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NEW ZEALAND FRESHWATER FISHERIES MISCELLANEOUS REPORT NO. 22

FEASIBILITY OF ESTABLISHING SELF-RECRUITING RAINBOW TROUT FISHERIES IN AUCKLAND REGIONAL COUNCIL WATER SUPPLY RESERVOIRS

by

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Report to: Auckland Regional Council

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MAF Fisheries

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ROTORUA

Servicing freshwater fisheries and aquaculture

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NEW ZEALAND FRESHWATER FISHERIES MISCELLANEOUS REPORTS

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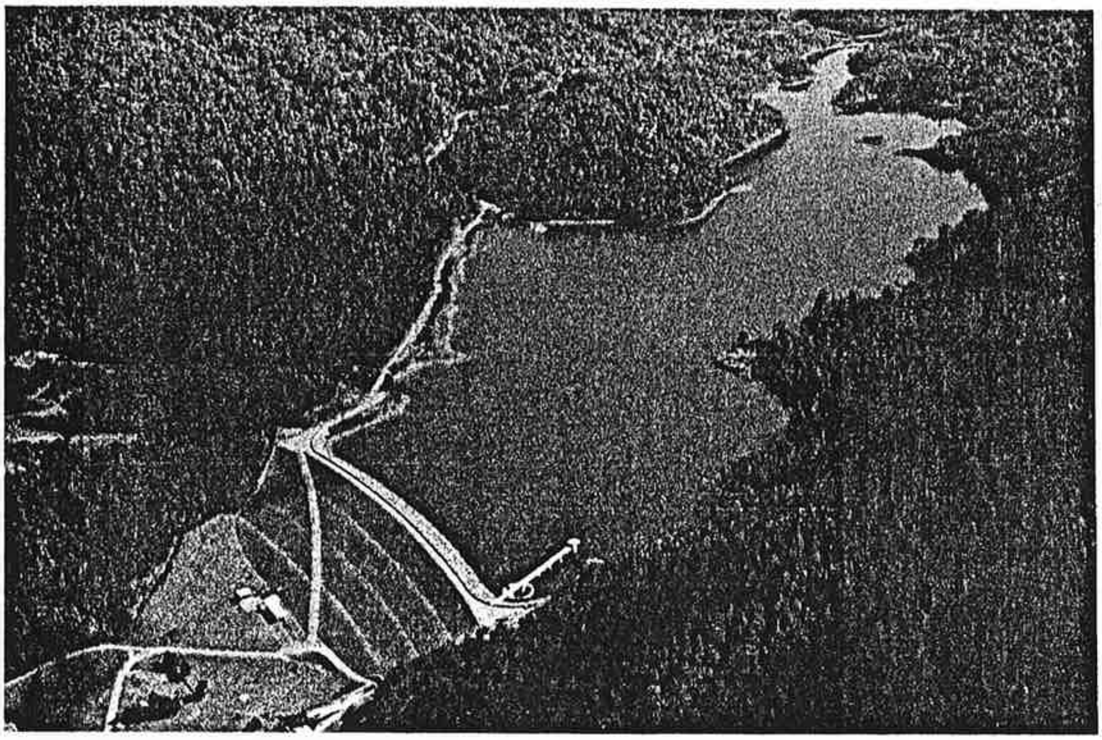

