.355	.016	.248	.009	59.7	2269
Sinking Lines	.205	.220	.014	.162	.009	68..8	1194
Upper Reach	.273	.291	.016	.219	.011	59.7	1129
Middle Reach	.276	.329	.021	.225	.012	63.2	1311
Lower Reach	.269	.301	.021	.208	.013	65.9	1023
Upper Reach floating line	.292	.306	.018	.232	.012	57.8	976
Upper Reach sinking line	.151	.191	.037	.139	.025	71.9	153
Middle Reach floating line	.300	.377	.030	.251	.016	61.4	862
Middle Reach sinking line	.228	.236	.025	.176	.016	61.4	862
Lower Reach floating line	.366	.419	.041	.280	.025	60.8	431
Lower Reach sinking line	.203	.215	.021	.158	.013	69.6	592

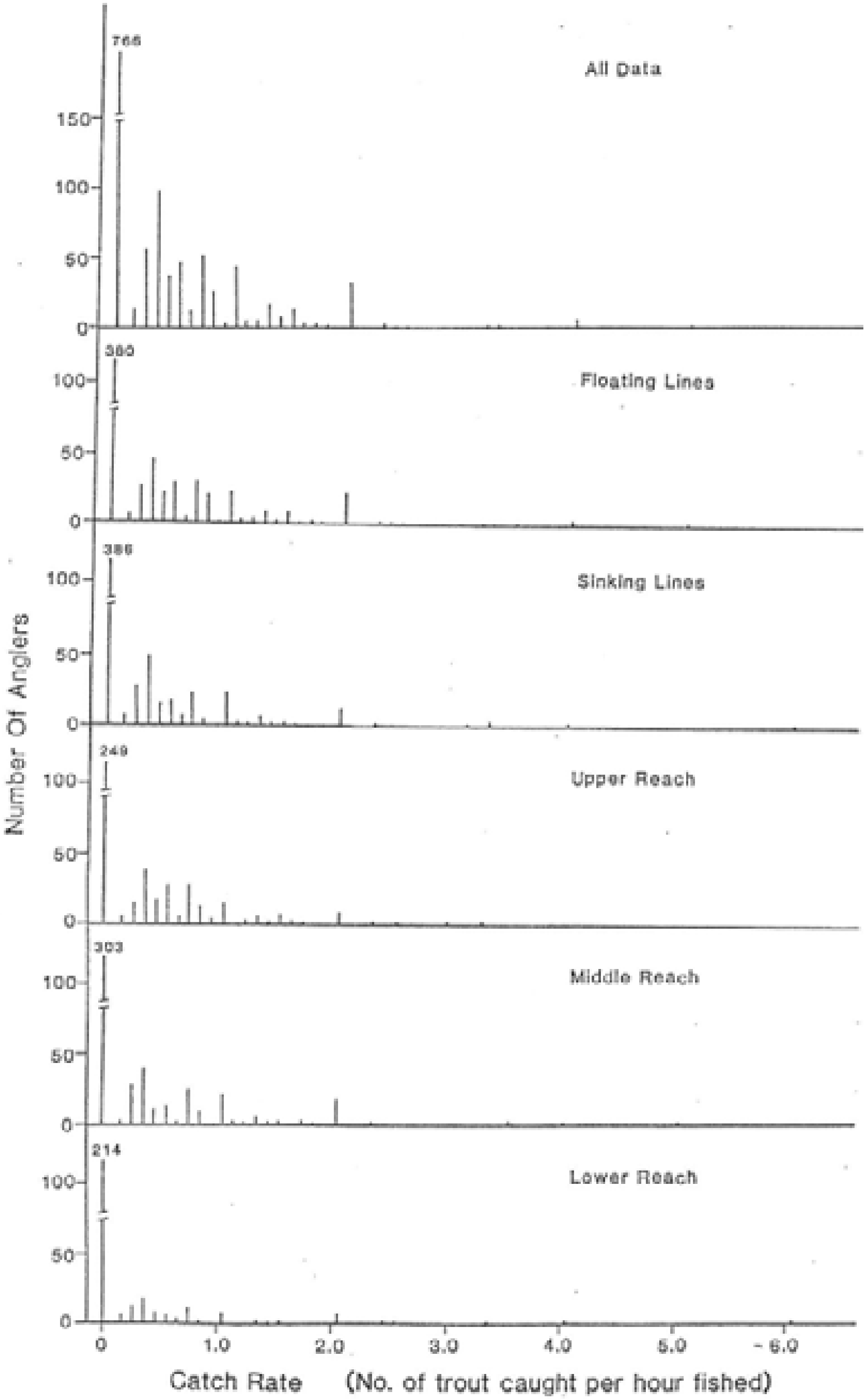


Figure 11. Catch rate distributions for the lower Tongariro River from May until October 1984 and in August 1985.

3.4.4 Catch Rates and Trout Numbers

Numbers of trout passing through the fish trap on the Waihukahuka Stream were used as a measure of the number of trout present in the Tongariro River. However, the duration of the count likely to be most strongly correlated with catch rates was unknown. Therefore counts were summed for periods from 1 to 50 days prior to the date of angling data collection to establish the most appropriate duration for counts (Table 4). Periods longer than 50 days could not be considered because the trap became operational only 52 days before angling data collection commenced in 1984.

Table 4. Correlation between CPUE, individual angler's catch rates and numbers of trout passing through the Waihukahuka trap for different periods prior to collection of angling data. Data are based on 3463 angler conducted over 45 days between 1984 and 1988. Individual catch rates and fish counts were Log(X +1) transformed. Correlation with individual angler's catch rates is significant (p < .05) when r > .062 and with CPUE when r > .291.

	Duration for fish counts (days)								
	1	2	5	10	15	20	30	40	50
Individuals	.059	.048	.068	.069	.084	.077	.068	.080	.094
CPUE	.105	.063	.196	.089	.040	.015	.081	.170	.241
Log(CPUE + 1)	.0175	.100	.165	.018	.047	.068	.036	.060	.126

3.4.5 Flow

Considerable effort was made to collect angling data over a wide range of flows, but because the duration of high flows was brief and because few anglers fished during flood conditions, little information was collected at abnormally high flows. Data were collected at near-normal mean (0600 to 1800 hrs) flows on 41 of the 45 days when anglers were interviewed. (Half daily-mean flows ranged from 27.4 to 34.2 cumecs.) On the remaining four days, mean flows ranged from 42.8 cumecs to 79.1 cumecs.

Increases in the number of trout entering the Waihukahuka Stream for periods up to five days were correlated with half daily mean flow (Table 5). However, there was no association between half daily mean flows and trout numbers accumulated more than five days prior to collection of angling data.

Table 5. Correlation between flow and numbers of trout passing through the Waihukahuka trap for different periods prior to collection of angling data (n = 45). Correlation is significant (p < .05) when r > .291.

Duration	1	2	5	10	15	20	30	40	50
Correlation	.472	.443	.312	.221	.102	-.013	-.009	.012	-.065

3.5 Modelling Variations in Catch Rates

A multiple regression model was used to identify associations between individual angler catch rates and potentially influential factors. Data were transformed if this accounted for additional variation in catch rates. The best fitting model was of the form:

$$\ln(\text{Catch rate} + 1) = A + b1X1 + b2X2 + \ldots + B9X9$$

where X = 1 for the upper reach and 0 for other reaches
X2 = 1 for the middle reach and 0 for other reaches
X3 = 1 for floating lines and 0 for sinking lines
X4 = ln(H) where H is the number of hours spent fishing.
X5 = where D is the average number of days per year spent fishing on the Tongariro River.
X6 = ln(Y) where Y is years angling experience
X7 = ln(F) where F is the half daily mean flow (cumecs) at Turangi.
X8 = the number of trout passing through the Waihukahuka trap during the day.
X9 = the number of trout passing through the Waihukahuka trap during the previous 50 days.

Table 6. Coefficients and Student's t values for the multiple regression model describing variation in the catch rates of individual anglers (n = 3463) fishing the Tongariro River between 1984 and 1988.

Parameter	Coefficients	t	p
Intercept	-.187	-	-
Reach (X1)	.0128	.858	ns
Reach (X2)	0.164	.856	ns
Line type (X3)	.0920	7.453	**
Hours (X4)	-.0048	-1.717	ns
Familiarity (X5)	.0692	16.114	**
Experience (X6)	.0013	.274	ns
Flow (X7)	-.0006	-.767	ns
Trout (1 day) (X8)	.0155	2.202	**
Trout (50days) (X9)	.0003	6.339	**

The regression (Table 6) accounted for 10.1% of the variation in catch rate data. Angler's familiarity with the river, the type of line used, and the number of trout entering the Waihukahuka Stream were the only influential variables.

A multiple regression model was fitted to daily CPUE estimates, flow and trap data (1, 5, and 50 day counts). However, the best fitting model accounted for only 7.7% of the variation in CPUE and none of the fitted coefficients differed significantly from zero.

3.6 Discussion

The factors affecting numbers of trout entering the Waihukahuka Stream have been identified sufficiently to account for much of the variation in trout numbers and to permit prediction of future runs. In contrast, useful prediction of catch rates is not yet possible. This is probably because certain key determinants such as water clarity (Glova 1987) and temperature (Alabaster 1986) were not included in the model, and also possibly because the number of trout in the Tongariro River was inadequately indexed by numbers entering the Waihukahuka

Stream.

The fidelity with which numbers of trout entering the Waihukahuka Stream indexes numbers present in the Tongariro River remains unknown. However, there are two observations which indicate that the two parameters are not unrelated. Firstly, there was weak, but significant correlation between catch rates and trout numbers entering the Waihukahuka Stream. Since catch rates and fish numbers would normally be related, some correlation between numbers of trout entering the Waihukahuka Stream and catch rates in the Tongariro River suggests that trout numbers in the Tongariro River are related to numbers entering the Waihukahuka Stream. Secondly, the association between seasonal flood frequencies in the Tongariro River and numbers of trout returning to the Waihukahuka Stream suggest that juvenile trout born in the Waihukahuka Stream spend a significant period of time in the lower Tongariro River where they are subject to the effects of floods which do not occur in the spring-fed Waihukahuka Stream. Thus, trout which use the Tongariro River, but not the Waihukahuka Stream, are affected by the same factors as those trout which do use the Waihukahuka Stream. This is probably why the run into the Waihukahuka Stream was correlated with annual average catch rates and so may index the run into the Tongariro River. However, this does not mean that the Waihukahuka run is necessarily a good index, or measure, of the Tongariro run. Therefore, despite weak correlations between catch rates and numbers of trout entering the Waihukahuka Stream, the possibility that catch rates are strongly dependent on numbers of trout in the Tongariro River, cannot be discounted. To assess this dependence, it is necessary to estimate numbers of trout in the Tongariro River and incorporate this in a model describing variation in catch rates.

Catch rates appeared to be little influenced by variation in half-daily mean flow. However, the historical data (Fig. 8) indicated a change in the relationship between trout numbers and annual average catch rates, such that trout became less catchable when diversion commenced. If this was caused by reduced mean flows then and it would be reasonable to expect catch rates to rise in response to increased mean flow. One explanation for this impact is that reduced catchability occurred because lower flows allowed faster migration through the lower Tongariro River thereby reducing the length of time trout were exposed to anglers. Higher mean flows or prolonged flood recession might slow upstream migration, thereby retaining trout for longer in places where anglers can fish for them. A possibility not considered is that lower flows might make the trout more accessible to anglers and so might counter the consequences (for anglers) of faster upstream migration. However, the lack of variation in longer-term mean flows precluded examination of possible associations between catch rates and medium term flow variation. This is unfortunate because any change in the minimum flow of the Tongariro River would affect the mean flow and, on the basis of the historical data, might affect catch rates.

Increased trout numbers were associated with low summer and autumn flood frequencies and with high winter and spring flood frequencies. This pattern could be explained if the balance between detrimental effects of floods (habitat disruption; reduced food abundance; downstream displacement; increased mortality) and beneficial effects (scouring sand and periphyton accumulations; maintenance of habitat quality and diversity) varied seasonally, depending on the prevalent life history stage. It may be that in summer, the prevalent stages (fry and small fingerlings; see Chapter 4) are particularly susceptible to the detrimental effects of floods and so derive little advantage from the beneficial effects of frequent floods. The normal transformation of summer flood frequencies (Table 1) implies that the benefits associated with a single summer flood exceed the detrimental impacts. However, harm exceeds benefit when more than one flood occurs during summer. In contrast, best fitting transformations for winter and spring flood frequencies imply that the incipient year class derived more advantage than harm from high flood frequencies.

Pollution during construction was associated with increased trout numbers whereas diversion was associated with decreased returns. Silt pollution was a particularly influential factor (18.7% of variation) but diversion had only minor impact (2.0% of variation) on trout numbers. Thus the effects of diversion on trout numbers is probably small compared with the influence of floods.

Ova collections were associated with decreased returns, but despite collections ranging from none to 3.06 million (this would require about 1400 parent trout), the extent of this impact (3.7% of variation) was small. Similarly, parent stock size also had little influence (1.1% of variation and since the coefficient was not significantly greater than zero ($p > .05$), this variable was removed in final trials to refine the fit of the model). Thus, the number of trout entering the Waihukahuka Stream was little affected by either past ova collections or parent stock size.

The model implies that the impact of ova collection is not proportional to the number collected, but is sigmoidal (i.e. the right hand side of a normal distribution), the rate of change diminishing with small collections (<100 000) and with large collections (>50 000). This can be explained if the output from just a few parent trout is sufficient to provide near complete occupation of nursery habitat (hence minor impact of massive ova collections); if output from many parents, spread throughout the year is necessary to attain maximum production from all viable nursery habitat (hence overall negative association between ova collections and subsequent returns); if the natural run normally exceeds the number required to attain maximum production (hence minor impact of small collections). Intense competition for juvenile habitat would be required to ensure that all marginally viable habitat was used and any fish which move or die are immediately replaced. This could only occur if fry production continuously exceeded the rearing capacity of available nursery habitat.

Fry liberations were associated with increased returns and accounted for 10.6% of variation in trout numbers. The number of fry liberated generally seem small compared with numbers likely to be produced naturally. Liberations were of 75,000 fry or fewer except on one occasion when 736,000 fry were released. If egg mortality were insignificant, this would approximate output from about 50 parent trout and on one occasion, about 500 parents. The total annual run of wild trout ranged from about 1200 to over 3000 trout. Thus, fry output from about 50 parent trout seems likely to be minor compared with potential output from the natural run. However, if redd survival was poor, perhaps because of redd superimposition, then these fry liberations might have more impact on subsequent returns than one might expect on the basis of the number liberated. If this were the case then these fry liberations would be equivalent to the actual output of many more than about 50 parent trout and so would be more likely to influence subsequent returns of adult trout.

Fingerling liberations were also associated with increased numbers of returning trout but these accounted for only 1.8% of the variation in trout numbers and so was not an important variable. This positive association is not consistent with observations of reduced survival of wild trout caused by liberations of hatchery reared trout (Vincent 1984).

Angling pressure, as indexed by annual licence sales data was associated with decreasing trout numbers and accounted for 6.9% of total variation. The best fitting model was obtained using a very steep exponential transformation (Table 1), suggesting that angling impact has increased at a rate more than proportional to licence sales. This can be explained if angling has become more efficient since the 1960's, due to the proliferation of runabouts, easier access and widespread use of more effective methods and equipment (e.g. lead and wire lines; new lures; echo sounders; fibreglass and graphite rods). Continuing increases in gear efficiency would cause corresponding increases in angling pressure per licence sold. Thus increases in annual licence sales would underestimate the increase in angling pressure since the early 1960's.

The proportions of each age group in the run resulting in the best fitting model were .078. .559, .242, and .121 for the 2+, 3+, 4+ and 5+ trout respectively. This implies that, on average, the trout were older (fewer 2+ and 3+, more 4+ and 5+ trout) than indicated by returns from the 1981 liberation of marked 1+ fingerlings. The significance of this observation is unknown.

CHAPTER FOUR

FEATURES OF RAINBOW TROUT ECOLOGY IN THE TONGARIRO RIVER

4.1 Introduction

The extent that juvenile trout use the Tongariro River system was examined to determine the importance for the trout population of flow provisions specifically for juvenile trout. Whilst it is known that large numbers of trout migrate through the lower river to spawn and that this migration supports the fishery, little is known about how juvenile trout use the lower Tongariro River. It is therefore unclear whether, or to what extent, flow provisions need to meet the requirements of juvenile trout.

The problem is to determine the importance for the population of juvenile life in the river. There are several aspects to this: do trout live and feed in the river for a significant period or do they immediately emigrate to the lake after emerging from redds; which parts of the Tongariro system do juvenile trout use and what are their seasonal patterns of abundance; what are the most successful juvenile life history patterns? All but the last of these questions were addressed using a monthly electrofishing sampling programme. Scales taken from adult trout caught in Lake Taupo were used to identify successful life history strategies. Finally, the diets of juvenile trout collected from the Tongariro River and from Lake Taupo were examined to explore reasons for observed juvenile life history strategies.

4.2 Juvenile Trout abundances.

Seasonal and spatial patterns of variation in juvenile trout abundances were assessed by electrofishing every month from July 1984 until August 1985 at seven sites; five on the lower Tongariro River (below Poutu intake, Puketarata, Breakaway Pool, Judges Pool and Pool) one on the Whitikau Stream and one on the Poutu Stream. Each site was chosen, within constraints imposed by access, to represent the main habitat features of the river in the general vicinity of the sampling site (Table 7). However, since it was felt that the Poutu intake site might not adequately represent juvenile trout habitat available further downstream in the gorge, further samples were collected at two sites in the gorge where habitat appeared particularly suitable for juvenile trout. In addition to the monthly sampling programme, samples were also collected in early 1986 to assess the effects of a major flood on the juvenile trout population.

On each sampling trip, the same distance along one margin of the river was electrofished once. The trout were killed and preserved in for subsequent examination in the laboratory. This sampling method provided measures of the relative abundances of juvenile trout. Size selectivity by the sampling gear was not assessed but is likely to be significant, with higher escapement for fry, which are little affected by the electric field, and also for large fingerlings, which are often agile enough to evade capture. Thus, the catch data provided an index rather than an absolute measure of abundance and size frequency distribution.

Table 7. parts of the Tongariro River considered to be represented by each electrofishing sampling site.

Site	Site length (m)	Reach	Reach length (km)
Poutu intake	100	Poutu intake to Puketarata bridge	7
Puketarata	100	Puketarata bridge to Sand Pool	5
Breakaway	40	Sand pool to Barlows Pool	4.5
Judges Pool	100	Barlows Pool to Bend Pool	6.5
DeLatours Pool	100	Bend Pool to mouth	7

4.2.1 Results

Juvenile trout were most abundant between Puketarata and Judges Pool and in the Whitikau Stream (Fig. 12). Comparatively low densities were observed in the Poutu Stream, at DeLatours Pool and at three sites below Poutu intake. Juvenile densities increased rapidly in spring to a maximum in December at most sites, declined slowly throughout the summer and autumn, remaining at a constant low level for the winter.

Fry numbers were most variable (Fig. 13), being scarce in winter but abundant from October until January. By contrast, there was little seasonal variation in large fingerling abundance. Small fingerling abundance increased as emergent fry grew but changes in modal length probably underestimated growth rates as fingerling emigration and fry emergence confounded the effect of growth on the juvenile length frequency distributions.

Juvenile trout abundance seemed to be closely related to the visual appearance of habitat quality. There was excellent and extensive juvenile trout habitat in the Whitikau Stream and at the Breakaway pool, where juvenile densities were consistently high, but lower densities were observed in the Poutu Stream and at DeLatours reach, where the substrate was dominated by sand and fine gravels. At the Poutu intake sampling reach the water was too deep and swift near the boat ramp to be good habitat but the margins of the shingle bar immediately below the intake appeared to be adequate. Sites in the gorge below the intake were chosen because the habitat appeared particularly suitable for juvenile trout. However, juvenile trout were scarce at all three sites when compared with densities observed in other areas of prime habitat.

4.3 Effect of Floods on Juvenile Trout Numbers.

There were six significant (>55 cumecs) floods during the sampling period and reduced densities of juvenile trout were often observed after floods (Fig. 14 and Table 8). Reductions occurred at all sites following floods in December and March.

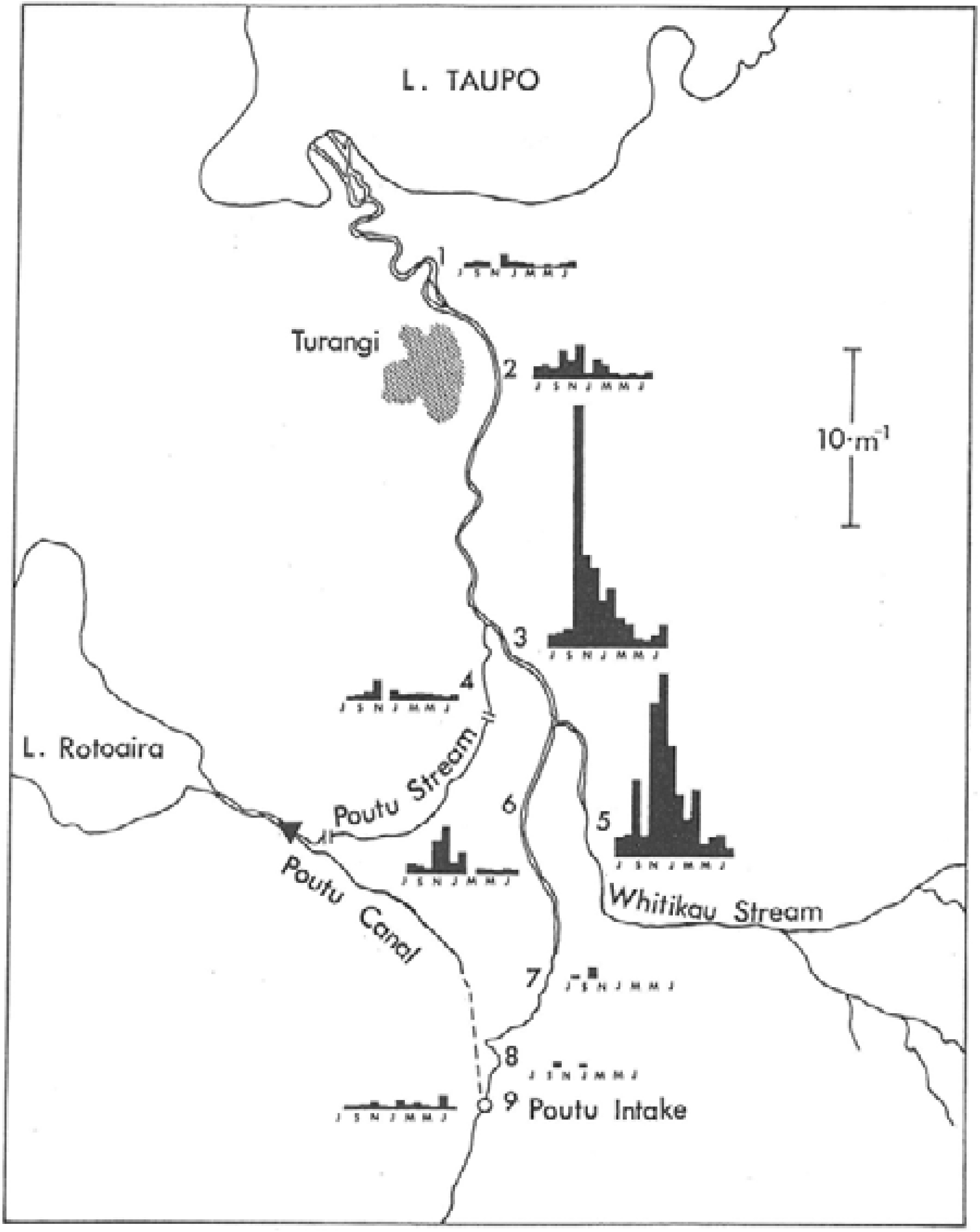


Figure 12. Seasonal and spatial patterns of juvenile rainbow trout abundance in the Lower Tongariro River from July 1984 until August 1985. Site 1 is at DeLatours Pool, site 2 at Judges Pool, site 3 at Breakaway Pool, site 4 on lower Poutu Stream, site 5 on the Whitikau Stream upstream of the Grotto, sites 7 & 8 in the gorge below Poutu intake and site 9 immediately below the intake.

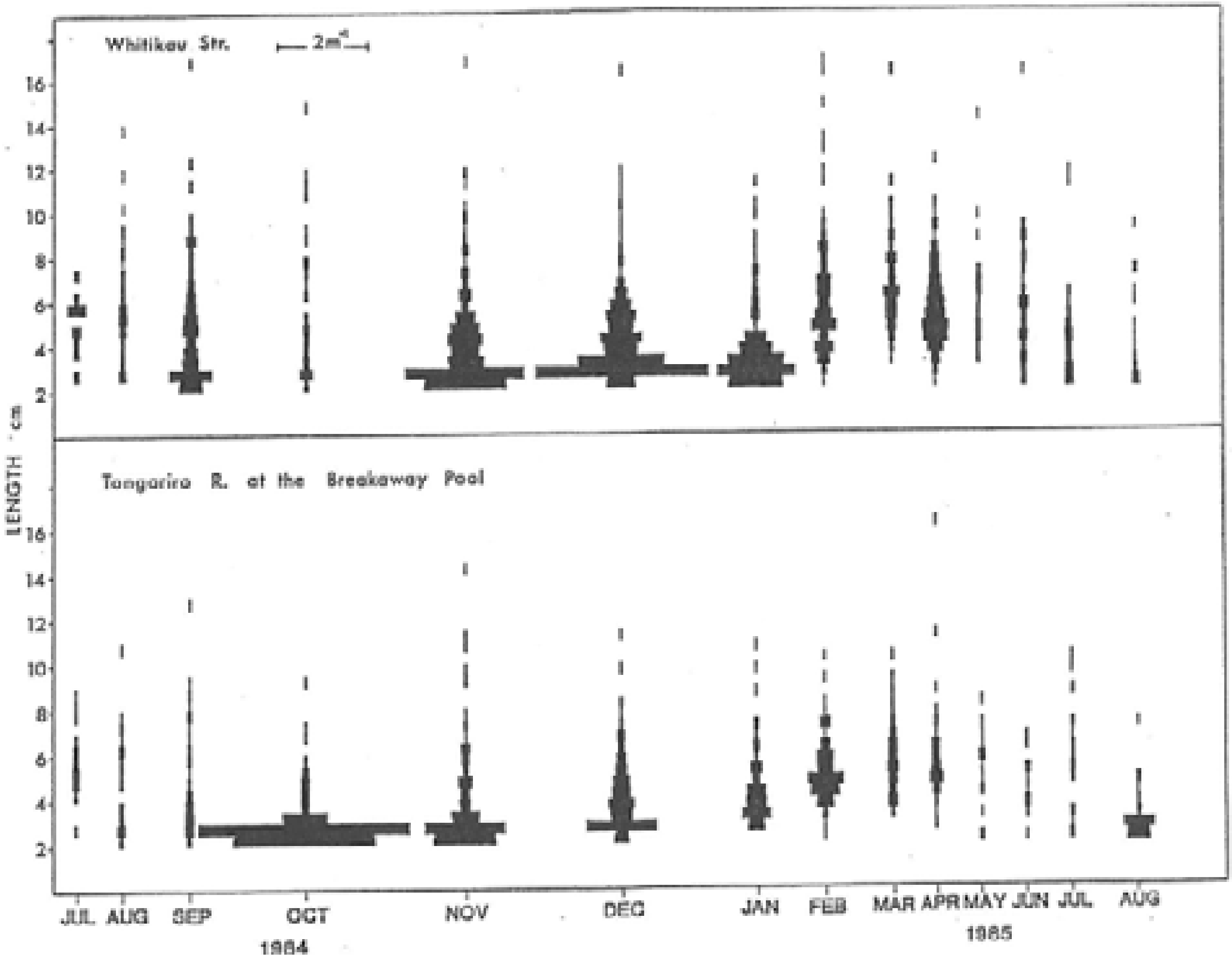


Figure 13. Seasonal variation in juvenile rainbow trout abundance and length distribution in the Whitikau Stream and in the lower Tongariro River at the Breakaway Pool. Bars express the number of trout taken (per metre electrofished) belonging to each 5mm length interval.

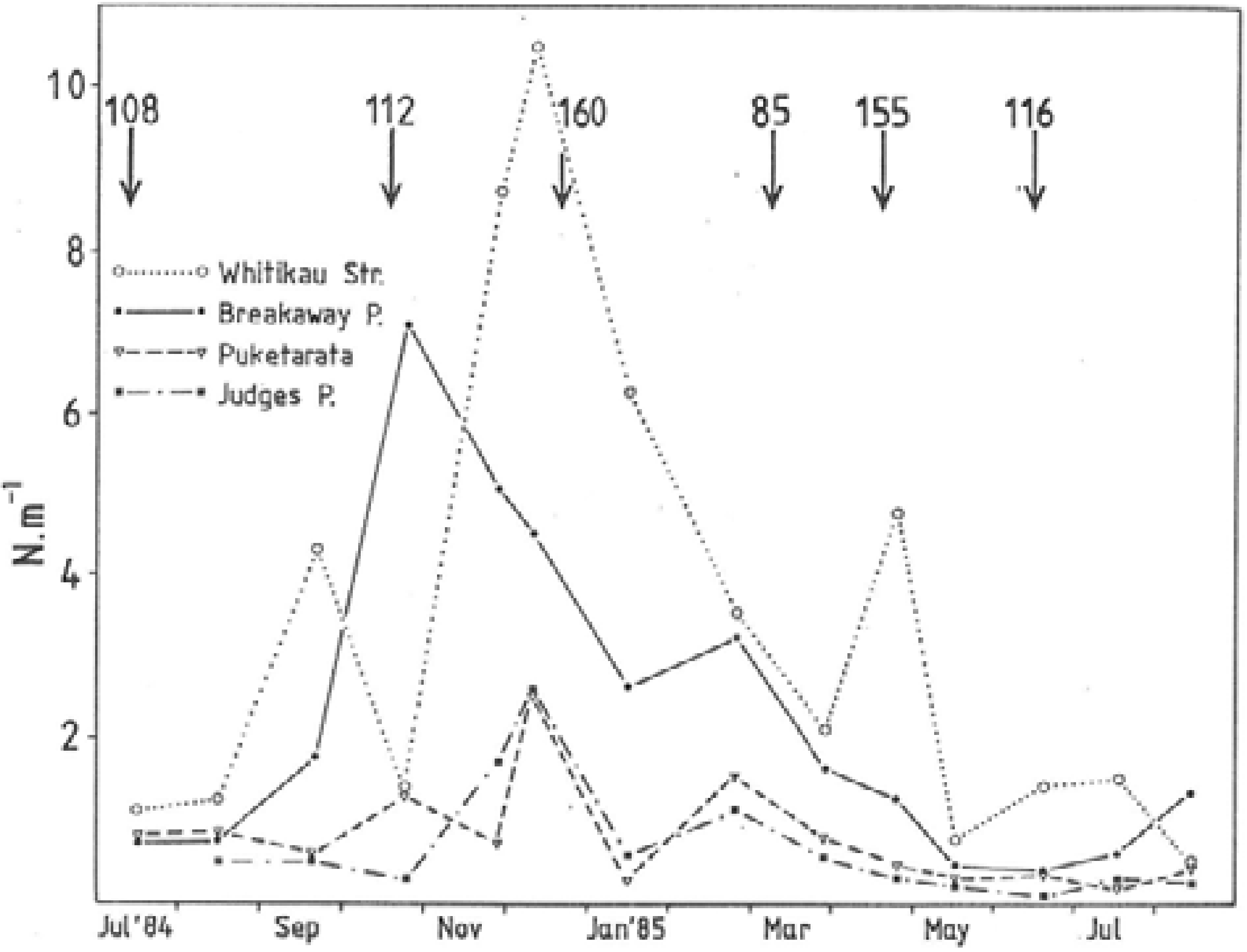


Figure 14. Variation in the number of juvenile trout caught (per metre electrofished) at four sites. Arrows indicate floods and the number above is the peak flow (cumecs) recorded at Turangi.

Table 8. The influence of floods on juvenile trout numbers. Data are numbers of visits to each sampling site on which there was an increase or decrease in the number of trout present on consecutive months.

	INCREASE	DECREASE
FLOOD	9	23
NO FLOOD	27	21

Ho: That changes in juvenile trout numbers are not affected by floods.
$X^2 = 6.14$ $p = 0.014$

A particularly large flood (>900 cumecs; third largest recorded since 1957) occurred on 4 January 1986 and was followed by another major flood on 25 January and three smaller floods in February and March. Sites which had been routinely sampled in were revisited to compare juvenile trout densities, which were substantially lower in the Whitikau Stream, at Puketarata and at the Breakaway Pool (Table 9). Subsequent sampling in February revealed no evidence of recovery, probably because subsequent lesser floods disrupted recolonization.

It seems that floods drive large numbers of juvenile trout out of the rivers into Lake Taupo. Spring floods would affect mainly fry, but rapid recolonization and recovery to normal densities is likely because of continued fry emergence both in tributaries and in the river. Recovery following summer floods would be slower because comparatively little fry emergence occurred after January and time is required for newly-recruited fry to grow into small fingerlings.

Table 9. Effect of a major flood on juvenile trout densities. Data are numbers of juvenile trout caught per metre electrofished. The December 1984 flood occurred on the 18th after the samples for that month had been collected. The January 1986 flood occurred on the 4th and to assess the effects of this flood, comparisons should be made with 1984/85 samples.

	1984/85			1986			
Sites	Dec 10	Jan 17	Feb 18	Jan 20	Feb 2	Feb 12	Mar 7
Whitikau Str.	10.5	6.3	3.5	0.11	0.03	0.05	0.18
Poutu intake	0.11	0.01	0.5	0.14	0.04	0.06	-
Puketarata	2.6	0.58	1.1	0.24	0.03	0.01	-
Breakaway Pool	4.5	2.7	4.5	0.93	1.13	0.80	-
Judges Pool	1.9	0.2	1.1	0.46	0.51	0.12	-
DeLatours Pool	0.57	0.15	0.1	0.17	0.11	0.18	-

4.4 Trout Scales and Life History Patterns.

Results from the monthly electrofishing programme indicate that juvenile trout emigrate to Lake Taupo at sizes ranging from fry up to juveniles at least 20 cm FL. However, it is not known which sizes contribute most to the fishery. This knowledge is required to identify effective practices for increasing numbers of trout available to anglers, and, in particular, for choosing objectives for flow management policies intended to maintain or increase production of whatever juvenile stage contributes most to the fishery.

A preliminary examination of adult trout scales revealed a zone of closely spaced circuli at the centre of the scale, abruptly followed by more widely spaced circuli (Fig. 15, below). Back-calculated length at the transition was consistent with that of large fingerlings. Accordingly, it was hypothesized that the closely spaced circuli indicated slow growth in a cold stream environment and the transition to wider spacing was associated with entry to Lake Taupo and faster growth thereafter. This being true, then back-calculations to determine the length of fingerlings at the time of entry to the lake would provide an estimate of the lengths of successful emigrants from the river. Thus the first step was to examine scales from juvenile trout collected in streams and in Lake Taupo to find out whether juvenile scale patterns were consistent with this hypothesis.

4.4.1 Methods

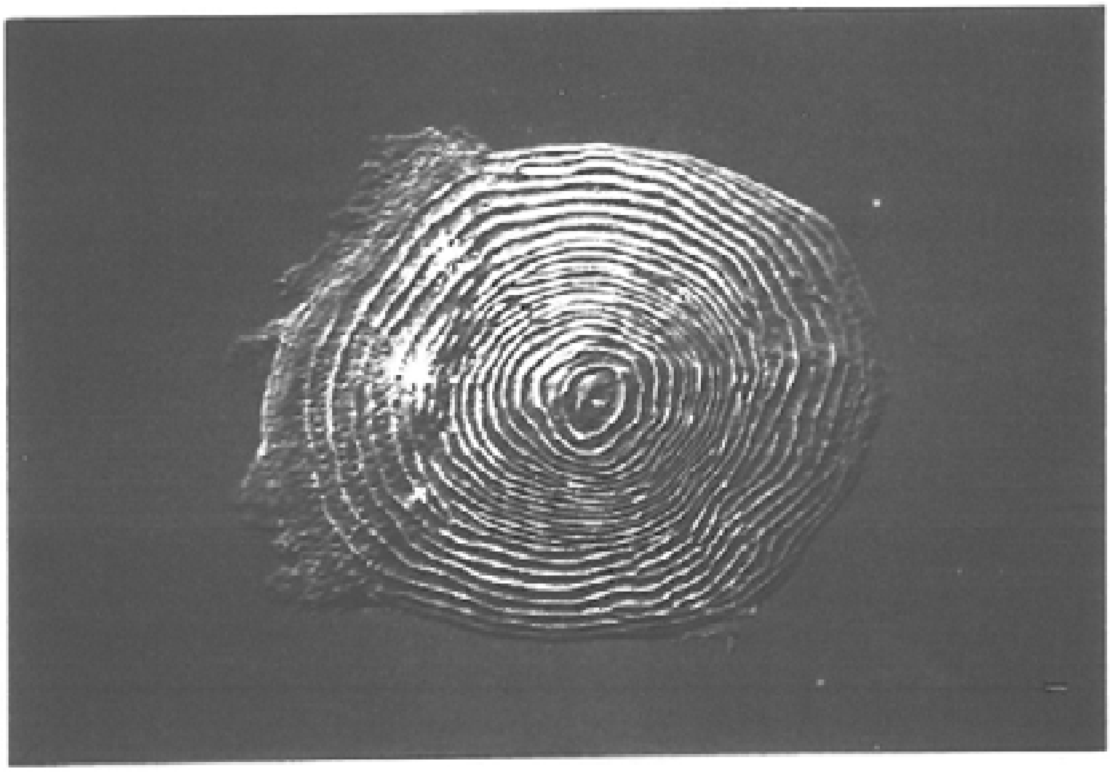
Scales were collected from measured (fork length; FL) sub-adult trout caught in Lake Taupo during a fishing tournament held on 21 and 22 April 1983 and from juvenile trout collected electrofishing in the Tongariro River. The total anterior scale radius and radius to each discontinuity in the circuli were measured, using an eyepiece micrometer, on five scales taken from near the middle of the fish under the dorsal fin. The regression of body length to scale radius was calculated (Fig. 16) and the Frazer-Lee equation was used to back-calculate length at formation of the first scale mark thus:

$$L_i = a + \frac{(L_c - a)\, S_i}{S_c}$$

where L_i = calculated length at age i;
a = intercept in the body-scale regression;
L_c = length of fish at capture;
S_c = radius of scale at capture;
S_i = scale measurement at annulus i.

4.4.2 Scale Patterns from Juvenile Trout

Scales from fingerlings less than about 5 cm FL were unreadable because there were too few circuli present to identify a change in spacing. However, scales from fingerlings up to about 9cm FL collected in November and December 1984 from the Tongariro River had evenly-spaced circuli, but larger specimens often had a zone of closely-spaced circuli, usually about midway along the scale radius (Fig. 15). Fingerlings larger than about 12cm FL collected in February and March 1985 were similar, with the closely-spaced circuli being nearer the centre of the scale, whereas smaller fingerlings had evenly-spaced circuli. It seems likely that these large fingerlings had spent the winter in the stream and that the band of closely-spaced circuli was associated with a period of depressed growth caused by low winter temperatures.



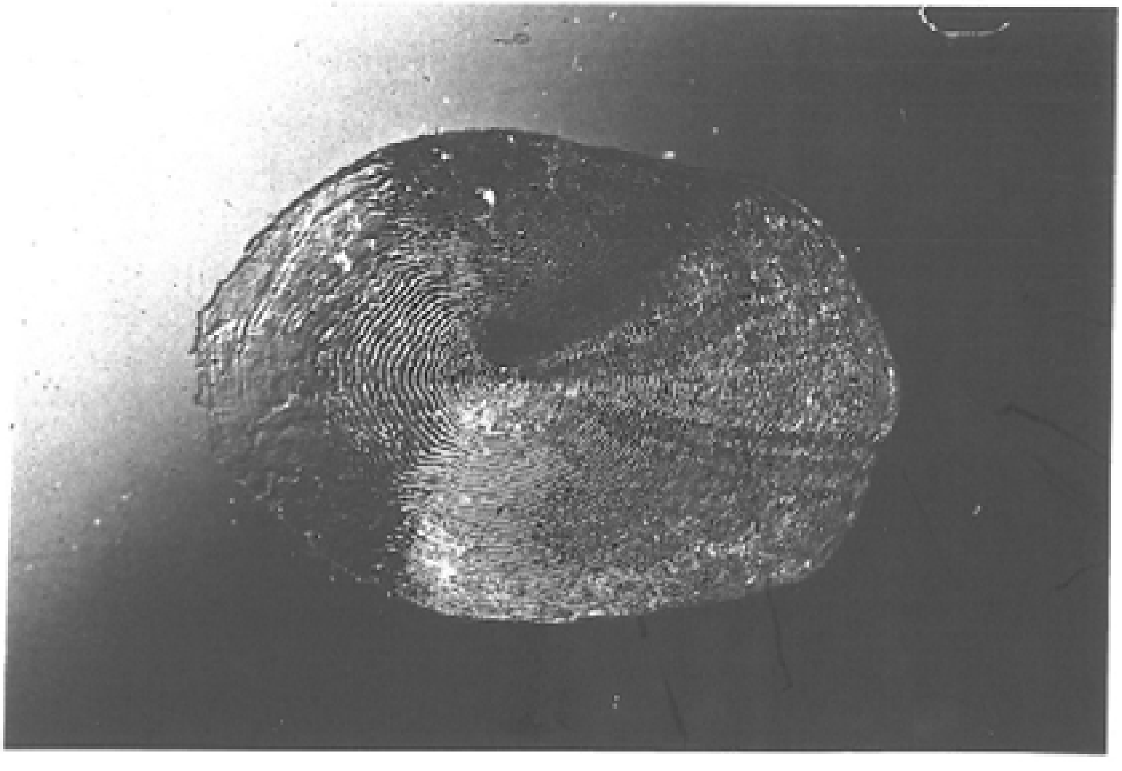


Figure 15. Scales from a raibow trout.

ABOVE: Juvenile (11.5 cm FL) collected in the Whitikau Stream in December 1984 showing a zone of compressed circuli probably associated with slow winter growth.

BELOW: Adult (50.0 cm FL) collected from Lake Taupo in April 1983 showing the transition from closely-spaced circuli near the centre of the scale to the wider spacing thought to be associated with growth in Lake Taupo.

Scales from eleven juvenile trout (6 to 15 cm FL) collected from Lake Taupo during February 1985 in nocturnal beach seine hauls had only one discontinuity, with closely-spaced circuli followed by a few more widely-spaced circuli near the scale margin. One, however, had evenly-spaced circuli over the whole scale, possibly because it was smaller than about 5 cm on lake entry and so a change in growth was not visible on the scale. Thus, ten of the specimens examined had a transition mark probably associated with lake entry whilst one did not.

These results are consistent with the hypothesis that "transition from closely to widely-spaced circuli is associated with entry into Lake Taupo". However, complications with marks associated with overwintering in streams and absence of marks in trout which enter the lake at a small size mean that identification of the transition mark associated with lake entry will not be possible with all trout.

4.4.3 Lengths of Successful Emigrants.

Scales were examined from 80 adult trout collected from Lake Taupo. Of these, 71 had an identifiable scale mark thought to be associated with lake entry. The remainder had no identifiable scale marks, so it was not possible to estimate their length at lake entry. Presumably, these fish were either too small at lake entry to form a recognisable scale mark or their growth rates were unaffected by the change from stream to lake habitat.

The body length-scale radius regression was calculated (Fig. 16) and the Frazer-Lee equation used to back-calculate lengths at lake entry (Fig. 17). Back-calculated lengths ranged from 7 to 20cm FL, being skewed to the right with a mode at 9cm FL, suggesting that the majority of successful emigrants arrived in Lake Taupo during summer and autumn when they were 8 to 15 cm FL, after spending the spring and early summer in tributary streams.

4.5 Feeding Habits

The stomach contents of juvenile trout collected at the Breakaway Pool and from Lake Taupo were examined to determine the foods of juvenile trout. Juvenile trout from the Breakaway Pool were collected by electrofishing and those from Lake Taupo were sampled in gill nets set on the bottom at 20 to 50 cm depth on 6th February 1986. The nets were lifted at dawn and the trout were stored on ice until the stomachs could be removed and contents counted and measured.

Trout from the Breakaway Pool were divided into two size classes: fry (<40 mm) and fingerlings (50 to 100 mm). Individuals of each taxon present in stomachs were counted and the volume of each taxon was measured. Data for up to ten fish for each group on each date were combined and averaged for presentation.

Juvenile trout collected from the Breakaway Pool fed on a variety of insect larvae (Fig. 18), with Chironomidae being the most important prey, followed by free-living caddis (Ryacopbilidae and Hydropyschidae) during the autumn and winter. Winged adults and terrestrial insects were not important components of their diet. Seasonal variation in feeding activity was not apparent for fry (Fig. 19) but a clear seasonal pattern was evident for fingerlings, whose stomachs contained about six times more in summer than in winter.

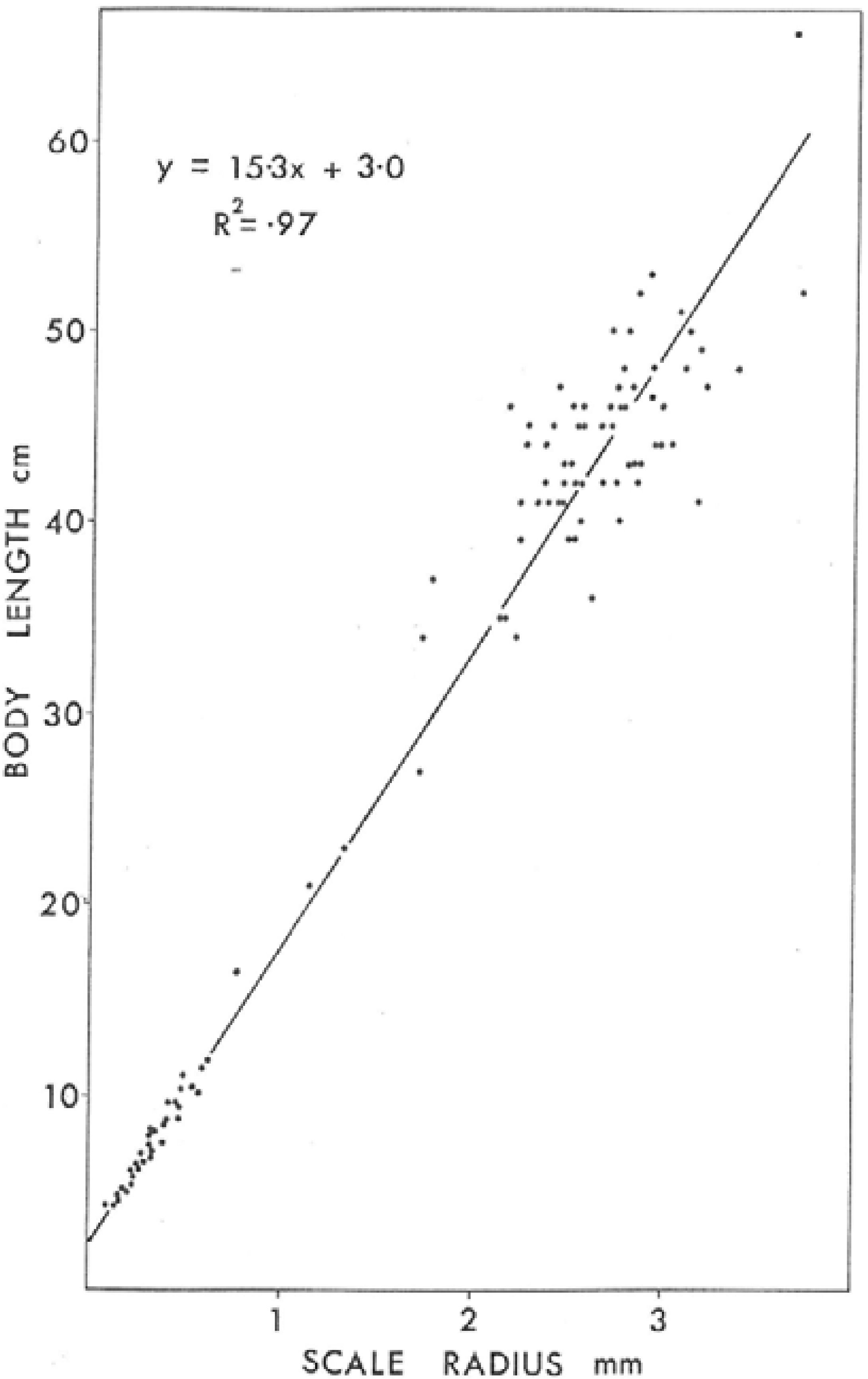


Figure 16. The relationship between body length and scale radius for Lake Taupo rainbow trout.

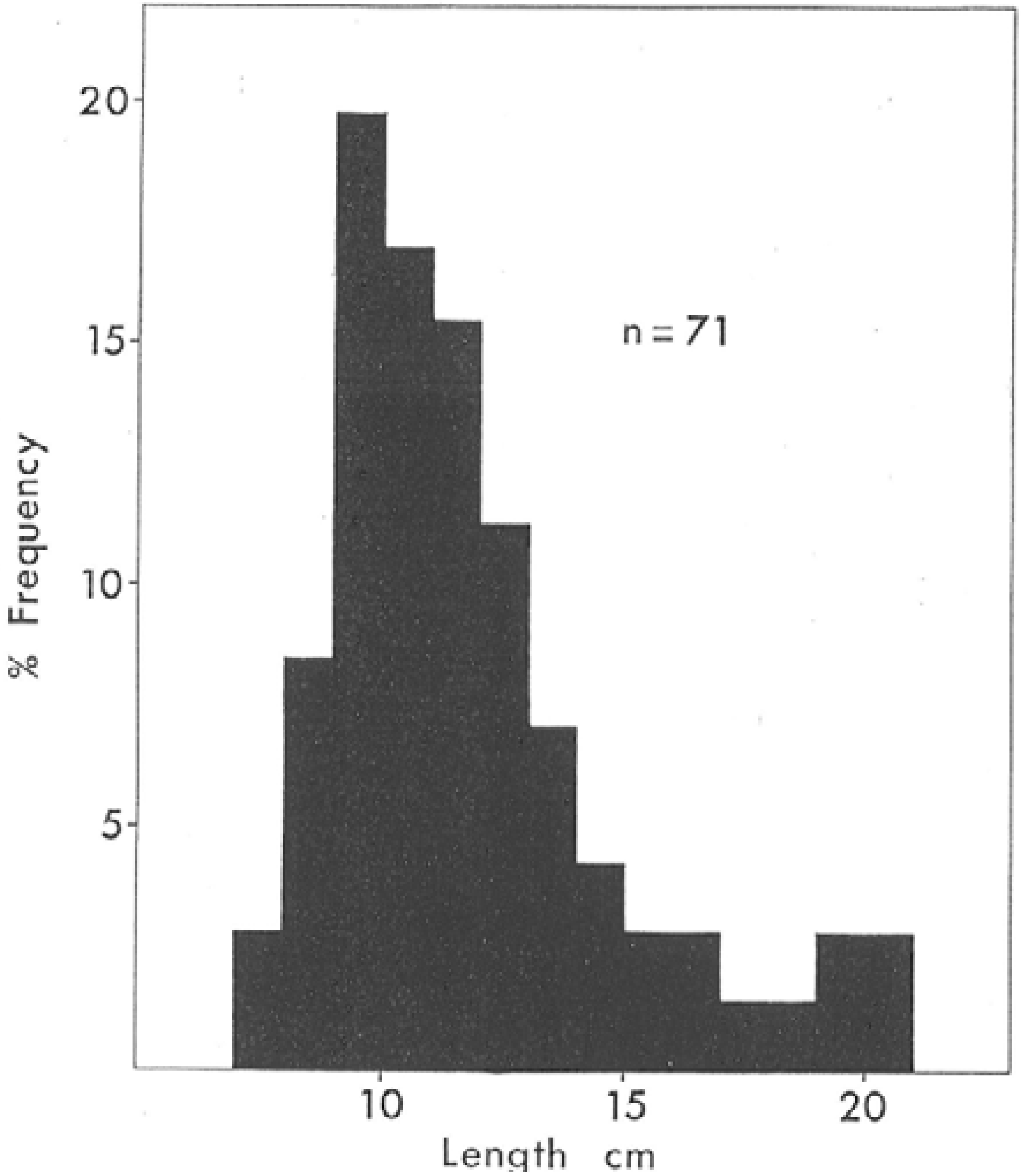


Figure 17. The length frequency distribution of successful emigrant juvenile rainbow trout on entry to Lake Taupo. Lengths were estimated by back-calculation using scales from adult trout.

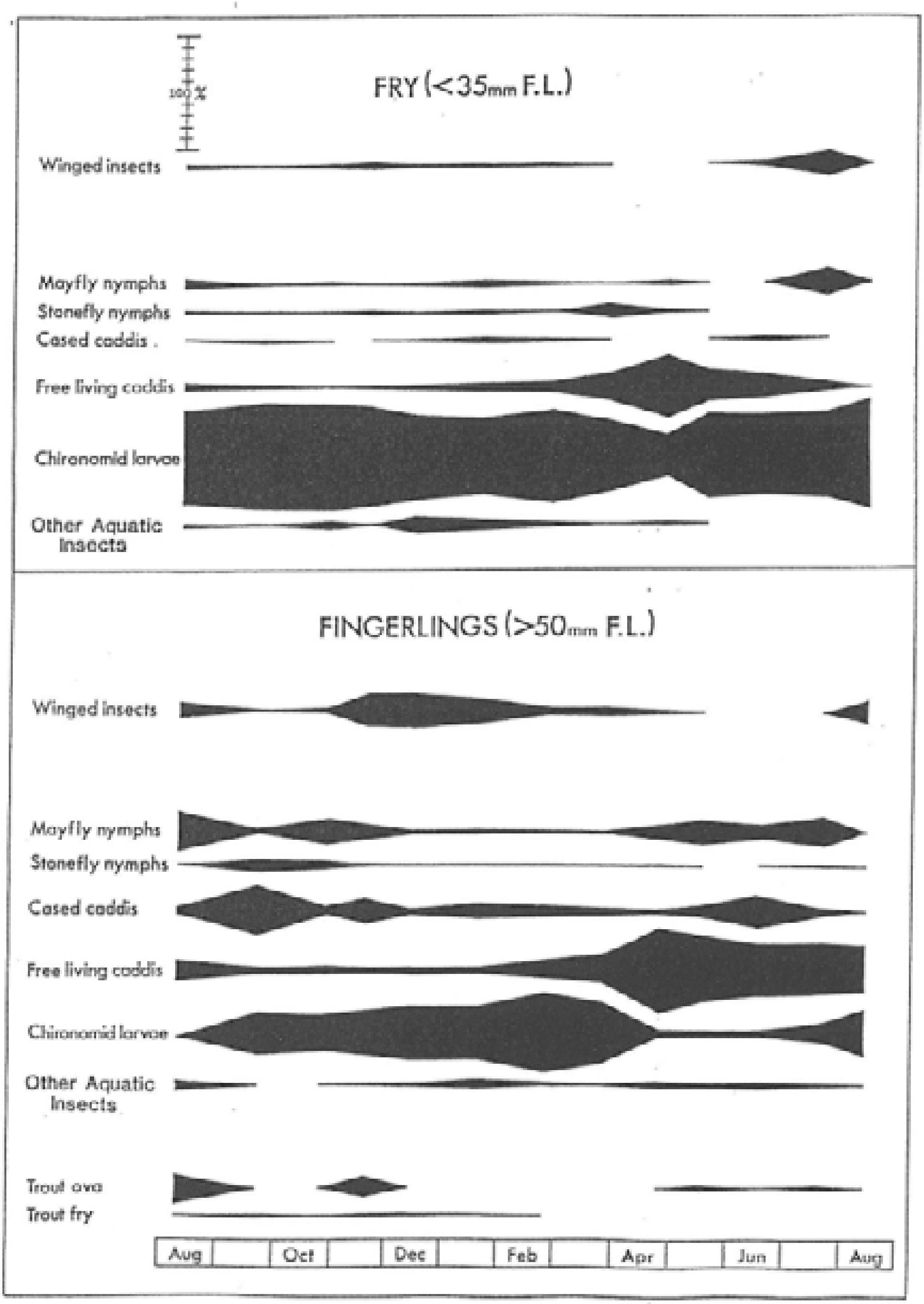


Figure 18. Seasonal variation in the diet of juvenile rainbow trout collected from the Tongariro River at the Breakaway Pool between August 1984 and August 1985.

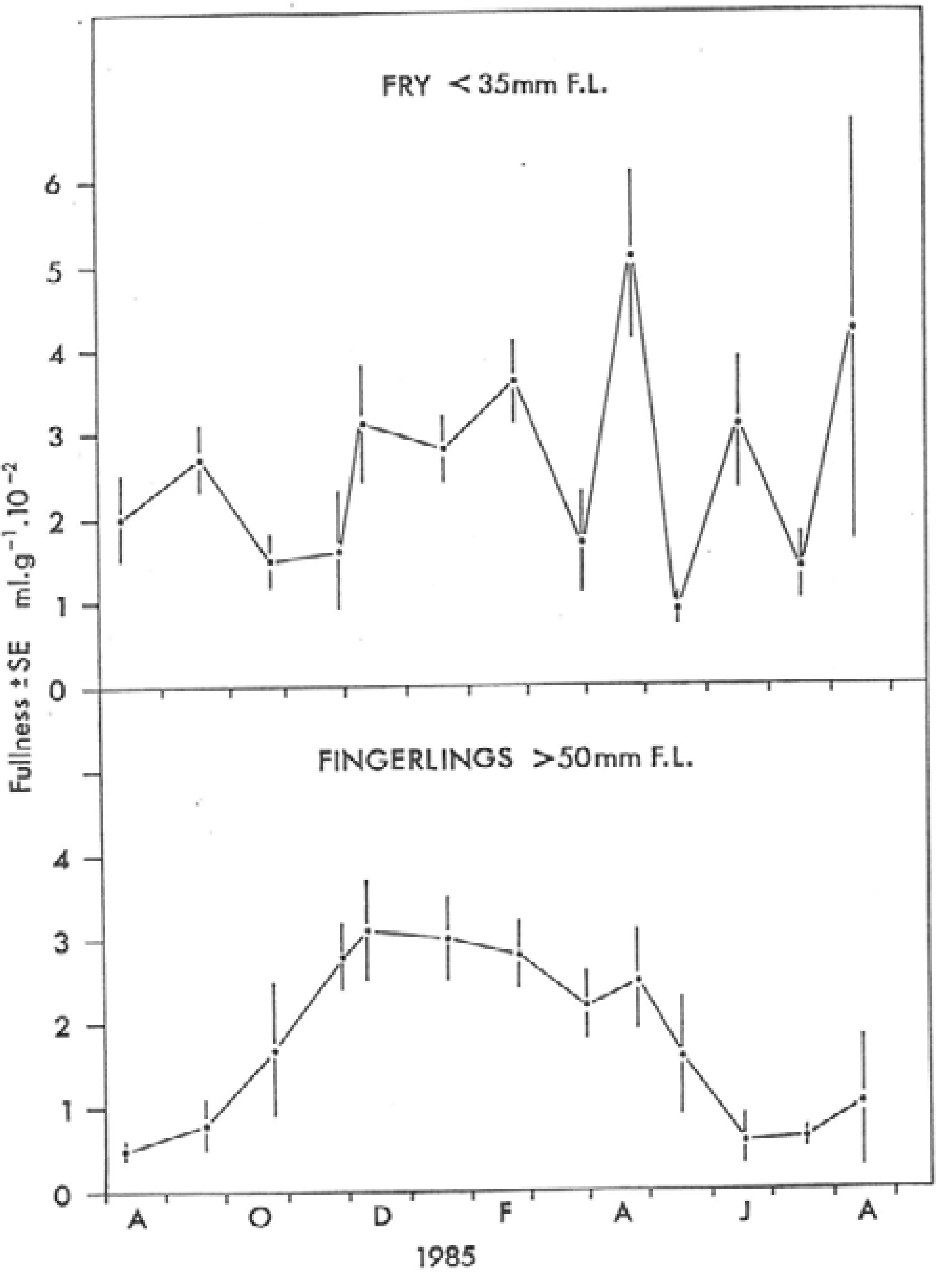


Figure 19. Seasonal variation in the relative quantity of food eaten by rainbow trout juveniles collected in the Tongariro at the Breakaway Pool between August 19984 and August 1985.

Almost all of the aquatic insects eaten by juvenile trout in the Tongariro River are species characteristic of stony, silt-free streams. This suggests that flow and sediment management practices which minimize fine sediment deposition and periphyton accumulation will benefit both aquatic insects and juvenile trout. Environmental perturbations which disrupt aquatic insect production will have most impact on the juvenile trout population during summer, when they are most numerous and feeding most actively.

The diet of trout in Lake Taupo was completely different from that of trout in the Tongariro River, with smelt (Retropinna retropinna) being virtually the only species eaten by juvenile trout (Figs. 20 and 21). Larger trout (Figs. 20, 21 and 22) ate more freshwater crayfish (Paranephrops planifrons) and bullies (Gobiomorphus cotidianus). However, there was no difference between the lengths of smelt eaten by small and large trout (Fig. 23). These findings are consistent with other studies of rainbow trout feeding in Lake Taupo and other central North Island lakes (Stephens 1984; Rowe 1984; Cryer in prep.).

4.6 Discussion

The monthly electrofishing surveys demonstrated that juvenile trout use the Tongariro River throughout the year and that they live, feed and grow there for some time before emigrating to Lake Taupo. Whilst it was clear that fry recruitment occurred between October and January, the seasonal timing of fingerling emigration was not obvious from these surveys. However, juvenile numbers at six sites decreased between April and May, and no floods occurred during this period, suggesting that there may be emigration, as distinct from downstream displacement, during autumn. Scale features indicated that a significant proportion overwintered in streams whilst others emigrated before the winter. Rosenau (unpubl. data) estimated from scales that about 65% of successful emigrants overwintered in the Waimarino Stream whilst only 35% overwintered in the Hinemaimaia River. He found that whilst the mean size of successful autumn and spring emigrants differed (larger in spring when most were one year old), the minimum size for successful emigration was constant both seasonally and for each of the streams studied. These findings indicate that although the way juveniles use streams varies in response to differences in stream habitat features, the minimum size for lake entry is determined by lake conditions, to which stocks from all streams are subjected after emigration.

Rosenau found that the minimum size for survival in Lake Taupo was 94 mm whereas in this study it was thought to be 70 mm. The difference probably reflects occasional variation in interpretation of scale features, such that Roseneau recognised two marks where only the inner of these would have been recognized in this study, and would have been thought to be associated with lake entry.

Observations of juvenile trout in Lake Taupo suggest that trout smaller than 15 cm FL are scarce, although there are two indications that substantial numbers of smaller juveniles probably enter the lake. Firstly, large numbers of fry present in the lower Tongariro River in spring appear to drift downstream towards the lake, becoming less numerous in the river as the summer progresses. Secondly, floods reduce juvenile numbers and presumably those which disappear are displaced downstream to the lake. Nevertheless, sampling in the lake with gill nets indicate that small (< 10 cm) juvenile trout are scarce. Stephens (1984) collected littoral fish samples fortnightly by day and by night from September 1979 until October 1981. Juvenile trout, some less than 10 cm FL, were a rare component of the catch in nocturnal beach seine samples but were not found by day. Cryer (in prep.) sampled trout quarterly from littoral, pelagic and profundal habitats using nets made up of panels with meshes ranging from 25 to 100 mm (knot to knot), which would be expected to catch

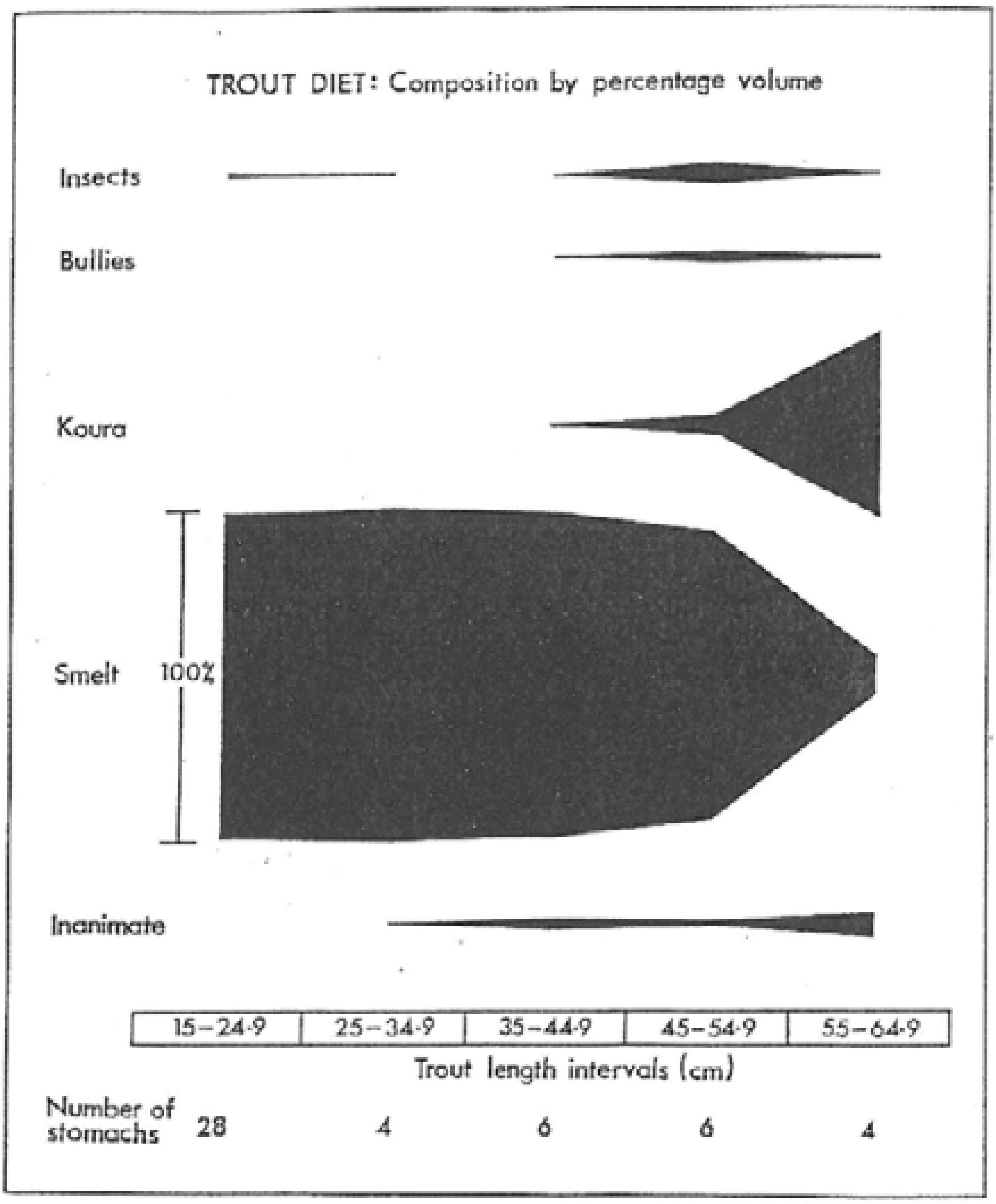


Figure 20. Size –related variation in the diet of rainbow trout caught in Lake Taupo using gill nets on 6 February 1986.

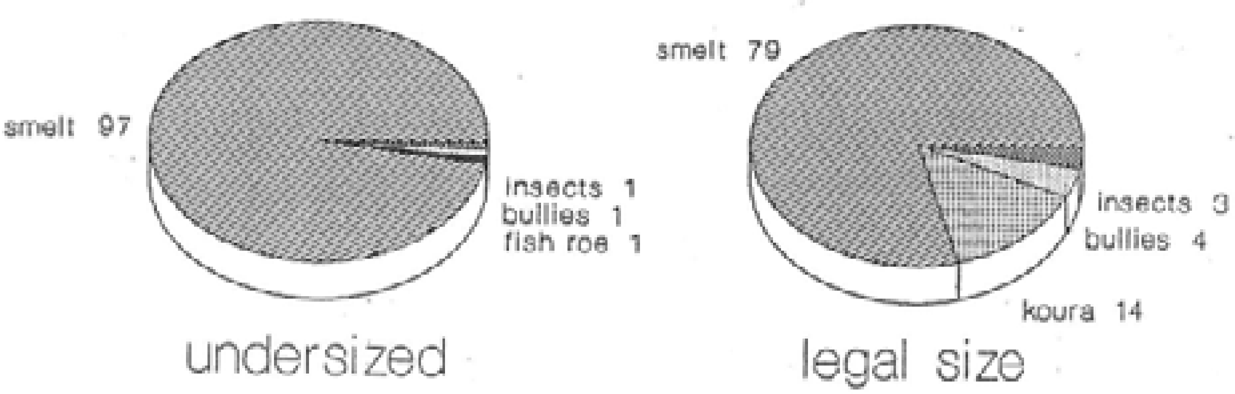


Figure 21. The diet (percent volume) of under-sized and legal sized (> 35 cm) trout caught in gill nets set in a variety of depths and habitat zones in Lake Taupo during 1988. Data are lumped for four quarterly sampling sessions. (Reproduced from 1989).

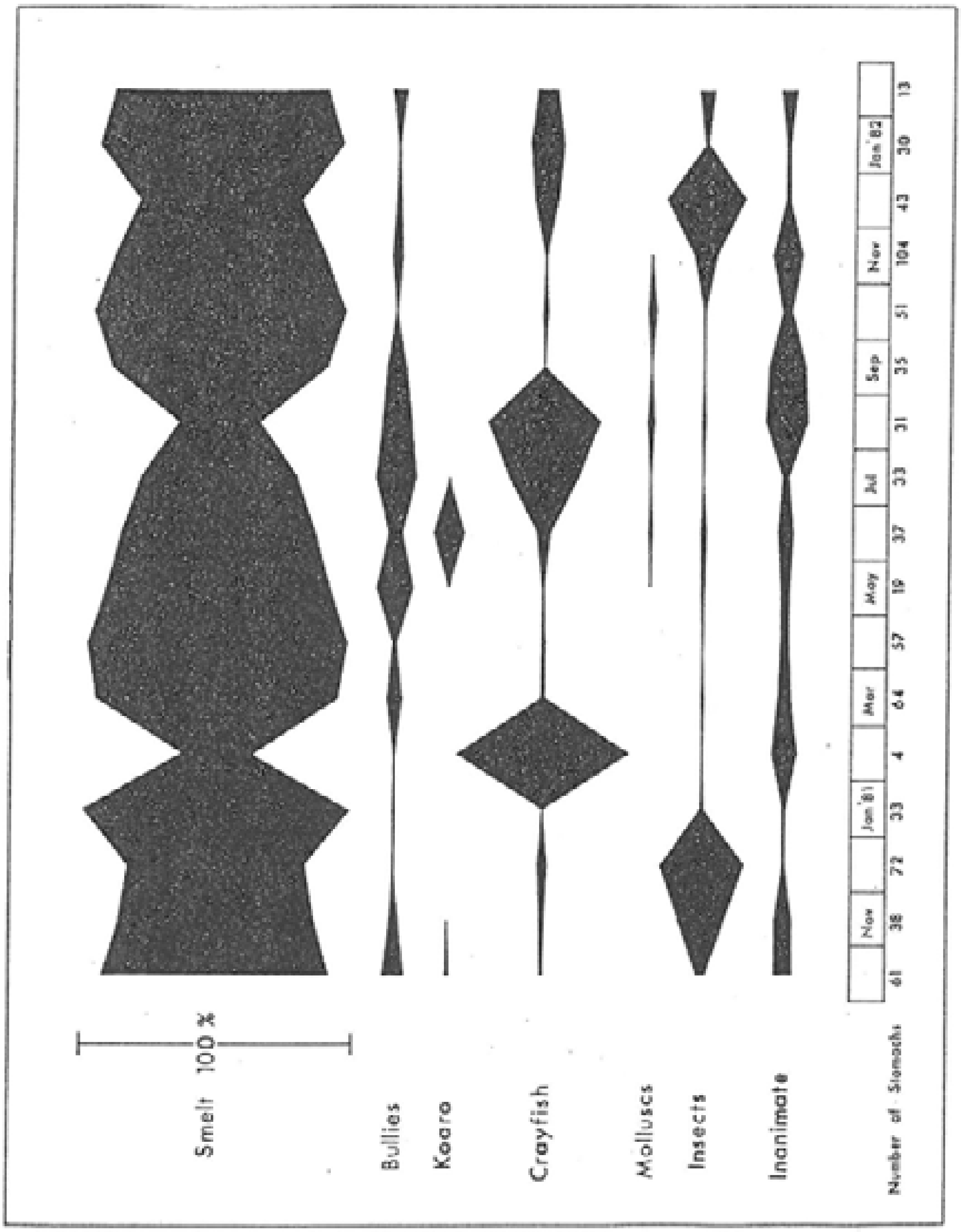


Figure 22. The diet of angler caught rainbow trout in Lake Taupo. Data are percentages, by volume, of each food item present in stomachs collected during the month indicated. (Reproduced from Stephens 1984).

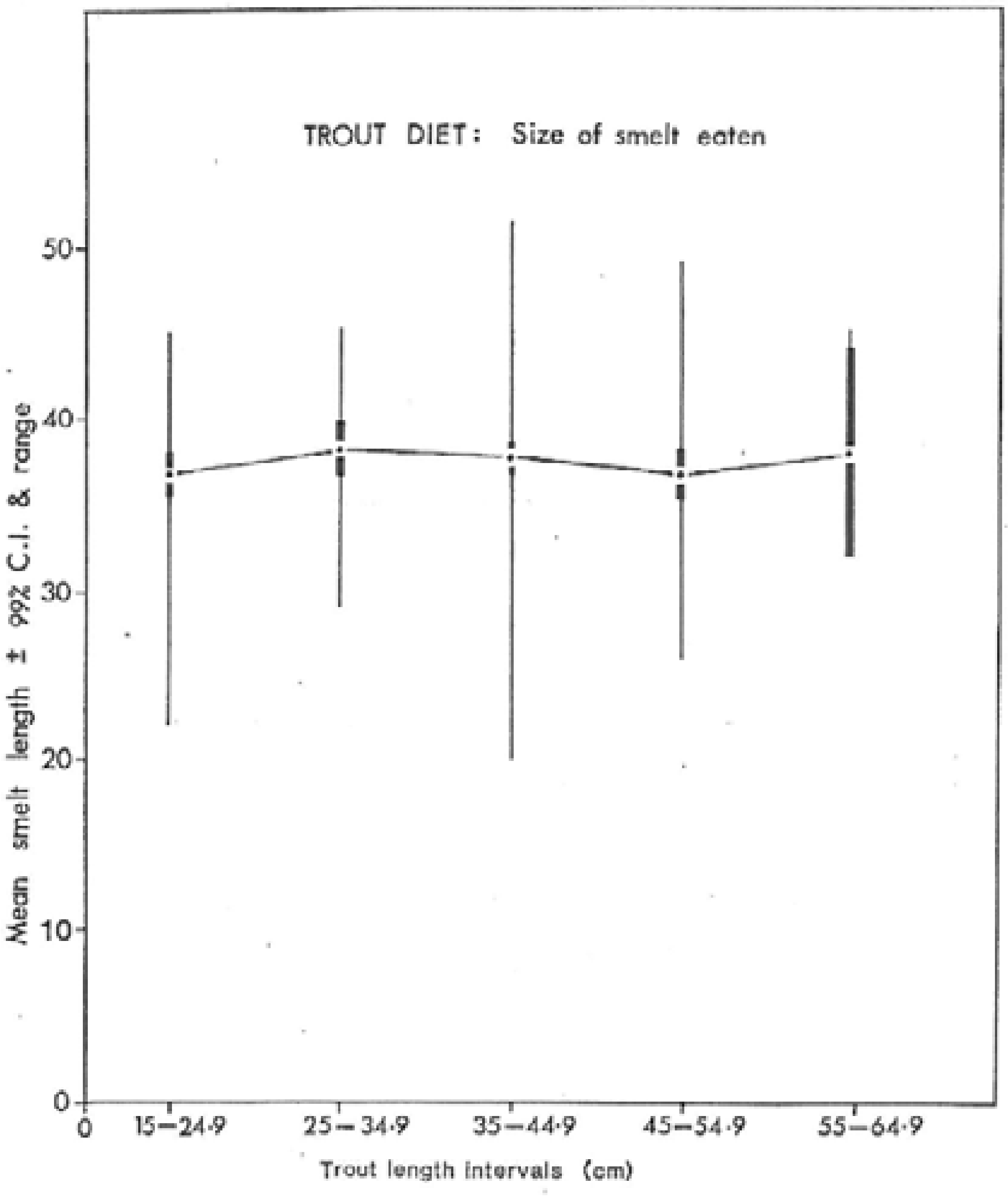


Figure 23. Variation in the lengths of smelt eaten by different-sized rainbow trout caught in gill nets set on 6 February 1986.

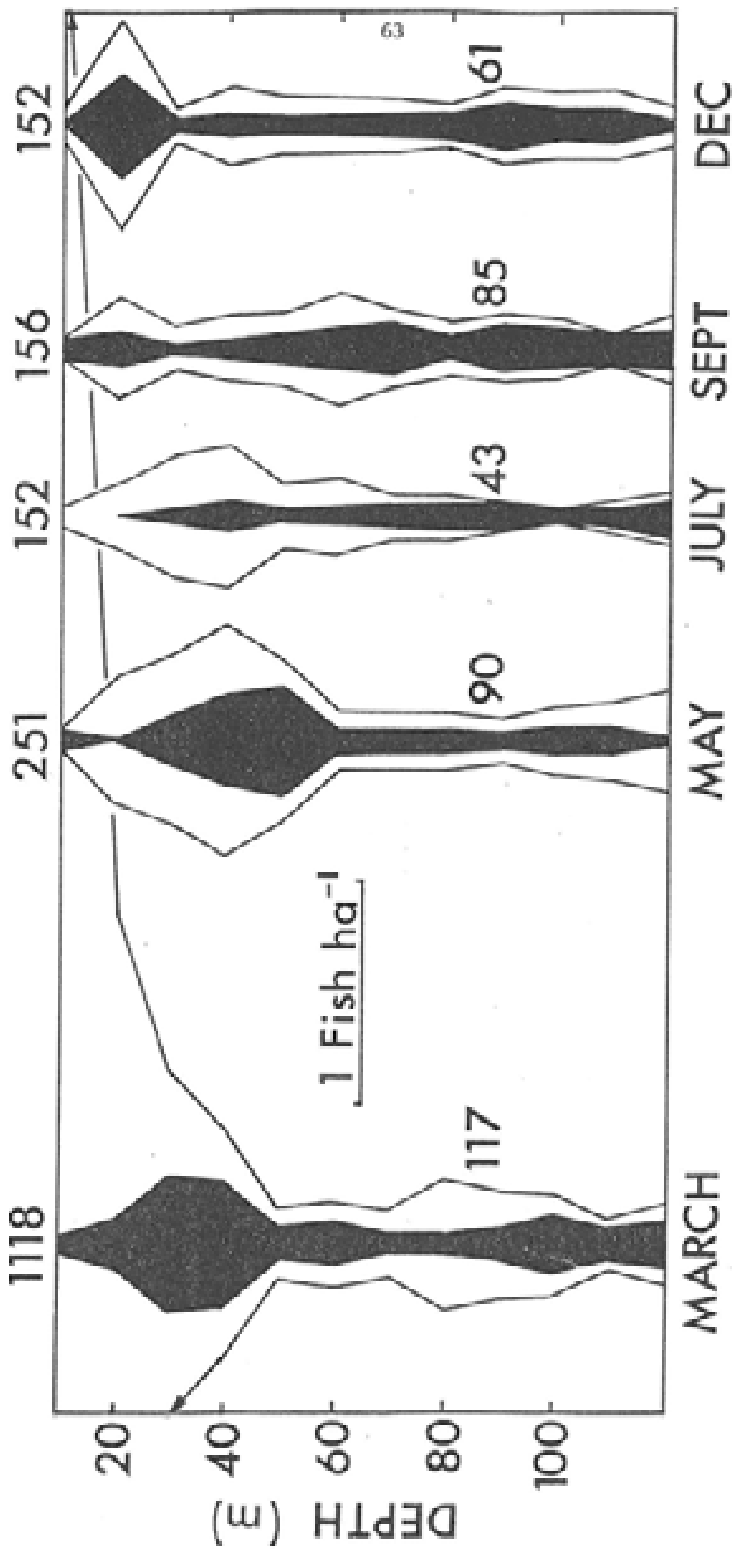
trout as small as 10 cm FL. Of 372 trout collected, only two were less than 15 cm FL (14.5 and 11.5 cm) but 93 were between 15 and 25cm FL. Acoustic surveys to estimate the number and size of trout present in the lake (Cryer in prep.) indicate that juvenile trout were abundant in March 1988 but that their numbers declined rapidly (Fig. 24). Thus, it seems likely that on occasions, considerable numbers of juveniles less than 10 cm FL enter the lake but few survive. Larger juveniles (10 to 15 cm) probably grow rapidly and so do not remain in this size range for long.

The reason for low of small juvenile trout in Lake Taupo may be related to the food resources available. In Lake Taupo, juvenile trout feed almost exclusively on smelt living in the pelagic and profundal zones (Stephens 1984; Cryer in prep.). It may be that trout less than about 9 cm FL are unable to live in the littoral zone, feeding on littoral invertebrates, and are insufficiently developed to feed on smelt, an active, wary prey which must be actively pursued and caught. Consequently, small juvenile trout in Lake Taupo would have little prospect of survival. However, it is not clear why juvenile trout seem unable to flourish in the littoral zone. One possibility is that they may be excluded by competition with bullies and smelt for invertebrate forage and by predation from bullies and fish eating birds.

Floods reduced the number of fingerlings present, particularly in summer and at sites where densities were usually high. There was also a significant negative association between summer (and autumn) flood frequency and subsequent returns to the Waihukahuka Stream (Section 3.3.2). It seems likely that floods in summer or autumn drive large numbers of juvenile trout out of the river to Lake Taupo before they have developed sufficiently to survive in the lake. The effects of winter and spring floods on juvenile trout numbers were less severe and flood frequencies were positively associated with subsequent returns. The lesser detrimental impact of winter and spring floods could be explained if redds are not damaged except by major floods (> 200 cumecs); displaced fry are soon replaced; and many fingerlings are large enough to either avoid displacement or survive in the lake. The positive association between returns to the Waihukahuka Stream and floods in winter, spring, or only one flood in summer, is probably related to the beneficial effects of floods on habitat quality. Accumulated periphyton and sand deposited amongst cobbles is removed by floods and this would increase the space available for invertebrates eaten by juvenile trout. Another possibility is that a single flood increases production of juveniles large enough to survive in the lake by removing some, enabling smaller ones to occupy vacated space and grow to sufficient size. More than one flood may not allow enough time for the second crop to reach sufficient size to survive in the lake. Thus the trout population may benefit more from the cleansing effects of frequent floods than it suffers from premature displacement downstream, except in summer and autumn when fry emergence and growth are insufficient to replace juveniles displaced downstream.

Numbers of trout found below Poutu intake and at two sites in the gorge downstream were low compared with similar habitat further downstream. It is possible that, due to the comparatively low number of trout spawning nearby and further upstream, there was insufficient fry production to fully colonise available habitat. However, spawning trout were seen near the intake, and in the pools downstream, throughout the breeding season. It is also possible that fluctuating flows, which are particularly marked in this part of the river (Fig. 4), restrict invertebrate food production and impede colonisation of apparently suitable habitat (Irvine 1984,1985; Ottaway and Clarke 1981; Ottaway and Forrest 1983; Thomas 1975).

Figure.24. Vertical distribution of trout in Lake Taupo during 1988 as determined by acoustic surveying. Dark kites represent legal sized individuals (> 35.0 cm), and outer unshaded kites represent undersized fish. Numerals above the panel denote the size of the whole lake-resident population, and those beside the kites denote the number of legal sized trout in the lake, in thousands of individuals. (Reproduced from Cryer 1989).



Since juvenile trout must reach about 9 cm in tributary streams before they are likely to survive and contribute to the fishery, it is clear that nursery habitat for fry and fingerlings must be of central importance to the wellbeing of both the Lake Taupo and Tongariro River fisheries. Electrofishing surveys indicated that numbers of juveniles were substantially greater in places where habitat quality appeared high (also see section 5.4). This suggests that the quality and extent of juvenile habitat is likely to be a key factor determining the number of fingerlings large enough to flourish in Lake Taupo. It is therefore important that the flow regime provides suitable habitat for all the requirements of growing fry and fingerlings. If, as appears to be the case, the cleansing effects of floods are beneficial and artificial flow fluctuations detrimental, then fingerling numbers and subsequent recruitment to the fishery would benefit from flow management policies which extend flood recessions to enhance cleansing effects; reduce artificial flow fluctuations to facilitate colonization of juvenile habitat; and reduced deposition of fine sediment which reduces and detracts from invertebrate habitat, particularly during summer and autumn when small fingerlings are most abundant and feeding most actively.

CHAPTER FIVE

FLOW REQUIREMENTS FOR TROUT IN THE TONGARIRO RIVER

5.1 Introduction

Regression modelling indicated a strong negative association between summer flood frequencies and subsequent returns of adult trout to the Waihukahuka Stream. The monthly electrofishing programme demonstrated that juvenile trout numbers were reduced by ordinary floods, particularly summer floods and were decimated by a major flood. It therefore, appears that the number of adult trout which contribute to the fishery is dependent on the number of juvenile trout able to develop in tributary streams to the stage at which they are ready to emigrate to Lake Taupo and flourish there. Regression modelling indicated that factors such as parent stock size, fry production and angling pressure had comparatively little influence on subsequent returns. This implies that these factors probably had little influence on production of juveniles large enough for life in Lake Taupo. The monthly electrofishing sampling programme demonstrated that juvenile trout numbers varied from place to place and it seemed that densities were usually particularly high where extensive, good quality habitat was available. Thus it seems likely that juvenile trout numbers, and hence numbers later available to the fishery were limited by floods in some years but in good years were probably limited by availability of suitable nursery habitat.

Suitable habitat is a general and rather vague term embracing many variable features of a river environment. It includes physical features such as depth, current speed, light, temperature and substrate composition, chemical factors such as oxygen, carbon, nitrate and phosphate availability, biological features such as food supply, competitors and predators and other qualitative factors such as cover, suspended sediment and flow variability. Any of these features can be affected by changes in flow (Shirvell 1979) and many of them are, to some extent, predictable. However, prediction of the consequences for fish of these changes to habitat is difficult and unreliable (Shirvell 1986).

Two particularly important features of physical habitat, depth and current speed, vary with flow and much of this variation can be predicted (Mosley and Jowett 1985). Since the depth, current speed and substrate preferences for the different trout life stages are known (Bovee 1978), it is possible to predict how habitat suitability, defined in terms of these three aspects of habitat, varies with flow. The problem here is to identify the discharge which provides most physical habitat for juvenile trout without detriment to other requirements of trout, such as conditions for invertebrate food production, feeding or spawning.

There are several methods for estimating the flow requirements of fish. The most sophisticated is the "Instream Flow Incremental Methodology" (IFIM) developed by the Cooperative Flow Group of the United States Fish and Wildlife Service. Whilst this method provides detailed predictions of physical habitat (measured as weighted usable area, WUA) at different flows, it has not yet been possible to predict biomass, population numbers or growth on the basis of these habitat measurements. It therefore seems appropriate to use the "Habitat Quality Index Model" (HQI), developed by Binns and Eiserman (1979) of the Wyoming Game and Fish Department, to provide additional guidance as to the likely relationship between trout habitat and discharge in the Tongariro River. This method is based on measurements of trout standing crop and features of their habitat such as maximum temperature, nitrate and fish food abundance which are not considered in the IFIM.

5.2 Instream Flow Incremental Methodology

This method assumes that a change in discharge will produce a corresponding change in the physical characteristics controlling the quality of a river for a selected use. Having defined the physical requirements of the selected use and related these to discharge, then loss or gain in river area suitable for a particular use caused by a change in discharge may be predicted. Unfortunately however, it has not yet been possible to predict how a species population will respond to a given change in suitable habitat area. This is largely because factors controlling the species' growth or population size are rarely known. If the controlling factor is unrelated to the amount of physical habitat available (e.g. floods, barriers to migration, disease, toxic substances, temperature) then population changes will not be associated with variation in the extent of this habitat.

Failure to establish a positive relationship between the amount of habitat and fish numbers or biomass has led to criticism of the validity of IFIM (Mathur *et al.* 1985,1986, Shirvell 1986). Orth and Maughan (1986) support the assumption that WUA and fish numbers and/or biomass are correlated. Mathur *et al.* (1986) point out that this assumption must be tested before flow management recommendations based on IFIM can be considered to be soundly based. Some validation studies support the IFIM assumption of a positive relationship between fish biomass and measurements of WUA (Slaney *et al.* 1984). However, no relationship between fish biomass or abundance and WUA has been demonstrated after a change in base flow. Furthermore, no relationship between fish production and WUA has ever been demonstrated (Shirvell 1986). Thus caution is essential in developing recommendations based on results of IFIM. Nevertheless, in spite of these deficiencies, IFIM is the most sophisticated and defensible method available to assess the impact of changes in flow on physical habitat for stream fauna.

5.2.1 Approach

The physical habitat requirements were defined for each of three controlling factors (depth, current speed, substrate) by a preference curve (Fig. 25), which provides an index of each factor's suitability for use over its possible range of values. Derivation of the curves is described by Bovee (1978) and Shirvell and Dungey (1983). The procedure and rationale for estimating nett habitat suitability for use is given by Bovee and Cochnauer (1977) and by Mosley and Jowett (1985) who provide the following summary:

The habitat preference index varies between 0 and 1. The nett suitability for use of a given location by a particular species or life stage is determined by the values of the habitat preference indices for the pertinent variables that control habitat quality. Thus, for example, a $10m^2$ area of stream bed with preference index values of 0.90, 0.85 and 1.0 for depth, velocity and substrate respectively, would have a net suitability for use of $0.9 * 0.85 * 1.0 = 0.765$. This $10m^2$ area may be regarded as equivalent to $7.65m^2$ of stream bed with a suitability for use of 1.0. By measuring depth, velocity and substrate and obtaining habitat preference index values at each measurement point from the appropriate curve and multiplying the index values by the stream bed areas for which measurements were representative, an overall index of habitat suitability known as weighted usable area (WUA) may be computed. By carrying out this procedure for a range of flows, the response of habitat quality to changes in flow may be estimated."

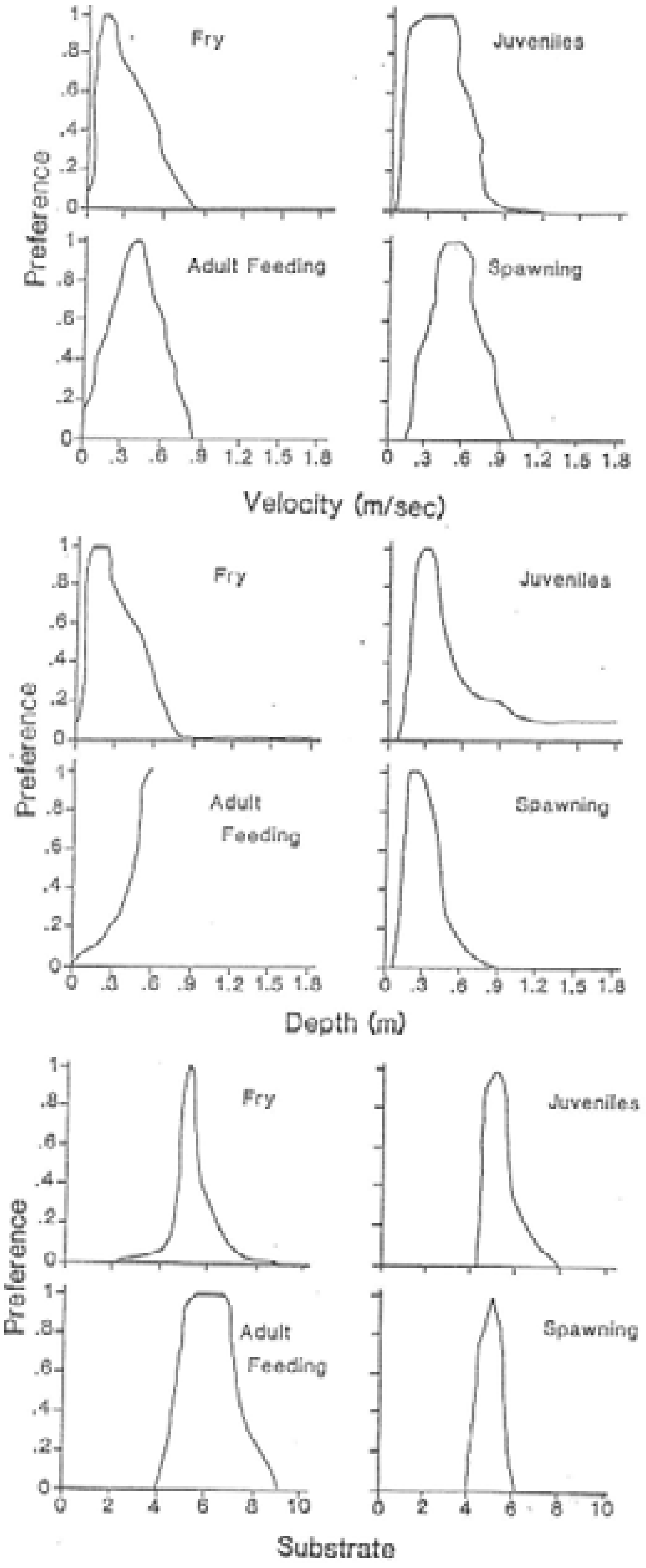


Figure 25. Rainbow trout preference indices for current velocity, depth and substrate composition, the latter expressed as coded values ranging from 1 (silt) to 9 (bedrock). (Reproduced from Bovee 1978.)

There are two procedures for application of the incremental method. One is to measure physical characteristics at a number of flows, the other is to collect measurements at one flow and use hydraulic modelling procedures to estimate hydraulic conditions at a range of flows and then use these data to calculate WUA values. In the Tongariro River, flows which differ from normal are usually short-lived. Thus measurements were collected at one flow and hydraulic conditions at other flows were estimated for calculation of WUA values.

The habitat suitability curves were developed for trout in North America and may not be the most appropriate for trout in the Tongariro River. However, because interpretation of IFIM predictions is not particularly sensitive to minor variations in preference curves (Shirvell 1986), this is not a problem.

5.2.2 Application

Four reaches, ranging from 150 m to 290m in length, were chosen. Each site was selected, within constraints imposed by access, to represent the main habitat features of the river within the general vicinity of the sample reach (Table 10).

Table 10. Sections of the Tongariro River considered to be represented by the sites chosen for habitat surveys.

Site	Reach length (m)	River section	Section length (km)
Poutu intake	150	Poutu intake to Sand Pool	12
Boulder Reach	290	Sand Pool to Barlows Pool	4.5
Judges Pool	287	Barlows Pool to Bend Pool	6.5
DeLatours Reach	158	Bend Pool to Lake Taupo	7

Cross-sections were established along the channel at approximately one channel-width intervals with extra cross-sections being added where flow was markedly non-uniform. Substrate composition was estimated, current velocity at 0.6 of total depth and water depth were measured with a Gurley or Pygmy bucket wheel current meter mounted on a graduated rod and the angle between the direction of local flow and the cross-section was estimated. Measurements were collected at intervals of 0.5 m where changes in depth, velocity or substrate were evident and at intervals up to 2m where the channel was uniform. Habitat preference curves given in Bovee (1978) were used to compute WUA indices for four life stages of rainbow trout. All hydraulic simulation work and computation of WUA indices (described by Mosley and Jowett 1985) was performed by Mr Ian Jowett (Fisheries Research Division, MAF, Christchurch).

5.2.3 Results

The form of the river channel at different flows (Table 11) was most affected by changes in flow at the Poutu intake and Boulder Reach sites where the river channel was broad and shallow. Lesser changes in channel width and wetted surface area were predicted for the other sites where the channel was confined by high banks.

Table 11. Simulated changes in the form of the river channel at different flows.

Flow (cumecs)	Width (m)	Depth (m)	Velocity ($m.s^{-1}$)	Surface Area (m^2)
5.0	25.6	0.54	0.39	3826
10.0	27.2	0.67	0.56	4077
15.0	29.2	0.75	0.66	4370
20.0	30.6	0.82	0.73	4588
25.0	32.3	0.87	0.79	4838
30.0	32.8	0.94	0.86	4913

BOULDER REACH

Flow (cumecs)	Width (m)	Depth (m)	Velocity ($m.s^{-1}$)	Surface Area (m^2)
5.0	41.6	0.53	0.29	12076
10.0	44.3	0.59	0.43	12868
15.0	49.7	0.61	0.48	14421
20.0	51.7	0.66	0.57	15001
25.0	52.3	0.71	0.66	15169
30.0	52.6	0.76	0.75	15274
35.0	52.8	0.80	0.83	15339
40.0	63.9	0.76	0.78	18542

JUDGES POOL

Flow (cumecs)	Width (m)	Depth (m)	Velocity ($m.s^{-1}$)	Surface Area (m^2)
5.0	26.3	0.36	0.47	7561
10.0	31.1	0.46	0.59	8928
15.0	34.2	0.54	0.68	9829
20.0	37.2	0.61	0.74	10685
25.0	40.0	0.65	0.79	11482
30.0	41.2	0.71	0.86	11838
35.0	42.2	0.77	0.92	12122
40.0	44.5	0.79	0.93	12783

DELATOURS REACH

Flow (cumecs)	Width (m)	Depth (m)	Velocity ($m.s^{-1}$)	Surface Area (m^2)
5.0	34.2	0.59	0.23	5391
10.0	35.8	.071	0.36	5651
15.0	36.7	0.84	0.44	5797
20.0	37.0	0.96	0.52	5840
25.0	37.3	1.07	0.58	5889
30.0	37.5	1.16	0.64	5918
35.0	37.6	1.26	0.69	5934

The relationships between discharge and habitat were similar for all life stages of rainbow trout (Figs. 26 & 27), with maxima at lower discharges than those which naturally occur in the Tongariro River. Maximum habitat for invertebrate food production was predicted at the highest flows (11 to 28 cumecs) whilst habitat for fry and fingerlings was maximal at less than 5 cumecs. Maximum habitat for adult trout feeding, resting and spawning lay between these extremes.

For Figure 26 the sites were:

300m below Poutu intake -P

Boulder Reach -B

Judges Pool -J

DeLatours Reach -D

The WUA refers to "weighted usable area" which is an index of available habitat area and is expressed here as a percentage of the wetted channel area. The highest point on each curve occurs at the flow which results in the greatest percentage of the channel providing suitable habitat (i.e. preferred depth, current velocity and substrate characteristics) and as such is a measure of habitat quality, not habitat area. Curves with high WUA values indicate that much of the channel provides suitable habitat and steep curves indicate sites that habitat quality is sensitive to variation in flow.

For Figure 27 the sites were:

300 m below Poutu intake -P

Boulder Reach -B

Judges Pool -J

DeLatours Reach -D

Here WUA is expressed as absolute area as opposed to percentage area as in Fig. 22. Comparison indicates that the total extent of suitable habitat is maximal at only slightly higher flows than those which maximize habitat quality.

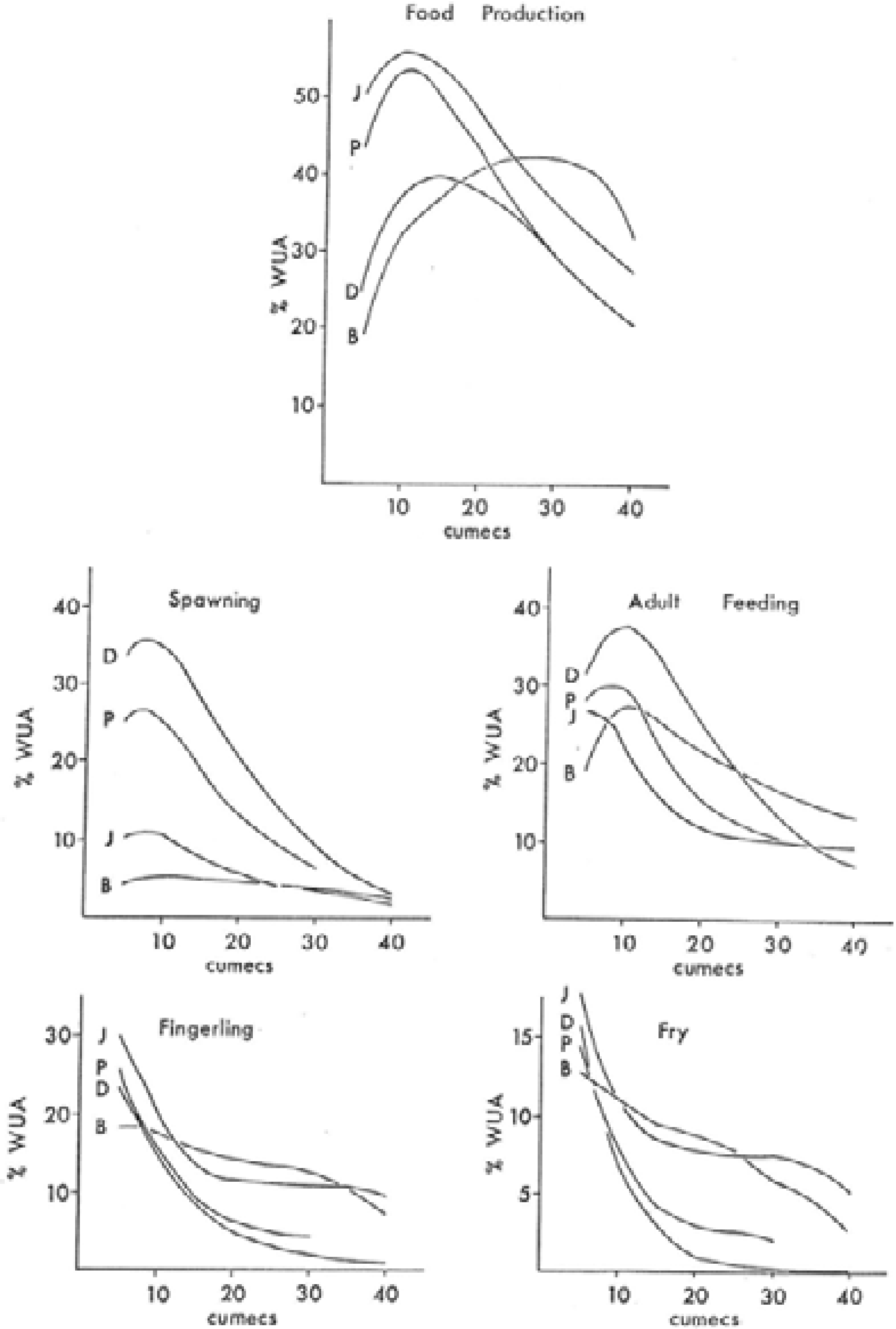


Figure 26. The relationship between flow and habitat for stream invertebrates and four rainbow trout life stages at four sites on the lower Tongariro River.

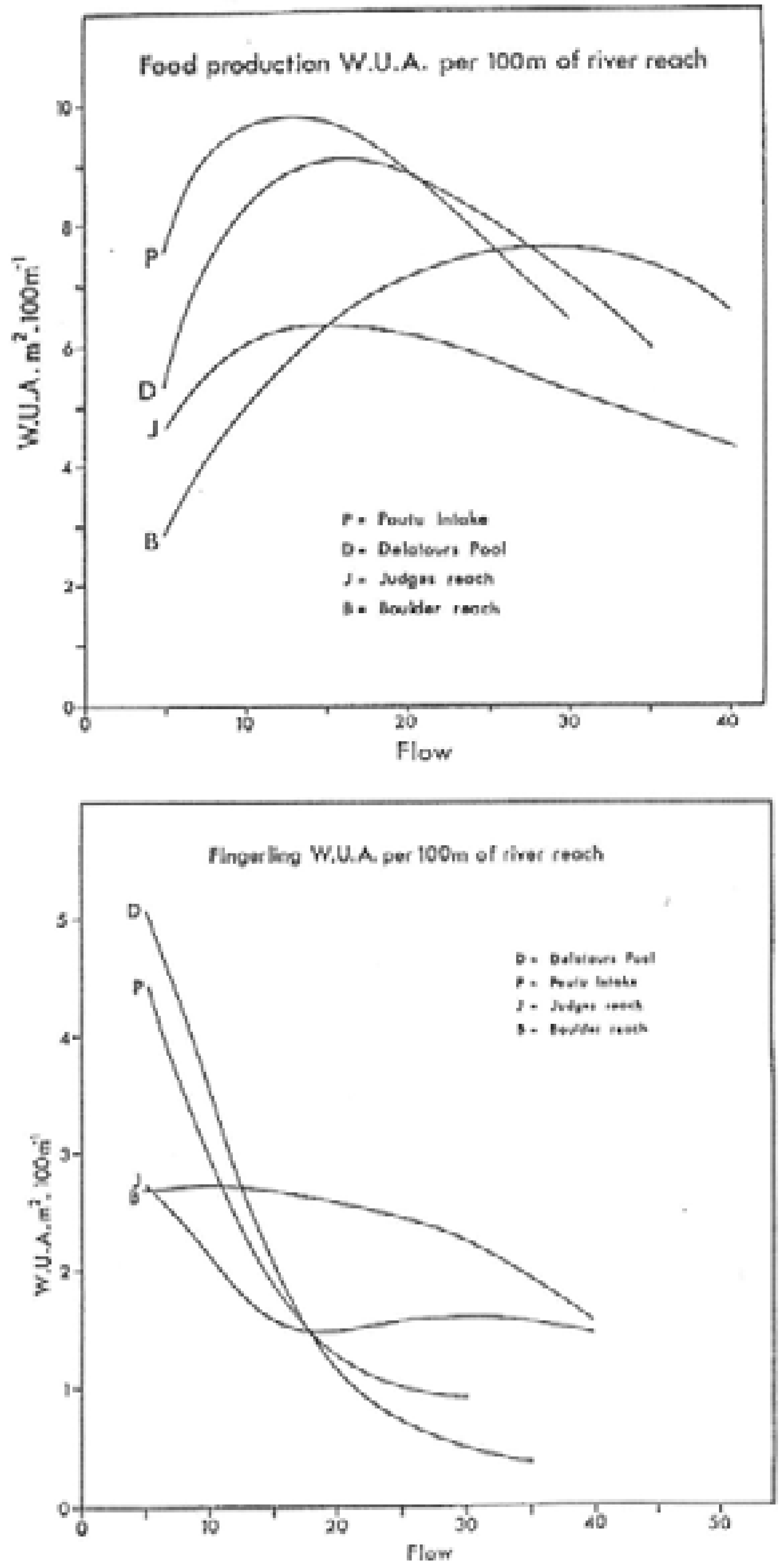


Figure 27. The relationship between flow and WUA for invertebrates and rainbow trout fingerlings at four sites on the lower Tongariro River.

5.3 Binns' Habitat Quality Index

This was used to estimate the carrying capacity of the Tongariro River at several different flows to provide a second guide as to the relationship between flow and trout habitat. The method used nine habitat variables to calculate an index, which was then used in a multiple regression equation to predict standing crop. The applicability of this method to New Zealand rivers is unknown, but model tests on large streams in Wyoming and smaller streams in British Columbia suggest that it is probably suitable for application outside the United States. Two potential limitations on application to the Tongariro River are, firstly, juvenile trout production is of primary concern in the Tongariro River but the model was developed for all trout life stages, and secondly, unlike Wyoming streams, winter ice formation is not a factor influencing the number of trout which the habitat can support.

Parameters used in the HQI model II were mean current velocity, nitrate nitrogen, substrate vegetation, mean wetted width, bank erosion, cover, critical period stream flow, annual stream flow variation and maximum summer temperature. Data for each of the four sample reaches on the lower Tongariro River were obtained from hydraulic modelling (mean current velocity, mean wetted width), by field observation (substrate vegetation, bank erosion, cover, temperature) and from M.W.D. Water & Soil Division (nitrate nitrogen from Schouten *et al.* 1981; flow records from Water & Soil unpubl. data). It was assumed that annual stream flow variation and submerged aquatic vegetation would increase at lower flows. Each parameter was assigned a rating, this being one of five possible values, ranging from 0 (very poor) to 4 (excellent), as described by Binns and Eiserman (1979; Table 3). These rated values (Table 12) were then used in the HQI regression model II:

$$\begin{aligned}\mathrm{Log}(Y + 1) = 1.12085\,\{ & -.903 + .807\mathrm{Log}\,(X1 + 1)\\ & + .877\,\mathrm{Log}(X2 + 1)\\ & + 1.233\,\mathrm{Log}(X3 + 1)\\ & + .631\,\mathrm{Log}(F + 1) + 0.182\mathrm{Log}\,(S + 1)\}\end{aligned}$$

Where:

Y = Predicted trout standing crop
X1 = Late summer stream flow
X3 = Max. summer stream temperature
X7 = Cover
X9 = Substrate vegetation
X11 = Stream width
F = Food index = X3(X4)(X9)(X10)
S = Shelter index = X7(X8)(X11)

X2 = Annual flow variation
X4 = Nitrate nitrogen
X8 = Stream bank erosion
X10 = Current velocity

Table 12. Rating values for the habitat parameters used in the HQI model and predicted standing crop estimates.

POUTU INTAKE

	FLOW (cumecs)					
	5	10	15	20	30	40
X1	4	4	4	4	4	4
X2	3	3	3	4	4	4
X3	4	4	4	4	4	4
X4	1	1	1	1	1	1
X7	3	3	4	4	4	4
X8	4	4	4	4	4	4
X9	3	3	3	3	3	3
X10	3	4	4	4	3	2
X11	1	1	1	1	1	1
F	36	48	48	48	36	24
S	12	12	16	16	16	16
Kg.ha^{-1}	195	233	245	298	250	195

BOULDER REACH

	FLOW (cumecs)						
	15	20	25	30	35	40	50
X1	4	4	4	4	4	4	4
X2	3	3	4	4	4	4	4
X3	4	4	4	4	4	4	4
X4	1	1	1	1	1	1	1
X7	3	3	4	4	4	4	4
X8	4	4	4	4	4	4	4
X9	3	3	3	3	3	3	3
X10	4	4	4	4	3	3	3
X11	0	0	0	0	0	0	0
F	48	48	48	48	36	36	36
S	0	0	0	0	0	0	0
Kg.ha^{-1}	146	146	178	178	149	149	149

JUDGES POOL

	FLOW (cumecs)					
	15	20	25	30	40	50
X1	4	4	4	4	4	4
X2	3	3	4	4	4	4
X3	4	4	4	4	4	4
X4	1	1	1	1	1	1
X7	3	3	4	4	4	4
X8	4	4	4	4	4	4
X9	2	2	2	2	2	2
X10	4	4	3	3	2	2
X11	1	1	1	1	1	0
F	32	32	24	24	16	16
S	12	12	16	16	16	0
$Kg.ha^{-1}$	182	182	195	195	152	91

DELATOURS REACH

	FLOW (cumecs)					
	15	20	25	30	40	50
X1	4	4	4	4	4	4
X2	4	4	4	4	4	4
X3	4	4	4	4	4	4
X4	1	1	1	1	1	1
X7	3	3	3	3	3	3
X8	3	3	3	3	3	3
X9	2	2	2	2	2	2
X10	3	4	4	4	4	3
X11	1	1	1	1	1	1
F	24	32	32	32	32	24
S	9	9	9	9	9	9
$Kg.ha^{-1}$	177	211	211	211	211	177

5.4 Results and Discussion

The HQI model II predicted trout biomass between 150 and 250 $Kg.ha^{-1}$ with maximum biomass at the Poutu intake and Reach sites and at flows of 25 to 30 cumecs (Table 12). Predicted site-related variation and the magnitude of the estimates were not consistent with field observations, and flows at which maximum trout biomass was predicted were somewhat higher than those providing most habitat, predicted by IFIM.

Electrofishing surveys demonstrated that the lowest juvenile trout densities occurred at Poutu intake and at Reach but the HQI model predicted maximum biomass at these sites. This anomaly may have occurred in part because the shelter index is sensitive to substrate vegetation and does not consider substrate composition. Boulders were a major source of shelter at Boulder Reach and at Judges Pool where aquatic vegetation was sparse. This would have resulted in a lower predicted standing crop, particularly for Judges Pool, but would not have explained why the maximum value was obtained where the observed value was lowest.

Samples from electrofishing sites indicated that juvenile trout biomass was in the range of 5 to 50 Kg.ha^{-1} but HQI estimates were 3 to 4 fold higher. The IFIM predicted maximum trout habitat indices at flows from 5 to 11 cumecs, whereas the HQI model predicted maximum trout biomass at flows of 25-30 cumecs. Some anomaly between electrofishing observations and model predictions is to be expected because the HQI model predicts standing crops for all trout, not just fingerlings. Discrepancies between predictions based on the HQI model and on IFIM must be expected because the HQI model is based on a wider range of habitat variables whereas the IFIM uses only three measures of physical habitat.

Nevertheless, these discrepancies suggest that the predictive ability of the HQI model is poor for juvenile trout in the Tongariro River. However, the general conclusion that trout production is likely to be higher at lower flows than would occur naturally was consistent with IFIM results.

One observation corroborated the IFIM results hut also emphasized deficiencies in the predictive ability of the model. There was strong correlation between fingerling density and WUA in the sample reaches (Fig. 28). The relationship seems to be exponential, suggesting that increases in WUA will be associated with a more than equivalent linear increase in fingerling numbers. Thus the assumption that WUA and trout numbers are correlated is supported. However, numbers of trout passing through the Waihukahuka Stream trap have not changed significantly since diversion in 1973. An increase would be expected on the basis of both the IFIM study and the HQI. Pre-diversion composite values (based on mean flows) for fingerling WUA and trout standing crop would have been about 0.81 m^2.m^{-1} of river channel and 161 Kg.ha^{-1} respectively, whilst post-diversion values are 1.41 m^2.m^{-1} and 237 Kg.ha^{-1}. On the basis of the relationship between WUA and fingerling density one would expect a 360% increase in the number of fingerlings present and later in the number of adults returning to the river. If fingerling density is, in fact, only proportional to WUA then a 75% increase would be expected, whereas the HQI model predicts a 47% increase. However, the observed increase since 1975, when the effects of the diversion would be expected to become apparent, was about 16%.

These discrepancies could occur if floods, pollution during construction of Rangipo, unnatural features of the regulated flow (e.g surges, truncated recessions, sediment deposition) impaired fingerling production. These features of the habitat, brought about by the diversion, cannot be accounted for in either model and this deficiency must constrain the predictive ability of both models. Nevertheless, results from these studies do provide some clues as to both how the diversion may have altered trout production in the lower Tongariro River and how trout production could be enhanced. It can be inferred from both models that diversion would have increased the amount of habitat available for trout. The observed increase in trout numbers since diversion suggests that physical habitat space did constrain fingerling production. The finding that the increase in trout numbers was smaller than the

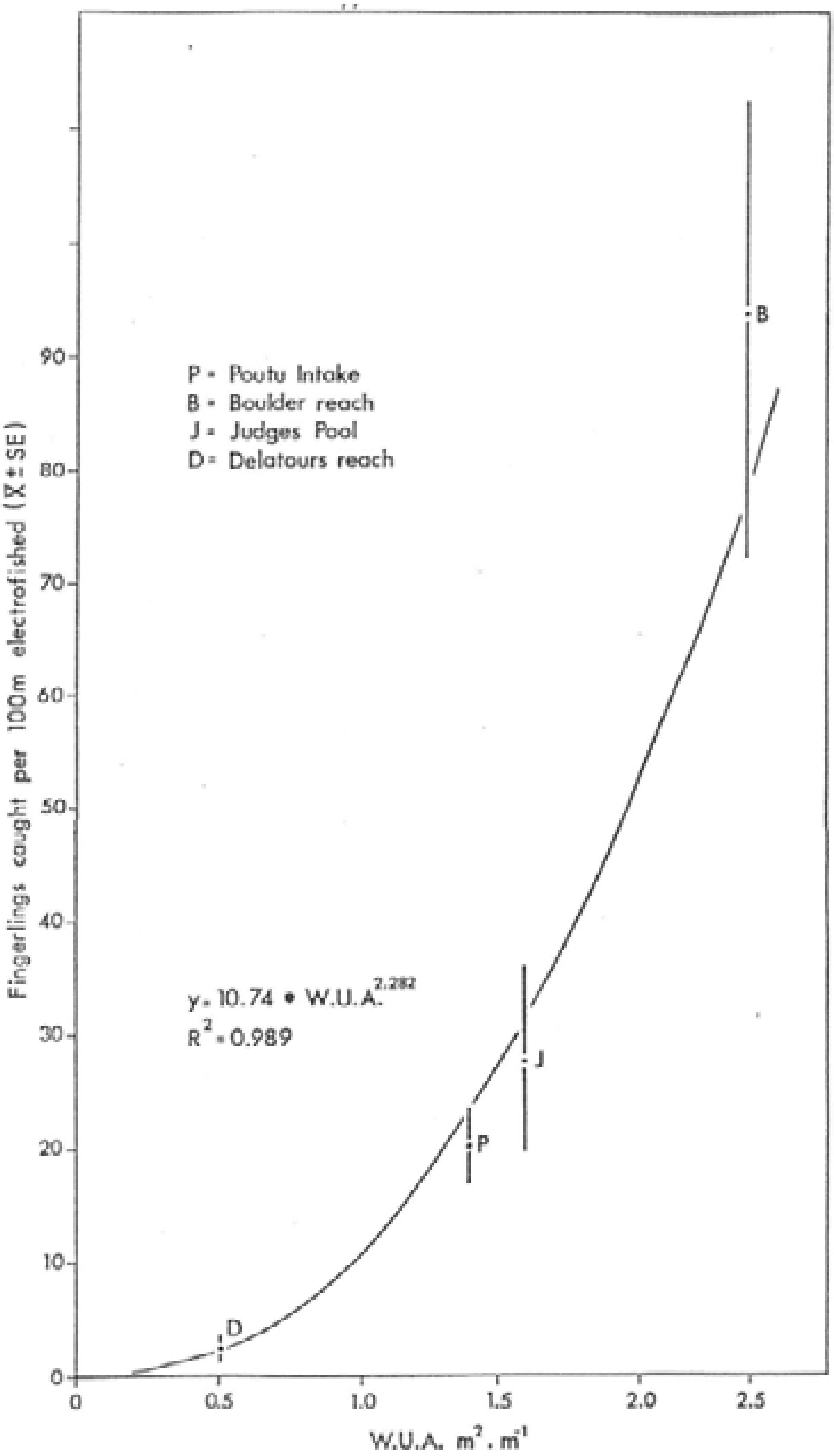


Figure 28. The relationship between fingerling density and habitat area (m^2 of WUA per m of river reach) at four sites on the lower Tongariro River.

increase in WUA implies that other features of juvenile habitat may now affect juvenile production. It seems likely that other features of the habitat which constrain recruitment and growth might become as important as physical habitat space in determining fingerling production. If this is the case then further flow reductions, intended to enhance trout production by increasing physical habitat space will not achieve that objective unless surges, abrupt recessions and sediment deposition can be substantially reduced.

5.5 Conclusions

The optimum flow for trout in the Tongariro River below Poutu intake is about 13 cumecs but in the mid-section of the lower river, where most fingerling production occurs, the optimum flow is between 13 and 27 cumecs. This is equivalent to flows between about 5 and 18 cumecs below Poutu intake. If the low IFIM result for Judges Pool is excluded (and the HQI result preferred) then the optimum flow would be between 13 and 18 cumecs. At lower flows, habitat suitable for invertebrate trout food diminishes, although the amount of space suitable for trout increases. At higher flows, both the extent of invertebrate food producing habitat and habitat for all trout life stages decrease.

Whilst flow reductions will increase the amount of physical habitat space available to trout, associated increases in juvenile trout production can be expected only if physical habitat space is the principal habitat feature limiting trout production.

CHAPTER SIX

RECOMMENDATIONS FOR FLOW MANAGEMENT

6.1 Introduction

The exceptional quality of the Tongariro River trout fishery depends on adult trout being large, numerous and readily caught in a pleasant environment for angling. Flow specifications and sediment management policies required for the fishery are a significant constraint on use of the river for power generation and it seems that flow management rules do not meet needs for power generation, angling or the trout as effectively as they might. In particular, the minimum mean daily flow requirement at Turangi and the restriction on the times for altering gate settings are significant constraints on generation efficiency which offer minimal benefit to the fishery.

Maintaining or increasing numbers of trout running into the Tongariro River will enrich the quality of angling because anglers will both see and catch more trout. There appears to be potential for some increase in the number of trout harvested by anglers as regression modelling of trout numbers entering the Waihukahuka Stream indicated that recruitment to the fishery was controlled by fingerling production, not by parent stock size.

Flow management objectives required to maintain or enhance angling qualities of the Tongariro are:

1 To minimize the frequency, rate and amplitude of surges.
2 To reduce the rate of flood recession.
3 To provide the flow required for maximum fingerling production.
4 To minimize sandy bedload.
5 To provide a flow regime in which trout are catchable.
6 To provide enough flow to satisfy aesthetic considerations.

These objectives are not mutually compatible and some compromises will be required.

6.2 Control of Discharge Fluctuations

Rapid fluctuations in discharge below Poutu intake appear to be a major factor limiting juvenile trout production for about 12 km downstream. Electrofishing surveys indicated that juvenile trout were scarce below the intake and in seemingly suitable places in the gorge downstream. It seemed likely on the basis of these observations and other studies (Irvine 1985, 1986 Ottaway and Clarke 1981, Cushman 1985) that habitat instability caused by artificial flow fluctuations and fine sediment deposition prevented juvenile trout making full use of available habitat in this part of the river. However, there is little evidence to refute the possibility that fry production near Poutu intake was insufficient to ensure full occupancy of available habitat.

There are two changes to present flow management rules which could assist in reducing surges and prolonging recessions:

1 Abolish the minimum mean daily flow requirement at Turangi.
2 Allow gate settings to be changed at any time of the day **and** instigate operation rules such that artificially-induced changes in water level below Poutu intake must not exceed 2 cmh^{-1}.

6.2.1 Minimum Flow at Turangi

The minimum mean daily flow requirement at Turangi causes some surges and is indirectly responsible for the occurrence of particularly low flows below Poutu intake immediately after a flood, with increasingly higher flows as the catchment dries. A more natural flow regime could be achieved if the only minimum flow requirement was an instantaneous minimum below Poutu intake.

At present, the minimum flow below Poutu intake is 11.3 cumecs but the modal flow is between 16 and 18 cumecs (Fig. 29). Flows increase during drought conditions to about 22 cumecs. If the minimum flow below Poutu intake was raised and there was no minimum requirement at Turangi, then a more natural recession would result. However, if the minimum flow was less than about 21 cumecs, minimum flows less than 27.2 cumecs will occur. For example, a 13 cumec minimum would result in occasional low flows at Turangi of around 20 cumecs during droughts. The flow below Poutu Intake would remain close to the minimum for longer periods as there would be no need to release additional water during dry spells. However, these minimum flow requirements would provide an additional 6 to 8 cumecs more water for generation at both Rangipo and Tokaanu power stations during droughts.

The habitat disruption caused by a given magnitude of surge would be more serious at low flows. Therefore, it is important that any change in flow management which results in a lower base flow must be accompanied by rules to control the rate of artificial floods and recessions. Unfortunately, relationships between surge frequency or magnitude and extent of damage to juvenile trout populations have never been quantified and therefore there is no objective basis for defining maximum allowable surge specifications. The suggested maximum of 2 cmh^{-1} is based on the supposition that observed failure to occupy apparently suitable habitat near Poutu intake is more a consequence of frequent minor water level fluctuations (c.a. 3 to 10 $cm.h^{-1}$) than the more unusual major surges. It seems reasonable to expect recolonization after a major surge to occur in the same way as occurs following a flood. Presumably, it is the frequent minor surges which impede recolonization in the gorge below Poutu intake after floods or other major flow perturbations. If this is correct then a maximum surge rule which controls only the major and unusual surges will be ineffectual in increasing trout production below Poutu intake.

Anticipated benefits following abolition of the minimum flow requirement at Turangi are:

1. Increased juvenile trout production, particularly in the gorge below Poutu intake, resulting in greater numbers of trout running into the Tongariro three years after implementation.
2. Reduced incidence of fry strandings and redd exposure.
3. Increased power generation.

6.2.2 Hours for Gate Adjustment

It has been suggested that the present restriction on hours for gate adjustment should not be lifted as this is the only protection available for anglers against surges caused by operator error (M. Raine, NZE, pers. comm.). Nevertheless, in the interests of both the fishery and efficient power generation, it seems more sensible to adjust settings in response to changes in flow rather than in anticipation of flows expected during the following day. Angler safety would be enhanced if a fail-safe system could be incorporated which prevented operators

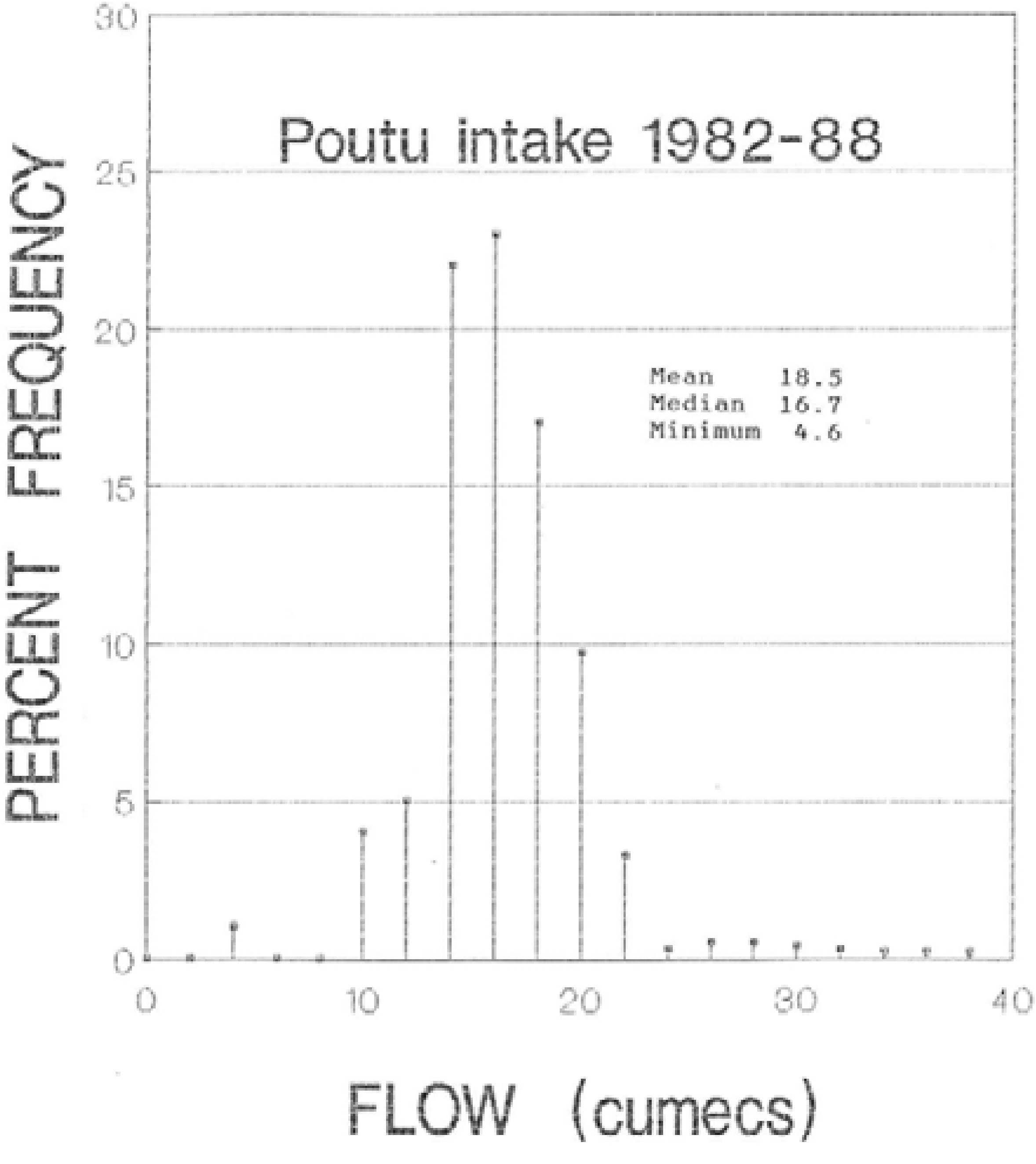


Figure 29. The distribution of flows below Poutu intake (1982 to 1988). Data are the percentage of time that flows are within each 2 cumec flow interval. Thus, flows were between 16 and 18 cumecs for 23% of the time during the six years monitored. (Data supplied by Water Resources Div. of DSIR).

causing water level changes at the stage recorder below Poutu intake greater than 2 $cm.h^{-1}$. Anticipated benefits to the fishery would be derived from reductions in:

1 Rates of artificial floods and recessions.
2 Surge frequency.
3 Surge magnitude.

These changes are likely to increase juvenile trout production as well as allowing more efficient use of available water for power generation. However, whilst it will improve the timing of the operators' response to changes in flow, enabling more efficient power production, it will also restrict the magnitude of their response.

6.3 Minimum Flows below Poutu Intake

Present flows are somewhat greater than those required to provide the greatest extent of physical habitat for trout and their invertebrate food resources. If physical habitat space for juveniles is the principal constraint on production then this could be enhanced by flow reductions. However, it is possible that some habitat feature other than physical habitat space is the principal constraint on production, even in years in which there are no major summer floods. This possibility increases at lower flows as suitable physical habitat becomes more extensive because as habitat becomes no longer limiting, something else becomes limiting. One possibility is that if juvenile habitat space became less limiting, invertebrate food production might become more limiting. It is therefore important to ensure that space for invertebrates is not reduced.

Maximum WUA for invertebrate food production in the lower Tongariro River occurs when the flow below Poutu intake is about 10 cumecs but total WUA varies little for flows between 8 and 15 cumecs (Fig. 30). A 10 cumec flow below Poutu intake (max. invertebrate WUA at 13 cumecs) would provide about 18 cumecs at Boulder Reach (max. invertebrate WUA at 27 cumecs), about 22 cumecs at Judges Pool (max. invertebrate WUA at 13 cumecs) and about 23 cumecs at Pool (max. invertebrate 16 cumecs). This suggests that if the minimum flow below Poutu intake were 8 cumecs then space for invertebrate food production would not be less than it is at present flows. However, invertebrates would fully utilize available habitat only if colonization were unimpeded by sand deposition and frequent flow perturbations.

Whilst this reduction in the compensation flow might benefit trout production and electricity generation, such a low flow may be inappropriate for angling, could be aesthetically unsatisfactory and will often be too low for rafting. Furthermore, the HQI model indicated that maximum trout production would occur at higher flows.

6.3.1 Requirements for Angling

Regression analyses indicated that catch rates were little affected by variation in half-daily mean flows. However, annual catch rates declined after diversion and it seemed that trout became less catchable after diversion. It is therefore possible that effects of long term flow variation on catch rates are quite different from the short term variations considered in the field study. Unfortunately, this hypothesis remains untested. In view of the need to understand what the implications of flow management policies will be for catch rates it is recommended that further research be undertaken to clarify relationships between flow and catch rates.

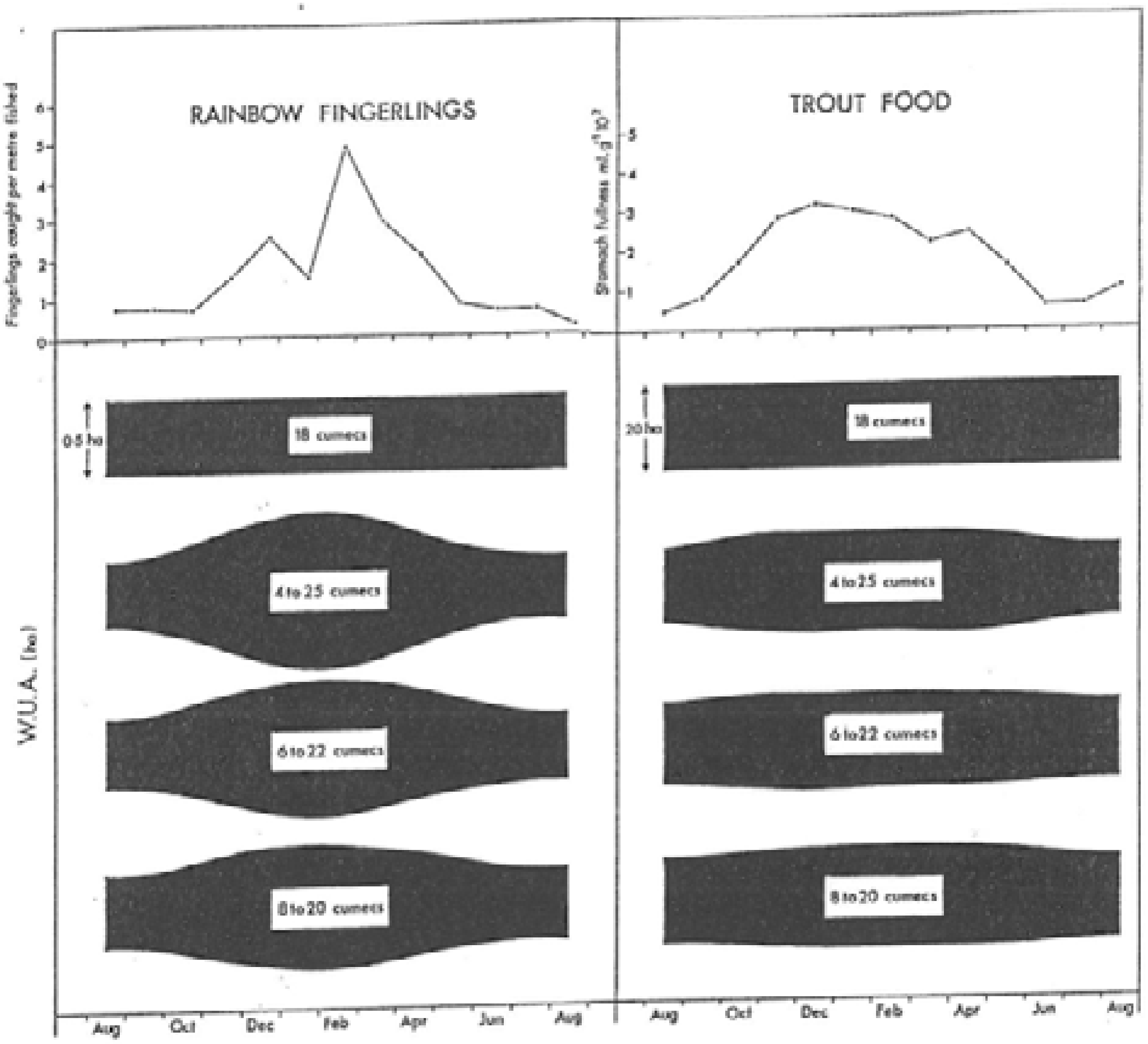


Figure 30. Predicted relationships between seasonal variation in flow and habitat for both rainbow trout fingerlings and their invertebrate food resources.

The top panels illustrate seasonal patterns of juvenile trout abundance and feeding between August 1984 and August 1985. These patterns indicate that if the flow regime were to be tailored to meet the requirements of juvenile trout then minimum flows should occur between January and March. This would extend the amount of habitat available to them at the time of year when they need it most.

The blackened areas in the lower panels illustrate how the amount of habitat for juvenile trout and invertebrates would vary under different ranges of seasonal variation in flows. The flow figures in the centre of each panel refer to the flow below Poutu intake and it is assumed that tributary flows between Poutu intake and Turangi provide a further 10 cumecs. The top illustration shows the amount of habitat available when the compensation flow is constant all year and the lower three panels indicate the amount of habitat when the compensation flow varies in a simple sinusoidal fashion, being maximal on July 31 and minimal on January 31.

6.3.2 Recommended Flows

The flow management policy likely to be most compatible with trout production, angling, rafting, aesthetics and electricity generation is for higher flows to be permitted during the winter angling season (May to September) with lower flows during summer and autumn. Higher winter flows would reduce accumulation of sand and periphyton, would provide for rafting and aesthetic considerations, and so could be expected to win popular approval whilst having little impact on juvenile trout, which make minimal use of the river during winter. During spring and summer, lower flows will extend physical habitat for juvenile trout and might compensate for lost generation capacity in winter when higher compensation flows are required. A minimum compensation flow below Poutu intake which varies from month to month is given in Table 13 below and simulated relationships between differing ranges of variation in flow, observed use of the river by rainbow trout fingerlings and WUA are illustrated in Fig. 30. These simulations suggest that substantial ranges of variation between seasonal flows will have a major impact on the extent of juvenile WUA but would not cause much change in invertebrate WUA. If the growth rates of juvenile trout are influenced by the number of trout sharing the available food resource then it is possible that increases in the amount of trout habitat relative to food producing habitat might result in depressed trout growth.

Table 13. Proposed instantaneous minimum compensation flows (cumecs) below Poutu intake.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
13	13	14	15	16	17	18	18	17	16	15	14

In view of the fact that the present flow regime is adequate to sustain an exceptional fishery and that there is some uncertainty regarding apparent relationships between flow, fingerling production and catch rates, it would be rash to implement immediately a variable flow regime with substantial seasonal variation as in Fig. 29. A more prudent approach would be to implement a lesser range of variation, as in Table 13, or alternatively, to maintain a minimum flow of 15 cumecs which is similar to that currently provided (Fig. 29). This, together with changes to flow rules and management procedures which reduce sand deposition, surges and particularly rapid recessions should enhance trout production. Baseline monitoring data on trout numbers and catch rates should be collected for at least five years as any response would not be complete for at least three years after implementation. Further adjustments may be considered desirable in the light of this assessment.

In the meanwhile it is recommended that:

1. The minimum flow requirement at Turangi be abandoned.
2. The minimum flow below Poutu intake be adjusted monthly as in Table 13.
3. Catch rates and numbers of trout running into the Tongariro River are monitored.
4. A research project is implemented to elucidate mechanisms affecting the relationship between catch rates and flow.

This flow regime will be adequate for rafting and will extend the amount of physical habitat suitable for trout, particularly below the Whitikau Stream confluence.

6.3.3 Discussion

Abolition of the minimum flow requirement at Turangi and raising the minimum flow below Poutu intake (to anything less than about 21 cumecs) would reduce flows throughout the lower Tongariro River during dry conditions. Low flows of 18 to 20 cumecs at Turangi could be expected during summer droughts if the summer minimum flow below Poutu intake were 13 cumecs, as proposed (Table 13). However, flows would be greater than at present when flows in the lower tributary catchments are high. If the above flow management recommendations are adopted, the recession will be more stable, the natural relationship between flow (below Poutu intake) and rainfall will be restored and sediment transport will be more efficient. These changes are expected to enhance both the quality of the Tongariro River as habitat for trout and to raise fingerling production, together raising the number of trout available to anglers both in Lake Taupo and in the Tongariro River. In addition, these two changes will significantly increase power generation at both Rangipo and Tokaanu power stations, particularly during dry spells.

Whilst even lower minimum compensation flows than those proposed would further increase both generation capacity and physical habitat for juvenile trout, lower flows would probably be considered aesthetically unsatisfactory and would increase the likelihood of introducing new constraints on juvenile trout production. Rafting becomes difficult at flows less than about 13 cumecs below Poutu intake and consequently lower summer compensation flows, when the river is most used for rafting, would not be favourably received by rafters. Lower summer flows may lead to higher summer water temperatures, but the risk of temperatures becoming too high for trout, whilst not quantified, is thought to be negligible. It is nevertheless recommended that water temperatures be monitored when flows are low during hot summer weather. If the water temperature seems likely to exceed 22.0 deg.C. at Turangi and water temperatures are cooler at Poutu intake then more water should be released into the lower river. It should be noted that juvenile rainbow trout can grow rapidly at temperatures approaching 20 deg.C. If higher water temperatures increase the growth of juvenile trout, this could raise their size on entry to Lake Taupo or abbreviate their life in the river. Either result would be likely to improve survival and recruitment to the fishery.

A greater compensation flow would probably be aesthetically more pleasing, more satisfactory for rafting and might slow upstream migrant trout, thereby making fresh run trout available to anglers for longer. However, it would cost generation capacity, and decrease the physical habitat space suitable for all trout life stages. Thus until relationships between catch rates, migration and flow are clarified, there appears to be little justification for higher flows than those proposed.

Monthly adjustment of the compensation flow to give a seasonally variable minimum flow has three advantages over a constant minimum flow. Firstly, the flow variation is likely to decrease accumulation of sand and periphyton. Secondly, it will increase juvenile nursery habitat at the time when there is most demand for it and thirdly, it will give anglers higher flows during the angling season which is what they seem to want. However, the processes affecting the relationship between flow and catch rate are not understood, nor is it clear whether flow reductions to increase physical habitat for juvenile trout will also enhance juvenile trout production. In view of these uncertainties, it seems sensible to implement conservative seasonal variation in the minimum compensation flow.

6.4 Flows through Rangipo Power Station.

Management of flows through Rangipo power station has to give due regard to the downstream effects of sudden cessation of tailrace discharge. Typically, a negative surge occurs first and is followed by a steep positive surge, the former being destructive to the biota, the latter hazardous for anglers. At present, the most dramatic surges are prevented by ensuring that tailrace discharge never exceeds the flow diverted to Lake Rotoaira. However, despite this rule, major surges can happen if failure occurs when tailrace discharge is large compared with the compensation flow below the intake. Furthermore, this rule costs significant generation capacity at Rangipo power station, particularly under low flow conditions.

There appear to be at least two solutions to this problem, but neither, because of its cost, is palatable:

1. To add further restrictions to the present operating rule such that:
    a) Tailrace discharge must never exceed diverted flow.
    b) Tailrace discharge must not exceed a specified proportion (e.g. 80%) of diverted flow when the flow below Poutu intake is low, perhaps less than 15 cumecs.

2. To build a dam and impoundment below Poutu intake designed to buffer upstream discharge fluctuations and contain sediment between major flood events so that all available water can be passed through Rangipo power station without risk to the fishery.

The first solution would further constrain generation capacity at Rangipo power station and is hard to justify because:

a) Evidence to demonstrate that these surges have significant detrimental impacts on the fishery is by inference only.
b) Unexpected failures are likely to become uncommon as experience with managing Rangipo increases.

The second solution would be a multi-million dollar project which would cause short term environmental problems but would allow both Rangipo and Tokaanu power stations to generate from all available water with minimal risk to the lower Tongariro fishery. It would seem that this solution would serve the best long term interests of both the fishery and the wider community if gains from increased electricity generation are sufficient to justify the capital cost of a third dam on the river. However, the economics of this are unknown. If this option is not feasible, gains from electricity generation will probably outweigh risks to the fishery if the existing rule limiting flows through Rangipo power station remains in place and unaltered.

A third solution, which is not recommended, would be to increase the capacity of the bypass tunnel so that its capacity equals that of the tunnel. However, this approach would offer no protection from equipment failures upstream of the powerhouse (e.g. headrace valve).

6.5 Flows below Rangipo Dam

The 0.6 cumec instantaneous minimum flow below Rangipo dam provides about 8% of the flow at Beggs Falls during average flows and about 24% of the flow in low flow conditions. Whilst this part of the river supports a rainbow trout population, it receives little attention from anglers and it seems unlikely that the 0.6 cumec residual flow is a significant factor maintaining the trout population. The section of the river between Rangipo dam and Poutu intake has been the most severely altered by the power development and there has never been any commitment to provide adequate flows to maintain a fishery in this part of the river. Such minimal fisheries interests as do exist would not be greatly impaired if this residual flow were abolished to increase generation capacity at Rangipo power station during low flow conditions. However, it has been suggested that a residual flow between Rangipo dam and the Pangarara stream confluence may be instrumental in maintaining the blue duck population between Rangipo and Poutu intake (Williams and Adams pers. comm.) Thus, on the basis of blue duck requirements, the 0.6 cumec residual flow should remain. However, on the basis of fisheries interests alone, the residual flow should be abolished.

6.6 Sediment Management

Practically all food organisms for river dwelling trout live amongst boulders and gravel. Sand substrate, particularly moving sand bedload is considered to be the poorest substrate for habitation and production of benthic food organisms (Hynes 1970). If the interstices between the stones become filled with sand, trout food production is reduced and the quality of juvenile trout habitat deteriorates. Alexander and Hansen (1986) found that sand concentrations of only 80 ppm had a profound effect on brook trout and their habitat. Population adjustment was via changes in rates, particularly in the juvenile stages of their life cycle. The growth rate of individual fish was not affected. Hansen *et al*. (1983) demonstrated that an instream sediment trap improved streambed composition and the quality of fish and invertebrate habitat. Sandy sediment was reduced by 86%, numbers of juvenile brown and rainbow trout increased by about 40% and older trout by 28% (Alexander and Hansen 1983). Thus it is in the best interests of the Tongariro fishery for flows and elements of the power scheme to be managed in a manner which minimizes fine sediment deposition.

6.6.1 Rangipo dam

Rangipo dam is a settling pond designed to remove all and much of the suspended sediment from the flow diverted through Rangipo power station. The sediment remains in the impoundment until the sluice gates in the base of the dam are opened and the lake partially drained to scour accumulated sediment into the river below the dam. At normal flows, this sandy material accumulates in the lower river as but at flood flows it is transported through the lower river as suspended load (M.W.D. 1980). In view of the habitat degradation caused by deposition of sandy bedload, it is desirable that scouring operations should be undertaken in a manner which ensures that sandy does not accumulate in the lower Tongariro. To this end, it is necessary that procedures recommended by M.W.D. (1980) be adopted and it is suggested that rules for flushing Rangipo dam be as follows:

1. The Rangipo sluice gates can be opened only when the flow below the dam exceeds 80 cumecs.
2. The Poutu tunnel must be closed not more than two hours after opening the Rangipo sluice gates.

3. The water level in the dam can be lowered if the Moawhango valve is fully open and the flow below the dam exceeds 100 cumecs.
4. The sluice gates should be closed slowly, so that the impoundment takes a minimum of twelve hours to fill.
5. Diversion of water into the Rangipo tunnel should not commence until 12 hours after the sluice gates have been fully closed.
6. The Poutu tunnel must not be re-opened until the water clarity is about 1.0 m at the Birch Pool (Tongariro Hatchery). This assessment should be made by Department of Conservation field staff.

These rules should ensure that scouring operations are expedited efficiently, that flows downstream are not disrupted and the sediment is transported down the lower river and is not deposited in the Poutu canal, Lake Rotoaira or in the lower Tongariro River.

6.6.2 Poutu Stream

The Poutu Stream supports both resident and migratory rainbow trout, the latter penetrating upstream some 600m to Poutu Falls. The resident population is largely inaccessible and receives little attention from anglers.

The power scheme has changed the source of the water in the stream, reduced the flow, increased its variability and introduced a new source of sediment. Sediment supply has increased but transport capacity has been reduced. A compensation flow of 0.6 cumecs is released from a valve in the Poutu canal and this carries sediment from the Tongariro River, particularly when the Tongariro is in flood. This valve is also used to drain the canal.

The compensation flow is often increased to provide the required minimum flow at Turangi whilst also maximizing the flow through Rangipo power station. This practice, which contributes to short term-flow variability both in the Tongariro River and in the Poutu Stream, would become unnecessary if the minimum flow requirement at Turangi were abandoned.

Angling values could be enhanced if:

1) The valve in the dam face be used to supply the compensation flow. This should be modified so that water is drawn from near the surface of the Rotoaira canal to prevent entrainment of sediment deposited near the dam face. The intake should be fitted with a screen and enclosed in a cage to ensure the safety of swimmers.

2) In accordance with present policies, sediment from the Poutu canal should be mechanically excavated and not allowed to enter the Poutu Stream.

3) A sediment trap, as described by Hansen *et al.* (1983) should be constructed immediately below the Poutu dam to collect sand and silt for mechanical removal.

4) The compensation flow should remain at 0.6 cumecs. When the streambed stabilises after the reduction in sediment supply an habitat survey should be undertaken to determine a more appropriate compensation flow for trout and for angling.

Control of sediment supply to the Poutu stream from the Tongariro River will increase trout production and should result in improved returns of adult trout to the lower part of the stream. However, it should be noted that these rules will significantly increase the cost of maintaining the Poutu canal.

6.6.3 Maintenance Programmes

Annual inspection and maintenance of power scheme components has generally taken place during February and March, which is within the period that the trout population is most sensitive to perturbations affecting juveniles in the river. Some activities, such as dewatering and sediment removal from Poutu canal, Rangipo dam, or Rotoaira channel cause turbidity, silt deposition or flow fluctuations in the lower Tongariro River. Since these activities are likely to have most impact on recruitment to the fishery if they take place in summer and early autumn, it is recommended that inspection and maintenance procedures which are likely to cause flow fluctuations, increased turbidity or sediment deposition in the lower Tongariro River be avoided from December until the end of March. Such activities should also be avoided between June and November when the river is most used by anglers. However, the study of factors affecting trout numbers suggested that habitat perturbations during this period would have less impact on the trout population.

6.7 Fishery Management

The goal for fishery management in the lower Tongariro River is to maximize angling opportunity and key components of the pleasure experienced through angling. However, both managers and anglers are hesitant to liberalize restrictions on angling which might increase the total catch. Similarly, anglers usually express concern whenever any innovative angling methods or more efficient equipment seem to result in improved angling success.

Results from this study indicate that such concerns are not fully justified as it seems that less than half of the returning adult trout were needed to supply enough offspring to utilize fully all available fingerling habitat. of spawning trout in the Whitikau, Waipa and Waihukahuka streams, as well as in parts of the Tongariro River, indicated that redd superimposition was commonplace. Thus there seemed to be more breeding adults than spawning habitat for them or nursery habitat for their progeny. On this basis, it seems that greater catches would be sustainable and therefore further restrictions on permissible equipment, duration of the season or extent of open waters are not justified, and that liberalization of the open water restriction to provide opportunity for uncrowded angling will not pose a threat to the fishery. However, escapement from the fishery is unknown and it will become more important to ensure there is adequate escapement as angling pressure increases.

The size of the adult trout population was thought to be greatly affected by the extent of nursery habitat for juveniles. Thus biological management aimed at increasing the amount and quality of nursery habitat will be the most effective means of producing more trout. Similarly, management efforts aimed at protecting existing stocks should give high priority to maintaining access for upstream migrants to tributary headwaters. Problems with impassable culverts and log jams, as occur in the Whitikau grotto, should be remedied promptly.

At present, migratory Taupo trout cannot penetrate the Puketarata, Waikoko or the headwaters of the Waipa Stream. Nursery habitat available in these streams appeared to be of a similar quality and extent to that available in the Whitikau Stream. It seems likely that if this habitat were available to Taupo trout through provision of fishways or fry liberations, ova planting or relocation of adult trout, then subsequent runs of adult trout could be increased. The first of these options would be the most expensive in the short term, whilst the other options would have to be undertaken annually as they do not allow for the return of adult trout. Any such enhancement projects undertaken upstream of the Poutu intake would also increase recruitment to the Lake Rotoaira fishery.

There may be some grounds for concern regarding the temporal distribution of angling effort and harvest. General field observations during the course of angling data collection suggested that angling effort and catch were considerably higher early in the season (April to June) than towards the end of the season (October to November), when the trout appeared more numerous. The largest and best quality trout seemed to be caught early in the season, before August, whereas ripe trout and kelts predominated later in the season. It is likely that the early-run fish are genetically distinct from the late-run trout (Mylechreest unpubl. data) and so the combined effects of angling and redd superimposition may select against this more desirable component of the trout population. In view of this, and the need to provide opportunity for uncrowded angling, it is recommended that steps be taken to promote angling during spring rather than in autumn.

6.8 A Checklist and Sequence for Implementation

The following recommendations should be implemented as a package, simultaneously and as soon as possible:

1. Abolition of the minimum flow requirement at Turangi.
2. Raise the minimum flow requirement below Poutu intake to 15 cumecs or implement a conservative monthly variable minimum flow as in Table 13.
3. Adopt the maximum surge rule so that artificially induced fluctuations in water level do not exceed 2 $cm.h^{-1}$ at the stage recorder below Poutu intake.
4. Abolish the restriction on hours for flow manipulation.

Recommendations to be implemented as soon as possible but not necessarily simultaneously are:

1. Obtain comment regarding feasibility of building a dam and impoundment so that all available water can be passed through Rangipo power station without risk to the fishery.
2. Modify the compensation valve in the Poutu dam.
3. Construct a sediment trap immediately below the Poutu dam.
4. Consider abolition of the 0.6 cumec compensation flow released from Rangipo dam.
5. Adopt rules developed by M.W.D. (1980) for flushing sediment from Rangipo dam.
6. Ascertain angler's views regarding the closed season in the Tongariro River upstream of the Whitikau Stream confluence.

Recommendations for further information required to improve management of the Tongariro River fishery are:

1. A study to assess the influence of flow on trout migration and catchability.
2. A study to establish the relationship between numbers of trout running into the Waihukahuka Stream and numbers running into the Tongariro River.
3. An assessment of the effects of new flow management practices on the fishery.
4. A monitoring programme to elucidate trends in annual harvest of trout in the Tongariro River.
5. A monitoring programme to elucidate trends in numbers of trout running into the Tongariro River.

When the research projects are finished and sufficient baseline data from the monitoring programme are available, further adjustments to the flow regime may be appropriate.

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APPENDIX ONE

PREVIOUS RECOMMENDATIONS FOR DESIGN AND OPERATION

1.1 Introduction

There have been five significant reports dealing with fisheries aspects of the Tongariro Power Development. The first (Hobbs 1958) offered general predictions as to the likely consequences for the various fisheries affected. The second report (Woods 1964), based on a detailed study of these fisheries, provided recommendations on fisheries management and design and operation of the power scheme. In 1973 the Electricity Department and Ministry of Works produced an Environmental Impact Statement for the Rangipo power project. The Commission for the Environment audited this statement, drawing attention to some environmental hazards associated with the project. Finally, the Ministry of Works released a series of papers (M.W.D. 1980) which examined flood routing and sediment management to develop recommendations for operation of the power scheme. It is relevant to examine these reports because they draw attention to key issues regarding the design and operation of the power scheme.

1.2 Hobbs 1958 - Notes on Fisheries Aspects of the Tongariro Power Development

This was a confidential report from the Marine Department to the Commissioner of Works providing a preliminary assessment of the impacts of the power scheme. It is of interest because it develops the key principle of power scheme development with minimum detrimental impact on the fishery. Hobbs observed that "**The striking increase in demand for electricity is not, in terms of growth, any more remarkable than the increase in demand for angling**" and so considered "**It is imperative that the new hydroelectric undertaking be integrated with rather than developed at the expense of freshwater fisheries. To the extent feasible, the two needs must be reconciled.**" Hobbs concluded that "**If the Hydro-electric authority shows a sympathetic appreciation of fishery needs, there is no reason why, without undue expense or serious hurt to the hydro-electric undertaking, the scheme of works should not be so developed as to prove beneficial on balance to freshwater fisheries.**"

1.3 Woods 1964 - Fisheries aspects of the Tongariro Power Development Project

There have been three studies to assess the impact of the power project and to offer some guidance for its operation. The first, by Woods (1964), examined the fisheries in the Tongariro River system, the headwaters of the Moawhango River, Whangaehu River and Wanganui River before construction commenced. He calculated that the proposed reduction in the natural base flow in the lower Tongariro River from about 52 cumecs to about 27.5 cumecs would result in channel width reductions of 2-7% and shallowing by 10-20 cm, but he did not expect these changes to have any major impact on the Tongariro River fishery. He also predicted that "**Fish may 'scare' more easily and be harder to hook.**" and "**Angling conditions would alter, possibly requiring lighter tackle and modified techniques".** He also recognised that the river's capacity to transport sediment would be reduced, little sediment would be diverted with the flow but sediment supply would continue as before. He therefore offered some specific guidelines for compensation flow management, proposing a seasonally variable compensation flow below Poutu intake ranging from about 6 cumecs in winter to nearly 16 cumecs in the autumn (Table 1), with regular pre-programmed freshes to "**clean the shingle**", "**create a narrower and deeper channel**", and "**to move fish into the river on spawning runs leaving them distributed in the river for the angler**". The reasons for the chosen pattern in base flow are not given.

Table 1 Monthly minimum compensation flow requirements (cumecs) below Poutu intake as recommended by Woods (1964).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
15.6	11.6	13.3	15.9	15.9	6.2	5.9	5.9	8.8	10.2	10.2	13.0

This was the first of five management recommendations. The others were that "**no action should be taken to prevent eels from reaching Lake Taupo**", that "**the flow of the Whangaehu River (mainstream) should not, in full or in part, be diverted into the power scheme area.", that "no food fish should be introduced into the new Wanganui Reservoirs until the threadworm (*Eustrongylides ignatus*) in Lake Rotoaira is under control**." and finally that "**no action involving construction work should be undertaken during the few years following the first deviations of flow**." Of these, only two recommendations have been adopted (those regarding the Whangaehu River diversion and food fish liberations into the Wanganui Reservoirs). The others have been ignored.

Recommendations regarding the size and frequency of artificial floods were not adopted because there were subsequent modifications to the proposed design which removed the storage capacity necessary for creation of artificial freshes. However, it is not clear why the seasonally variable flow regime was not adopted. Similarly, it is not clear why eels were considered sufficiently threatening to the fishery to justify the expensive barriers at Moawhango dam and the Wairehu rotary screens. Woods' recommendation that construction work should cease for a few years following diversion was impractical and his reasons for giving this advice are vague. Perhaps of most significance was Woods' failure to examine his underlying assumption that the number of adult trout running into the Tongariro River is determined by the number of eggs spawned and fry reaching Lake Taupo. It seems dangerously presumptuous to design a flow regime to enhance spawning and fry production without demonstrating that fry can flourish and grow in the lake. However, his recommendation that further research would be necessary to refine knowledge of the flow requirements for the lower Tongariro fishery was pertinent.

1.4 Environmental Impact Statement

In 1973 an Environmental Impact Statement for the Rangipo power Project was released. The authors (Power Division of M.W.D. & Development Division of the Ministry of Energy) indicated that the greatest impact on the river environment would be the reduction in flow down the Tongariro River between Rangipo dam and the Poutu intake. In view of this the Nature Conservation Council recommended that a minimum flow of 0.6 cumecs should be released from the dam to the river at all times. Undesirable impacts on river fauna would be exacerbated by high flows during floods or when the power station is shut down. The authors point out that "**In the latter case the flow will be the present Upper Tongariro flow plus the diverted flow from the Moawhango. This makes it unlikely that any fishery of consequence could be maintained, in view of the elevation of the area and the impact of the flow ranges on the flora and fauna of the stream bed. To a certain extent the fishery value above the Rangipo dam will also be reduced.**"

No impact on the Lower Tongariro fishery was expected to result from normal operation of Rangipo power station, but it was acknowledged that an unexpected shutdown would cause a shortfall in the compensation flow in the Lower Tongariro River. This is because if the power station "trips out", the flow of water through the station would stop and water would start to spill down the Tongariro River at Rangipo dam, taking 2-3 hours to reach Poutu intake. For this 2-3 hour period, only the residual flow coming over Begg's Falls would be available to provide the compensation flow. Under normal flow conditions this would be about 6.8 cumecs but under dry conditions the flow would be only 2.3 cumecs. The authors then state that "**In this event the intake would be operated so that all water reaching it was initially channelled down the lower Tongariro.**" An investigation was made into the probability of unexpected shutdowns and it was concluded that the likelihood of complete shutdown was one occurrence in 25 years. The authors anticipated plant failures during the first few weeks of operation and therefore "**recommended that during this period, the bypass flow down the upper Tongariro be kept sufficiently large to prevent a change in the lower Tongariro flow should the station go off line suddenly**.'' This has been partially incorporated in the 'Interim Operating Rules -1979' which states that "**the flow through Rangipo power station shall not exceed the flow diverted into the Poutu tunnel**." To achieve this, water is often spilled from Rangipo dam and generation capacity is sacrificed. However, it should be noted that this rule does not prevent disruption of the compensation flow, it only reduces the magnitude of disruption.

Whilst the Environmental Impact Statement provided a useful assessment of likely impacts of the power scheme, certain problems were either underrated or unforeseen and detailed operational procedures were lacking. In particular, it was not pointed out that surges associated with gate changes are detrimental to juvenile trout (cause stranding, particularly at night) and major surges could pose a threat to anglers and so would have to be restricted to a three hour time slot when the river is closed to anglers. Ramifications of this have been considerable. Gate changes have to be made in anticipation of flow conditions in the following 24 hours, freshes arriving outside this time slot cannot be used fully for power generation and artificial flow variations occur at a greater rate than would be necessary given continued gate operation.

1.5 Audit of the Environmental Impact Statement

The Commission for the Environment audited this statement and expressed concern regarding the effects of siltation and artificial fluctuations in the compensation flow. The Commission recognised that the lower Tongariro fishery functions as a migration channel and nursery for trout and that nursery habitat is very susceptible to siltation and changes in water level. The authors considered that siltation "**problems will arise because of the diversion of water from the Tongariro into the Poutu tunnel**" and that "**it seems likely that there will be a build-up of material at the Rangipo diversion which would be swept down the upper Tongariro at times of high flood and the volume deposited in the bed of the lower Tongariro will therefore be greater if Rangipo is developed**,'' The authors then comment on artificial fluctuations in the flow: "**Other than the effect on bottom substrate of the deposition of materials brought down by floods the main threat to the fishery will be fluctuation in river levels resulting from the operation of the station.**'' The Commission failed to recognize other sources of equipment failure which can cause shortfalls in the compensation flow in the lower Tongariro and although calculations for estimation of the probability of fault occurrence were checked by the D.S.I.R., the actual frequency of flow disruption was grossly underestimated. Nevertheless, considerable emphasis was given to investigating a system to bypass the powerhouse, although there was no recommendation for investigation into other ways to control surges in the lower Tongariro. The bypass was constructed as suggested but it has failed to prevent artificial surges in the lower Tongariro. In practice, unexpected failures which cause compensation flow disruption have occurred several times a year and it has not proved possible to adjust the Poutu tunnel gate to preserve the compensation flow (as suggested in the Environmental Impact Statement). There are two reasons for the latter problem. Firstly, appropriate adjustment is dependent on good judgement and swift action by the station operator, which cannot be guaranteed, and secondly, because of the danger which inappropriate gate adjustments could pose to anglers, there is an operating rule which permits gate changes only between 2300 hrs and 0200 hrs so that associated surges will occur only outside legal angling hours.

1.6 M.W.D. 1980 - Sediment & Operation of Poutu, Rangipo and Lake Rotoaira

In 1980, the M.W.D. released a series of papers by Dawson, Riddell, Jowett and Jones which examined flood routing and sediment management and provided guidelines for operation and management of Rangipo dam, Poutu intake, Poutu dam and Lake Rotoaira. Jones pointed out that in the Tongariro River, sediment supply continued as before but diversion had reduced the ability of the river to transport it. However, the natural pattern of sediment movement has been interrupted by the Rangipo dam where sediment accumulates until it is removed during flushing operations. Flushing has been undertaken only twice to date, but M.W.D. studies indicate that this could take place 4-6 times annually once the lake bed has developed a stable profile, which is expected to occur by 1987-88. Recent Electricity Division studies (Raine pers. comm.) indicate that, whilst flow conditions suitable for flushing occur several times each year, the dam needs to be flushed only once every 2-4 years.

Since flow diversion reduces the river's transport capacity, releases of sediment from the impoundment should be confined to periods of sustained high flow to ensure that this material is transported through the system and not deposited within it. The M.W.D. (1980) showed that the scouring operation should take 3 to 12 hours and is most efficiently expedited when the sluice gates are fully opened, the water level in the impoundment is lowered, all diversions cease, but discharge from the Moawhango tunnel continues. These measures ensure that the complete Tongariro flow and water from the Moawhango tunnel will be available to flush the sediment from the Tongariro system. The M.W.D. recommended that "**full flow in the lower Tongariro should continue for some time after flushing operations have ceased and the water has become clear. Actual operating experience and observations will be necessary before a procedure can be defined but the possibility of no diversion occurring for several days should be considered. The loss of water should be regarded as an operating and maintenance cost on Rangipo power scheme.**" This procedure for scouring Rangipo dam and the 120 cumec closure rule were expected to minimize sediment deposition in the lower Tongariro River, Poutu canal, Lake Rotoaira and the Poutu stream, the last of which Jowett regarded as "**quite incapable of carrying extra sediment.**"

In order to reduce the quantity of sediment carried into the Poutu canal (and thence to Lake Rotoaira and the Poutu stream) and also to improve sediment transport in the lower Tongariro River, M.W.D. recommended that the Poutu tunnel be closed whenever natural river flows above Poutu intake exceed 120 cumecs. However, in practice, the value of the water available during freshes (which carry most of the offending sediment) is greater than the costs associated with sediment excavation, and consequently these recommendations have not been adopted (M.W.D. Hydrological staff, pers. comm.).

1.7 Summary

Key issues arising from these reports include development of the principle that hydroelectric power development must be integrated with, rather than developed at the expense of, freshwater fisheries. From Woods' (1964) report it became clear that it was necessary to identify the life stage and controlling factors determining the number of trout running into the Tongariro River before effective river management policies could be identified. The Environmental Impact Statement pointed out that the Rangipo power scheme would seriously damage fishery values between Rangipo dam and Poutu intake, but made little of consequences for the flow regime in the lower river. The Audit drew attention to anticipated problems with fine sediment accumulation and surges. The M.W.D. report provided detailed and well-supported recommendations for sediment management required for both efficient operation of the scheme and wellbeing of the fishery.

APPENDIX TWO

THE SHAND AGREEMENT

The following letter was circulated to most if not all Acclimatisation Societies and other representatives of angling interests. Assurances from the Minister of Electricity (T.P. Shand) regarding protection of angling interests are listed.

Mr. Brian Quickfall
Secretary, Taranaki Acclimatisation Society,
Box 57,
New Plymouth

Dear Mr. Quickfall,

The Prime Minister has asked me to reply to your telegram of 5 August about the Tongariro power scheme. I assume that your main concern is the effect of the scheme on fishing, and will confine most of my reply to this aspect.

In the very early stages of the investigations it was realised that if the scheme was to go ahead adequate steps would have to be taken to safeguard the world-famous fishing potential of this area. Contact was established then with the Departments concerned with inland fisheries, and has continued ever since. The Marine Department has carried out a tremendous amount of biological research over this period, culminating in the recent release of a most comprehensive technical report 'Fisheries Aspects of the Tongariro Power Development Project.' I understand that the Marine Department has kept fishing interests generally informed of developments through the meetings of the Freshwater Fisheries Advisory Council.

On 3 August a meeting was held in Wellington to discuss the fishing aspects of the Tongariro scheme with representatives of the three Acclimatisation Societies directly concerned, and the Federation of lake Taupo Fishing Clubs. The steps being taken to safeguard the fishing were described and the following assurances, which I have since confirmed in writing, were given to the societies:

1. Sufficient water will be spilled at the Poutu canal intake to provide the recommended mean flow of approximately 1000 cubic feet per second in the Tongariro River at Turangi Bridge.

2. The principal of providing artificial freshes in the Tongariro River to give the best possible fishing conditions is confirmed. The Department will supplement the natural flow of the river with the extra water from the Moawhango catchment and with water released from storage to give as far as the available water will permit the recommended pattern of flow.

3. The technical problems involved in deciding the best position for the Tokaanu Power Station tailrace outlet are still being investigated. If the tailrace discharges into Waihi Bay the Government accepts responsibility for dealing with any consequent problems which may arise in the silting up of the Tongariro River delta.

4. The contaminated Whangaehu water will be entirely excluded from the scheme.

5. In dry spells the flow in the Wanganui and Whakapapa Rivers will 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 temporarily discontinued

6. Collaboration between the New Zealand Electricity Department and the Departments concerned with fishing will continue into the future and operationg procedures will be modified whiere necessary in the light of experience.

The officers of the Marine and Internal Affairs Departments who were present at the meting stated that they were more than satisfied with these safeguards and consider that the fishing potential of the area will not be substantially altered by the power scheme. I would suggest that you might approach the Marine Department for a copy of the fisheries report and obtain their comments at first hand. In the meantime I enclose copies of two press statements recently issued by the Minister of Marine and myself.

I cannto agree with your assertion that the power scheme has been suddenly imposed. The proposals have been public knowledge for a number of years and as I have said earlier I understand fishing interests have been kept generally informed by the Marine Department. The scheme received some publicity in 1963 when the Power Planning Committee recommended it for approval and again in March, 1964 when Government approved it in principle subject to being satisfied that suitable arrangements can be made to preserve the interests of parties who would be adversely affected by the scheme. Discussions with these parties have been going on ever since and Government has not yet given its approval for construction to commence.

In reply to your request for alternative schemes to be investigated I am enclosing a copy of the report of the Planning Committee on Electric Power Development in New Zealand. You will see from this that possible alternatives were very fully considered by the committee but were found to have serious economic or technical disadvantages. I think this report will also convince you of the magnitude of the task the Government is facing in providing for the future power needs of the country.

Yours faithfully

T. P. SHAND

Secretary for Marine,
<u>WELLINGTON</u>

APPENDIX THREE

EFFECTS OF SCOURING RANGIPO DAM ON JUVENILE RAINBOW TROUT IN THE LOWER TONGARIRO RIVER

3.1 Introduction

During January and February 1985 a series of thunderstorms over the volcanic plateau caused large quantities of sand to be carried, principally by the Waihohonu Stream, into the Rangipo reservoir where the Water & Soil Division, M.W.D., estimate that about 19,500 cubic metres were deposited. Since this material threatened normal operation of Rangipo intake, the reservoir was partially dewatered during the annual maintenance shutdown to expose the sediment for mechanical excavation of about 3,300 cubic metres, which was removed to a nearby spoil dump. This part of the operation caused some discolouration in the river downstream but had no obvious impact on either fish or invertebrate habitat in the lower Tongariro. However, on 9 March 1985, while the river was in low summer flow, the sluice gates were opened to dewater the reservoir completely. This caused substantial quantities of sediment to be sluiced into the lower river. Water & Soil Division estimate that, in total, some 15,500 cubic metres of sediment were removed from the reservoir during the shutdown period. Since only 3,300 cubic metres was removed mechanically, one can infer that some 12,200 cubic metres was sluiced into the lower river. This is a considerable quantity, being about half the annual sediment discharge for the Tongariro River at Rangipo.

The sluicing operation took place under low flow conditions and consequently sand was deposited in the river margins, which is the principal habitat zone for juvenile trout. However, the habitat disruption was brief because a minor fresh occurred on 15 March 1985 and this improved river margin habitat. Complete restoration occurred during a major fresh on 20 April 1985.

Sand deposition generally reduces trout production through depressed growth, biomass and numeric abundance, all of which are caused by disruption of aquatic invertebrate production (Winterbourn 1981; Cowie 1985). There is often a time lag between habitat restoration and recovery of fish production while surviving invertebrates breed and re-colonise available habitat.

Since sediment sluicing operations will be a regular feature of the management of Rangipo reservoir, it was considered useful to assess the effects of this event to provide some guidance for the river's managers regarding the significance of artificially induced sand deposition for juvenile trout. Thus, this study examines whether or not there was any reduction in juvenile trout density, biomass or growth associated with the scouring operation.

3.1.1 Approach Samples of juvenile trout were collected monthly, as part of another study, at a number of sites in the Tongariro River and at one site on the Whitikau Stream. It was therefore possible to compare data before and after the scouring operation at both impacted sites and at a control site.

Juvenile trout densities and biomass are most easily assessed by electrofishing specific sites. The most sensitive indicator of a change in growth is variation in 'condition' (the relationship between fish length and weight) as determined from samples collected at some of the sites electrofished.

The 'condition' (K) or weight-for-length for animals such as fish is defined by:

$$K = \text{Observed weight} / \text{Predicted weight}$$

where predicted weight is given by the population length-weight regression. K values greater than 1 imply above average growth and K values less than 1 imply impaired growth. One can determine whether variation in growth has occurred principally in a particular size range of fish by examining the relationship between length and condition.

3.2 Study area and methods

Whilst a resident trout population exists between Rangipo dam and Poutu intake, the area of main concern is the lower river between Poutu intake and Lake Taupo. Parts of this section are the spawning and nursery habitat for migratory Lake Taupo trout. There are five sampling sites in this part of the river, at Poutu intake, Puketarata, Breakaway Pool, Judges Pool and DeLatours Pool. Another site, on the Whitikau Stream, was the control site. At each site, the same length of river margin was electrofished once, the catch being retained and preserved in formalin. Subsequently, fork lengths (rounded down to the nearest millimetre) and, for samples collected at Judges Pool, Breakaway Pool and the Whitikau Stream, individual weights (of fish blotted dry on tissue paper) were measured to the nearest milligram.

3.3 Juvenile Trout Densities and Biomass

The number and biomass of young trout taken electrofishing at the six sampling stations are given in Tables 1 and 2 respectively.

Table 1. Numbers of juvenile trout per 100 m of river margin electrofished.

	Before 9 March		After 9 March	
	January	February	March	April
Poutu intake	1	45	25	33
Puketarata	58	112	58	32
Breakaway	265	325	150	130
Judges Pool	20	111	78	33
DeLatours Pool	15	14	5	0
Whitikau Str. (control)	627.5	352.5	212.5	382

Table 2. The biomass (g) of young trout per 100 m of river margin electrofished.

	Before 9 March		After 9 March	
	January	February	March	April
Poutu intake	0.6	505.4	249.1	492.9
Puketarata	51.6	139.2	134.1	76.7
Breakaway	384.9	660.3	469.5	487.7
Judges Pool	14.7	209.8	179.8	69.1
DeLatours Pool	12.0	79.3	3.9	30.0
Whitikau Str. (control)	66.7	1734.3	971.5	1386.1

Bartlett's test for homogeneity of variances for data grouped before and after the impact indicated heterogeneity:

Density: $B_c = 21.45$; df = 11 $.025 < p < .05$
Biomass: $B_c = 22.17$; df = 11 $.01 < p < .025$

Furthermore, the variances were dependent on the mean:

Density: $VAR = 0.571 * MEAN^{1.63}$ r = 0.77 ; df = 11
Biomass: $VAR = 4.37 * MEAN^{1.43}$ r = 0.79 ; df = 11

To prevent violations of assumptions critical to the validity of ANOVA, data transformations were necessary to eliminate systematic heterogeneity of the variances. The exponents (1.63 and 1.43) were between 1 and 2, and therefore, in accordance with Taylor's power law, the chosen transformation was:

$$Z = LN (X + 1)$$

where Z is the transformed value of the datum X.

Two way analysis of variance was used to test the following hypotheses using the data given in Tables 1 and 2.

Trout densities did not vary between sampling stations:
F = 8.089 ; df = 4,10 ; $0.0025 < p < 0.005$
Trout densities did not vary before and after 9 March:
F = 0.918 ; df = 1,10 ; NS
Trout biomass did not vary between sampling stations:
F = 4.226 ; df = 4,10 ; $0.025 < p < 0.05$
Trout biomass did not vary before and after 9 March:
F = 0.312 ; df = 1,10 ; NS

Since there was significant variation in both trout density and biomass amongst sampling sites, but not at different times, it is appropriate to examine trout variations at two sites (Tables 3 and 4), one potentially impacted, and the other, a control site.

Table 3. Juvenile trout densities at two sampling stations, the Breakaway Pool and the Whitikau Stream (control). Data are numbers of trout caught per 100 m electrofished before (December, January and February) and after (March April and May) the scouring event.

Breakaway Pool		Whitikau Stream	
Before	After	Before	After
427.5	150.0	825.0	212.5
265.0	130.0	627.5	382.0
325.0	45.0	352.5	77.5

Table 4. Juvenile trout biomass at two sampling stations. Data are the biomass of the trout caught per 100 m electrofished before and after the scouring event and (Dec-Feb and Mar-May).

Breakaway Pool		Whitikau Stream	
Before	After	Before	After
548.9	469.5	1388.1	971.5
384.9	487.7	663.7	1386.1
660.3	96.0	1734.3	627.1

After the logarithmic data transformation described above, a two-way ANOVA procedure was used to test the following hypotheses:

Trout density was the same at both sampling stations:
F = 3.22 ; df = 1,8 ; NS
Trout biomass was the same at both sampling stations:
F = 9.24 ; df = 1,8 ; $.01 < p < .025$
Trout density was the same before and after the scouring event:
F = 12.75 ; df = 1,8 ; $0.005 < p < 0.01$
Trout biomass was the same before and after the scouring event:
F = 1.55 ; df = 1,8 ; NS
Trout density variation before and after the scouring event was the same at both sampling locations:
F = 3.0E-5 ; df = 1,8 ; NS
Trout biomass variation before and after the scouring event was the same at both sampling locations:
F = 0.35 ; df = 1,8 ; NS

Thus there was significant site-related variation in juvenile trout biomass and temporal variation in trout density but neither of these were associated with the scouring event.

3.4 Length-weight Relationships

Power curves were fitted to length and weight data obtained for young trout sampled between January and April in the Tongariro R. at Judges Pool and the Breakaway Pool and at a single site in the Whitikau Stream (Table 5.).

Table 5 Regression equations describing length-weight data obtained for juvenile trout at two sites in the Tongariro River and one site in the Whitikau Stream.

Sample	N	Elevation	Slope	RR
Judges Pool -Jan 1985	21	3.937E-6	3.321	0.988
Breakaway Pool -Jan '85	101	5.444E-6	3.222	0.995
Whitikau Str - Jan '85	120	4.916E-6	3.257	0.995
Judges Pool -Feb '85	85	6.331E-6	3.180	0.994
Breakaway Pool -Feb '85	127	6.344E-6	3.178	0.994
Whitikau Str. -Feb '85	133	6.363E-6	3.169	0.996
Judges Pool Mar '85	78	1.059E-5	3.047	0.991
Breakaway Pool -Mar '85	59	9.389E-6	3.068	0.996
Whitikau Str. Mar '85	75	7.039E-6	3.144	0.995
Judges Pool -Apr '85	33	1.243E-5	3.023	0.987
Breakaway Pool - Apr '85	44	9.559E-6	3.077	0.984
Whitikau Str. - Apr '85	174	6.969E-6	3.151	0.990

A one-way analysis of variance procedure was used to determine whether or not there were any significant differences amongst these sample regressions by testing the two hypotheses:

The slopes are all similar: $F = 5.4$; df = 11,1026 ; $p < 0.0005$
The elevations are similar: $F = 10.2$; df = 11,1037 ; $p < 0.0005$

Thus the length-weight relationships were variable. There was a seasonal decline in the slopes for all three sites, although the drop was greatest for potentially impacted sites.

The equation which best described the data from all samples was:

$$\text{(predicted) WEIGHT} = 6.914\text{E-}6 * \text{LENGTH}^{3.155}$$

This length-weight relationship was used to calculate condition factors (K) for each sample and a two way procedure was then used to examine the nature of variation in condition factors by testing the following hypotheses:
There was no monthly variation in K : $F = 19.1$; df = 3,592
$p << 0.0005$
There was no site related variation in K: $F = 1.47$; df = 1,592
$P > 0.1$ (NS)
Monthly variation in K was the same at all sites:
$F = 8.52$; df = 3,592 ; $p << 0.005$

Condition was significantly and negatively correlated with length (Table 6) in samples from sites potentially affected by the scouring operation, indicating that the larger fingerlings were affected more severely than the smaller ones.

Table 6. Mean condition factors (K) and correlation with trout length. The ** indicates significance at the 0.01 probability level whilst * indicates significance at the 0.05 probability level. Probability levels are corrected for multiple comparisons.

Sample Site and Date	N	K	Correlation	p
Judges Pool -Jan 1985	21	1.017	0.356	NS
Breakaway Pool -Jan '85	101	1.009	0.242	NS
Whitikau Str - Jan '85	120	1.044	0.304	*
Judges Pool -Feb '85	85	1.009	0.047	NS
Breakaway Pool -Feb '85	127	1.005	0.047	NS
Whitikau Str. -Feb '85	133	0.975	0.030	NS
Judges Pool Mar '85	78	1.001	-0.351	*
Breakaway Pool -Mar '85	59	0.961	-0.404	*
Whitikau Str. Mar '85	75	0.974	0.450	**
Judges Pool -Apr '85	33	1.068	-0.358	NS
Breakaway Pool - Apr '85	44	1.018	-0.200	NS
Whitikau Str. - Apr '85	174	0.997	-0.045	NS

3.5 Conclusions

There was significant site-related variation in juvenile trout densities but no significant variation associated with the scouring event. Although densities declined from an average of 44.4 fish per 100 m electrofished to 29.8 fish per 100 m after the scouring operation, this change was not significant when other sources of variability in these measurements was considered. Comparison between densities at the Breakaway Pool and at the Whitikau Stream indicate that much of the observed decline in juvenile trout abundance was a general phenomenon and not associated with the scouring operation.

There was significant variation in condition for Tongariro River trout which did not occur in the Whitikau Stream during the same time period. From this one can infer that the scouring event caused a measurable deterioration in juvenile trout condition, although the magnitude of this was small. Condition was significantly correlated with length at some sites because larger trout lost more condition than the smaller ones. Thus the scouring operation had a greater impact on larger fingerlings than on smaller ones. This probably occurred because the larger stream insects (mayflies, stoneflies and caddis), eaten by larger trout, would be more seriously affected by siltation than smaller insect groups (chironomids and simulids) which are mainly eaten by small fingerlings.

The impact of scouring was detected only by measurement of juvenile trout condition and the magnitude of the impact was slightly less than variation caused by other naturally occurring seasonal events. Impact on condition was detected only because the number of replicate measurements was high (>= 75) and their variance was small. By contrast, only two and three measurements were available for examining sources of variation in trout density and biomass data which had extremely large variances. Consequently, the magnitude of the impact would have had to be considerable to be detectable. However, had there been some warning of this event a few days in advance, it would have been a straightforward matter to design and implement a brief sampling programme which would have been considerably more sensitive to the effects of the scouring operation.

The overall impact of the scouring operation on the fishery was minor and is most unlikely to influence the size of the adult run up the Tongariro in 1987. The fresh which fortuitously occurred soon after the sluicing of Rangipo dam probably removed sufficient fine sediment to curtail damage caused by sand deposits in the river margins.

Undesirable impacts of scouring Rangipo dam could be minimized if Electricorp were to abide by the operational guidelines formulated by M.W.D. (1980). That is, scouring should take place only when flows at Rangipo dam exceed 100 cubic metres/sec, there should be no diversion into the Rangipo tunnel until 12 hours after the water clears below Rangipo dam and the Poutu tunnel should not be opened for 3 days after scouring. These restrictions were designed to ensure that most of the sediment from Rangipo is transported through the middle reaches of the Tongariro River and so minimize any detrimental impact on the fishery. In my opinion, these procedures will achieve that objective.

APPENDIX FOUR

Below are the data to which the model describing variation in numbers of trout entering the Waihukahuka Stream was fitted. Following this is a listing of the program used to fit the model. The fields, referred to in line 340 of the program listing are:

YR	-The year in which the predominant age group was born.
OVA	-The number of ova (X 1000) collected in the year YR.
AWIN	-The number of floods during the winter of year YR
FRY	-The number of fry (X 1000) liberated in year YR.
ASPR	-The number of floods during the spring of year YR.
FINGS	-The number of fingerlings released in year YR + 1
ASUM	-The number of floods during the summer after year YR
AAUT	-The number of floods during the autumn of year YR + 1
WADULTS	-The number of wild rainbow trout returning in year YR + 3
PK	-Estimated parent stock size (number of trout).
L5	-The number of licences sold in year YR
L4	-The number of licences sold in year YR + 1
L3	-The number of licences sold in year YR + 2
L2	-The number of licences sold in year YR + 3
DIV	-Dummy variable for pre-diversion (0) and post-diversion (1).
MUD	-Dummy variable for tunnelling waste pollution (1).

```
1958,0,5,0,3,0,8,4,1352.1,1509.9,4.706,4.9732,4.4974,3.5572,0,0

1959,0,1,0,4,0,2,2,2382.2,1509.9,4.9732,4.4974,3.5572,4.1609,0,0

1960,1670,6,0,4,0,1,3,2221,786,4.4974,3.5572,4.1609,4.2974,0,0

1961,3060,5,0,2,0,4,6,1491,0,3.5572,4.1609,4.2974,4.0166,0,0

1962,1826,8,0,10,0,5,2,2144,1286,4.1609,4.2974,4.0166,4.185,0,0

1963,1379,6,0,3,0,4,1,1317,1394,4.2974,4.0166,4.185,4.3745,0,0

1964,592,4,0,3,0,5,1,1627,1136,4.0166,4.185,4.3745,4.5761,0,0

1965,1800,5,736,2,0,5,4,1680,1064,4.185,4.3745,4.576,4.4515,0,0

1966,1580,4,67,3,0,4,3,1491,369,4.3745,4.5761,4.4515,4.6277,0,0

1967,1982,7,72,4,0,4,5,1016,438,4.576,4.4515,4.6277,4.9454,0,0

1968,1237,5,20,3,0,4,4,999,938,4.4515,4.6277,4.9454,5.8708,0,0

1969,1189,0,35,2,0,1,3,1231,778,4.6277,4.9454,5.8708,5.514,0,0

1970,422,6,12,6,0,3,1,1392,763,4.9454,5.8708,5.514,5.5691,0,0

1971,574,6,8,8,8,3,3,1677,655,5.8708,5.514,5.5691,5.7079,0,0

1972,523,4,32,2,9.6,1,4,1902,917,5.514,5.569,5.7079,6.8827,0,0

1973,948,5,13,3,0,0,3,2657,823,5.5691,5.7079,6.8827,6.8798,0,1

1974,713,5,75,2,4.112,1,2,1644,1249,5.708,6.8827,6.88,6.2912,1,0

1975,77,5,0,6,8,4,4,1321,1856,6.8827,6.8798,6.2912,6.2477,1,0

1976,657,7,0,0,0,2,1,1454,2263,6.8798,6.2912,6.2477,6.4943,1,0

1977,80,4,0,4,10,1,2,2263,1596,6.2912,6.2477,6.4943,6.9105,1,0

1978,16,4,0,3,10.056,1,5,2454,1311,6.248,6.4943,6.9105,7.1234,1,0

1979,209.4,2,0,6,10,5,6,2384,1328,6.4943,6.9105,7.1234,7.452,1,1

1980,25.7,7,0,6,10,1,0,2269,2248,6.9105,7.1234,7.452,6.9515,1,0

1981,238.7,3,0,4,10,4,2,1560,2311,7.1234,7.4518,6.9515,7.7213,1,0

1982,26,1,0,2,10,3,3,1269,2368,7.4518,6.9515,7.7213,7.6303,1,0

1983,0,3,0,4,10,2,5,1147,2269,6.9515,7.7213,7.6303,8.2282,1,0

1984,1.7,2,0,1,1.708,2,2,1145,1559,7.7213,7.63,8.2282,8.383,1,0

1985,5,3,0,2,5.3,6,4,560.6,1266,7.6303,8.2282,8.3829,8.4,1,0
```

```
10 REM TRAPRUN models numbers of trout passing through the Waihukahuka trap.
20 REM There are optional transformations of flood frequency, hatchery and
30 REM licence sales data, weighted according to the age structure of the
40 REM run.  This version does not include parent stock size data.
50 REM Model predictions are obtained by setting PRED$ = Y.
60 PRED$ = "N"
70 WMEAN=4.5 :SPMEAN=13.5 : SUMEAN=.98 : AMEAN = 0 : OVAMEAN=0
80 WSDEV=15: SPSDEV=31 : SUSDEV=.88 : ASDEV= 4.3 : OVASDEV=254
90 WVAR=2*WSDEV^2 : SPVAR=2*SPSDEV^2 : SUVAR=2*SUSDEV^2 : AVAR=2*ASDEV^2
100 OVAR = 2 * OVASDEV ^ 2
110 OPEN "I",1, "TRAP.DAT"
120 OPEN "O",2, "TRAP.PAK"
130 P5 = .121 : P4 = .242 : P3 = .559 : P2 = .078
140 P = P5 : GOSUB 370
150 W5=W : SP5=SP : SU5=SU : A5=A : O5=O : F5=F : D5=D : FL5=FL
160 P = P4 : GOSUB 370
170 W4=W : SP4=SP : SU4=SU : A4=A : O4=O : F4=F : D4=D : FL4=FL
180 P = P3 : GOSUB 370
190 W3=W:SP3=SP:SU3=SU:A3=A:O3=O:F3=F:D3=D:FL3=FL:TROUT=WADULTS
200 P = P2 : GOSUB 370
210 W2=W:SP2=SP:SU2=SU:A2=A:O2=O:F2=F:D2=D:FL2=FL:TROUT2=WADULTS
220 GOSUB 780
230 W5 = W4 * P5/P4 : W4 = W3 * P4/P3 : W3 = W2 * P3/P2
240 SP5 = SP4 * P5/P4 : SP4 = SP3 * P4/P3 : SP3 = SP2 * P3/P2
250 SU5 = SU4 * P5/P4 : SU4 = SU3 * P4/P3 : SU3 = SU2 * P3/P2
260 A5 = A4 * P5/P4 : A4 = A3 * P4/P3 : A3 = A2 * P3/P2
270 O5 = O4 * P5/P4 : O4 = O3 * P4/P3 : O3 = O2 * P3/P2
280 F5 = F4 * P5/P4 : F4 = F3 * P4/P3 : F3 = F2 * P3/P2
290 D5 = D4 * P5/P4 : D4 = D3 * P4/P3 : D3 = D2 * P3/P2
300 FL5 = FL4 * P5/P4 : FL4 = FL3 * P4/P3 : FL3 = FL2 * P3/P2
310 TROUT = TROUT2 : MURK = MUD2 : FPRESS = FPRESS2
320 GOSUB 370 : W2=W:SP2=SP:SU2=SU:A2=A:O2=O:F2=F:D2=D:FL2=FL
330 GOSUB 780
340 IF NOT EOF(1) THEN GOTO 230
350 CLOSE #1,#2
360 IF BYPASS$ = "Y" THEN GOTO 2660 ELSE GOTO 860
370 INPUT #1,YR,OVA,AWIN,FRY,ASPR,FINGS,ASUM,AAUT,WADULTS,PK,L5,L4,L3,L2,DIV,MU
380 REM W = P * LOG(AWIN + 1)
390 W = P * AWIN ^ .12
400 REM W = P * (1/((AWIN+1)^1)
410 REM W = P * (EXP(- ((AWIN - WMEAN)^2)/WVAR))
420 REM W = P * (EXP(-((LOG(AWIN + 1) - WGM)^2)/WGVAR))
430 SP = P * ASPR ^ 9.8
440 REM SP = P * LOG(ASPR + 1)
450 REM SP = P * (EXP(-((ASPR - SPMEAN)^2)/SPVAR))
460 REM SP = P * (EXP(-((LOG(ASPR + 1) - SPGM)^2)/SPGVAR))
470 REM SU = P * ASUM ^ .95
480 REM SU = P * LOG(ASUM + 1)
490 SU = P * (EXP(-((ASUM - SUMEAN)^2)/SUVAR))
500 REM SU = P * (EXP(-((LOG(ASUM + 1) - SUGM)^2)/SUGVAR))
510 REM SU = P * (1 / ((ASUM + 1) ^ .1))
520 REM A = P * LOG(AAUT + 1)
530 A = P * AAUT^1.22
540 REM A = P * (EXP(-((AAUT - AMEAN)^2)/AVAR))
550 REM A = P * (1 / ((AAUT + 1) ^.05))
560 REM O = P * (1 / ((OVA + 1) ^ 10))
570 REM O = P * OVA^1
580 REM O = P * (1 / (1 + (.0002 * (4.2 ^ (LOG(OVA + 1))))))
590 REM O = P * (LOG(OVA + 1))
600 O = P * (EXP(-((OVA - OVAMEAN)^2)/OVAR))
610 F = P * FRY^5
620 REM F = P * FRY
630 REM F = P * (LOG(FRY + 1))
640 REM F = P * (1 / ((FRY + 1)^1))
650 REM F = P * (EXP(-((FRY - FRYMEAN)^2)/FRYVAR))
660 REM FL = P * FINGS
670 REM FL = P * LOG(FINGS + 1)
680 FL = P * FINGS ^ 18
690 D = P * DIV
700 REM FP5 = P5 * (LOG(L5+L4+L3+L2)) : FP4 = P4 * (LOG(L4+L3+L2))
710 REM FP3 = P3 * (LOG(L3+L2)) : FP2 = P2 * LOG(L2)
720 B = 9.5
```

```
730 FP5 = P5 * (L5+L4+L3+L2)^B
740 FP4 = P4 * (L4+L3+L2)^B : FP3 = P3 * (L3+L2)^B : FP2 = P2 * (L2)^B
750 FPRESS2 = FP5 + FP4 + FP3 + FP2
760 TROUT2 = WADULTS : MUD2 = MUD
770 RETURN
780 WIN = W5 + W4 + W3 + W2 : SPR = SP5 + SP4 + SP3 + SP2
790 SUM = SU5 + SU4 + SU3 + SU2 : AUT = A5 + A4 + A3 + A2
800 STRIP = O5 + O4 + O3 + O2 : FRYLIB = F5 + F4 + F3 + F2
810 FINGLIB = FL5 + FL4 + FL3 + FL2 : FPRESS = FP5 + FP4 + FP3 + FP2
820 TPS = D5 + D4 + D3 + D2
830 PRINT #2, TROUT;WIN;SPR;SUM;AUT;STRIP;FRYLIB;FINGLIB;FPRESS;TPS;MURK
840 REM LPRINT "RUN = ";TROUT;TAB(30);"STOCK = ";PSTK
850 RETURN
860 DATACOLUMNS = 11
870 DEFINT I-N: ON ERROR GOTO 2520: WIDTH 80
880 BL$=CHR$(7)
890 BS$=CHR$(8)
900 FF$=CHR$(12)
910 P = DATACOLUMNS - 1 : COLS= P+1
920 GOSUB 1100
930 WHILE NOT EOF(1): GOSUB 1030: WEND: N=ROWS: ROWS=0
940 IF N<COLS THEN PRINT BL$"*** INSUFFICIENT DATA ROWS ***": GOTO 2620
950 DIM X(N.P), Y(N), T(P)
960 CLOSE: OPEN"I".1.IFIL$
970 WHILE NOT EOF(1): GOSUB 1030
980  Y(ROWS)=COL!(1)
990  FOR C=1 TO P: X(ROWS,C)= COL!(C+1): NEXT
1000 WEND
1010 GOTO 1220
1020 ' ===<GET ROW>===  (3800..3900) ** IN: HICOL,ICOLS,SOL(),ROWS ** OUT: ROWS
COL!()
1030 PRINT".";
1040 IF EOF(1) THEN RETURN
1050 FOR COL=1 TO HICOL:INPUT #1.COL!(SEL(COL)):NEXT
1060 IF HICOL<ICOLS THEN LINE INPUT #1.GI$
1070 ROWS=ROWS+1
1080 RETURN
1090 ' ===<INPARAMSET>===        (3900..4000) ** IN: COLS ** OUT: IFIL$,ICOLS,HI
)
1100 ROWS=0: HICOL=0: ICOLS=0
1110 IFIL$ = "TRAP.PAK"
1120 ON ERROR GOTO 1200
1130 CLOSE 1: OPEN "I",1,IFIL$
1140 ON ERROR GOTO 2520
1150 WHILE ICOLS<COLS: ICOLS = DATACOLUMNS : WEND
1160 DIM COL!(COLS), SEL(ICOLS)
1170 FOR COL=1 TO COLS: TS=0: WHILE TS<1 OR TS>ICOLS: TS = COL: WEND: SEL(TS)=C
L: NEXT
1180 FOR COL=ICOLS TO 1 STEP -1: IF SEL(COL) THEN HICOL=COL: RETURN
1190 NEXT
1200 PRINT BL$"*** "IFIL$;": BAD FILE NAME!": RESUME 1110
1210 ' >>-------> MAIN ALGORITHM SECTION <-------<< (4000-5995)
1220 FOR I=1 TO P:FOR I1=1 TO N:T(I)=T(I)+X(I1.I):NEXT:T(I)=T(I)/N:NEXT
1230 FOR I1=1 TO N:Y1=Y1+Y(I1):NEXT:Y1=Y1/N
1240 '
1250 DIM Z(P,P), D(P)
1260 FOR J=1 TO P:S1=0
1270  FOR I=1 TO N:S1=S1+(Y(I)-Y1)*(X(I.J)-T(J)):NEXT
1280  D(J)=S1:S1=0
1290  FOR K=J TO P: S1=0
1300   FOR I=1 TO N:S1=S1+(X(I,J)-T(J))*(X(I,K)-T(K)):NEXT
1310   Z(J,K)=S1:Z(K,J)=S1
1320 NEXT K,J
1330 '
1340 ERASE X: DIM ZI#(P,P)
1350 NT=N: N=P: GOSUB 1470: N=NT          ' -<MATRIX INVERT>-
1360 DIM W(P)
1370 GOSUB 1600                           ' -<MATRIX MULT>-
1380 M1!=0
1390 FOR I=1 TO P:M1!=M1!+W(I)*T(I):NEXT
1400 W(0)= Y1 -M1!: C9=0
1410 FOR I=1 TO N:C9=C9+(Y(I)-Y1)^2:NEXT
```

```
1420 C1=0
1430 FOR I=1 TO P:C1=C1+W(I)*D(I):NEXT
1440 C2= C9 -C1: L= N -1: K= L -P: C8= C1/P: C7= C2/K: C6= C9/L
1450 GOTO 1630
1460 ' ---<MAT INV: JORDAN>--- IN: Z(N,N),N OUT: ZI#(N,N) USES: R,C,R2,X#,Y#
1470 FOR R=1 TO N:FOR C=1 TO N:ZI#(R,C)=Z(R,C):NEXT C,R
1480 FOR R=1 TO N:X#=ZI#(R,1)
1490  FOR C=1 TO N
1500   IF C<N THEN ZI#(R,C)=ZI#(R,C+1)/X# ELSE ZI#(R,C)=1/X#
1510  NEXT C
1520  FOR R2=1 TO N:IF R2=R THEN 1560 ELSE X#=ZI#(R2,1)
1530   FOR C=1 TO N:Y#=ZI#(R,C)*X#
1540    IF C<N THEN ZI#(R2,C)=ZI#(R2,C+1)-Y# ELSE ZI#(R2,C)=-Y#
1550   NEXT C
1560  NEXT R2
1570 NEXT R
1580 RETURN
1590 ' ---<MATRIX MULTIPLY>--- (SPCL CASE: W(P,1)=ZI#(P,P)*D(P,1))
1600 FOR I=1 TO P:T=0:FOR J=1 TO P:T=T+ZI#(I,J)*D(J):NEXT:W(I)=T:NEXT
1610 RETURN
1620 ' >>-------> OUTPUT SECTION <-------<< (6000-6995)
1630 PRINT
1640 GOSUB 2330: IF MO=4 THEN 2620
1650 HD$="TERM             COEFFICIENT                  T-TEST"
1660 H2$="----             -----------                 ----------"
1670 T1=16: T2=41
1680 PRINT
1690 FOR I=0 TO P: GOSUB 2130: IF CQ THEN I=P: GOTO 1770
1700   IF I=0 OR (ZI#(I,I)*C7<=0) THEN TT!= 0         ELSE TT!= W(I)/SQR(ZI#(I,I
*C7)
1710   ON MO GOTO 1720,1750,1760
1720   PRINT "B";I;
1730   PRINT TAB(T1);:PRINT USING "#####.#######";W(I);: PRINT TAB(T2);
1740   PRINT USING "##.#####";TT!: GOTO 1770
1750   LPRINT"B";I,W(I),TT!: GOTO 1770
1760   PRINT #2,I;W(I),TT!
1770 NEXT I: IF CQ THEN 1630
1780 HD$="SUM SQ        DEG FR      MEAN SQ"
1790 H2$="------        ------      -------"
1800 T1=23: T2=38: T3=48
1810 IF CDW THEN GOSUB 1980
1820 H3$="DUE TO REGRESSION": H4$="ABOUT REGRESSION": H5$="TOTAL"
1830 H6$="R-SQUARED": H7$="F-TEST": H8$="DURBIN-WATSON"
1840 ON MO GOTO 1850,1910, 1630
1850 PRINT: PRINT TAB(T1);HD$: PRINT TAB(T1);H2$
1860 PRINT H3$;TAB(T1)C1;TAB(T2)P;TAB(T3)C8
1870 PRINT H4$;TAB(T1)C2;TAB(T2)K;TAB(T3)C7
1880 PRINT H5$;TAB(T1)C9;TAB(T2)L;TAB(T3)C6: PRINT
1890 PRINT H6$,C1/C9: PRINT H7$,C8/C7: IF CDW THEN PRINT H8$,DUWA
1900 GOTO 1630
1910 LPRINT:LPRINT TAB(T1);HD$:LPRINT TAB(T1);H2$: LPRINT
1920 LPRINT H3$;TAB(T1)C1;TAB(T2)P;TAB(T3)C8
1930 LPRINT H4$;TAB(T1)C2;TAB(T2)K;TAB(T3)C7
1940 LPRINT H5$;TAB(T1)C9;TAB(T2)L;TAB(T3)C6:LPRINT
1950 LPRINT H6$,C1/C9: LPRINT H7$,C8/C7: IF CDW THEN LPRINT H8$,DUWA
1960 LPRINT: GOTO 1630
1970 ' ---<DURBIN-WATSON>---
1980 CLOSE #1: OPEN"I",1,IFIL$
1990 IF RFIL$<>"" THEN CLOSE #2: OPEN"O",2,RFIL$
2000 SRES2=0: SDRES2=0
2010 FOR I=1 TO N: GOSUB 1040
2020  YHAT= W(0)
2030  FOR C=1 TO P: YHAT= YHAT +W(C)*COL!(C+1): NEXT
2040  RES= COL!(1)-YHAT: SRES2= SRES2 +RES^2
2050  IF I>1 THEN SDRES2= SDRES2 +(RES-ORES)^2
2060  ORES= RES
2070  IF RFIL$<>"" THEN PRINT #2,RES;YHAT
2080 NEXT I
2090 DUWA= SDRES2/SRES2
2100 RFIL$="": CLOSE #2
2110 RETURN
2120 ' ---<PAGING ROUTINE>---
```

```
2130 IF MO=3 THEN RETURN          '{not needed for file O/P}
2140 IF PH$="" THEN PH$="---> MLINREG ("+IFIL$+"): "
2150 IF ML=0 THEN LC=0:IF MO=1 THEN ML=18:GOTO 2230 ELSE ML=53: PG=1: PRINT: P
NT"--> MAKE PRINTER READY": LINE INPUT"Page Header: ";Z$: PH$=PH$+Z$: GOTO 227
2160 LC=LC+1: IF (LC MOD ML) THEN RETURN
2170 IF MO=2 THEN 2260
2190 PRINT: LINE INPUT"Continue or Quit (C,Q)? ";I$: I$= LEFT$(I$,1)
2210 IF INSTR(" Qq",I$)>1 THEN CQ= -1: RETURN   ELSE CQ= 0
2230 CLS: PRINT HD$: PRINT H2$: PRINT
2240 RETURN
2260 LPRINT FF$;
2270 LPRINT: LPRINT PH$;TAB(66)"PAGE ";PG: LPRINT
2280 LPRINT HD$: LPRINT H2$: LPRINT
2290 PG=PG+1
2300 RETURN
2310 ' ---< SET OUTPUT MODE >---
2320 '   ** IN: **OUT: MO,ML,CQ
2330 LINE INPUT"Output to Screen, Printer, File - or Quit (S,P,F,Q)? ";I$
2340 MO=INSTR(" SsPpFfQq",LEFT$(I$,1)): IF MO<2 THEN 2330 ELSE MO=MO\2  'MO: M
of Output {1=Screen;2=Printer;3=File;4=EXIT}
2350 ML=0: CQ=0: PH$=""           'reset PAGOUT vars
2360 IF MO<>3 THEN RETURN
2370 LINE INPUT "Name of Output file: ";I$
2380 ON ERROR GOTO 2440
2390 CLOSE 2: OPEN "I",2,I$
2400 PRINT I$;" exists: re-use it (Y,N)? ";: LINE INPUT II$
2410 II=INSTR(" YyNn",LEFT$(II$,1)): IF II<2 THEN 2400 ELSE IF II>3 THEN 2370
2420 CLOSE 2: OPEN "O",2,I$
2430 ON ERROR GOTO 2520: RETURN
2440 IF ERR=53 THEN RESUME 2420 ELSE 2430
2450 ' =====<UTILITY ROUTINES>===== (7000-7500: COMMON / 7500-8000: UNIQUE)
2460 ' ---<GET Y/N ANS>--- (IN: PROM$   OUT: YN%)
2470 YN%=0
2480 WHILE YN%=0: PRINT PROM$;: LINE INPUT" (Y/N)? ";YN$: YN%= INSTR(" YyNn",LI
T$(YN$,1))\2: WEND
2490 YN%= YN% -2
2500 RETURN
2510 ' <------<< ERROR TRAPS >>------> (9000-9995)
2520 ' (ERRORECOVERY STARTS HERE - IF IMPLEMENTED; DON'T DELETE THIS REM)
2530 IF ERR=62 AND ERL=1050 THEN PRINT BL$"*** BAD INPUT:ABORTING ***":GOTO 26
2540 ' * * * * *  UNRECOVERABLE ERRORS  * * * * *
2550 PRINT: PRINT
2560 PRINT BL$ "       * * *  E R R O R  * * *"
2570 PRINT "Check your input data for validity..."
2580 PRINT "Try re-running the program..."
2590 PRINT "And/or call NORTHWEST ANALYTICAL for help!"
2600 PRINT "ERROR DESCRIPTION --"
2610 ' >>-----> EGRESS >>----->
2620 ON ERROR GOTO 0
2630 CLOSE: DEFSNG A-Z:
2640 IF PRED$ <> "Y" THEN GOTO 2820
2650 OPEN "I",1, "ALLTRAP.DAT" : BYPASS = "Y" : GOTO 120
2660 INPUT "DO YOU WANT A HARD COPY - S (for screen) P (for printer)";P$
2670 OPEN "I",2,IFIL$
2680 PRINT TAB(1);"ACTUAL RUN";TAB(30);"PREDICTED RUN"
2690 IF P$ = "P" THEN LPRINT TAB(1);"ACTUAL RUN";TAB(30);"PREDICTED RUN"
2700 PRINT ""
2710 IF P$ = "P" THEN LPRINT ""
2720 INPUT #2, TROUT,WIN,SP,SU,AU,O,FRY,FINGS,LIC,TPS,MUD
2730 PTROUT = W(0) + W(1)*WIN + W(2)*SP + W(3)*SU + W(4)*AUT + W(5)*O + W(6)*FF
 + W(7)*FINGS + W(8)*LIC + W(9)*TPS + W(10)*MUD
2740 IF TROUT = 9999 THEN T$ = "????" ELSE T$ = STR$(TROUT)
2750 PRINT TAB(2);T$;TAB(30):PRINT USING "####.#";PTROUT
2760 IF P$ = "P" THEN LPRINT TAB(2);T$;TAB(30):LPRINT USING "####.#";PTROUT
2770 IF NOT EOF(2) THEN GOTO 2720
2780 CLOSE #2
2790 IF OK$ = "Y" THEN GOTO 2820
2800 IF P$ = "S" THEN INPUT "DO YOU WANT TO PRINT THIS - Y/N";OK$
2810 IF OK$ = "Y" THEN P$ = "P" : GOTO 2670
2820 END
```