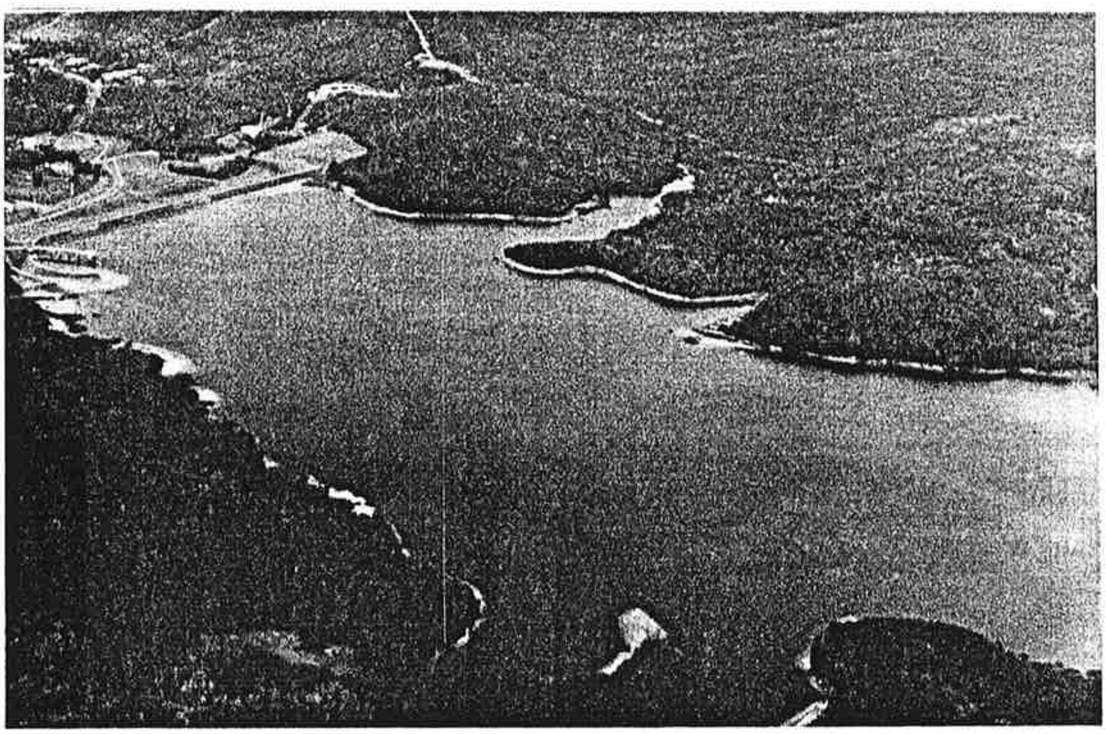

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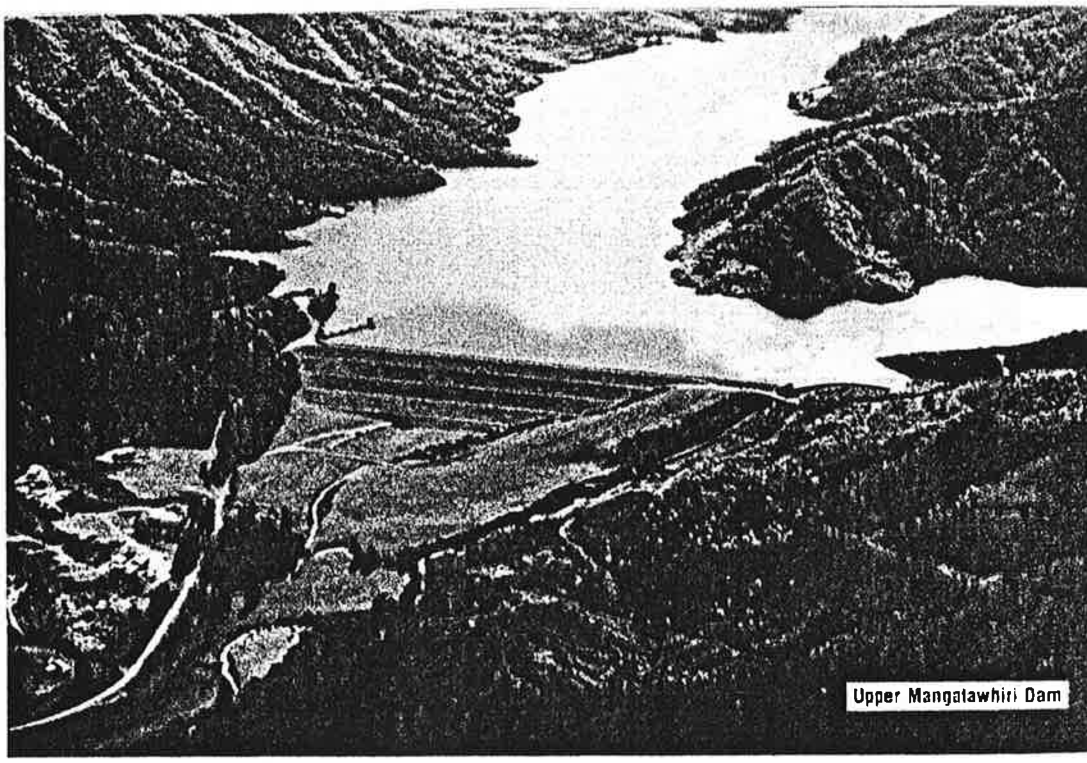

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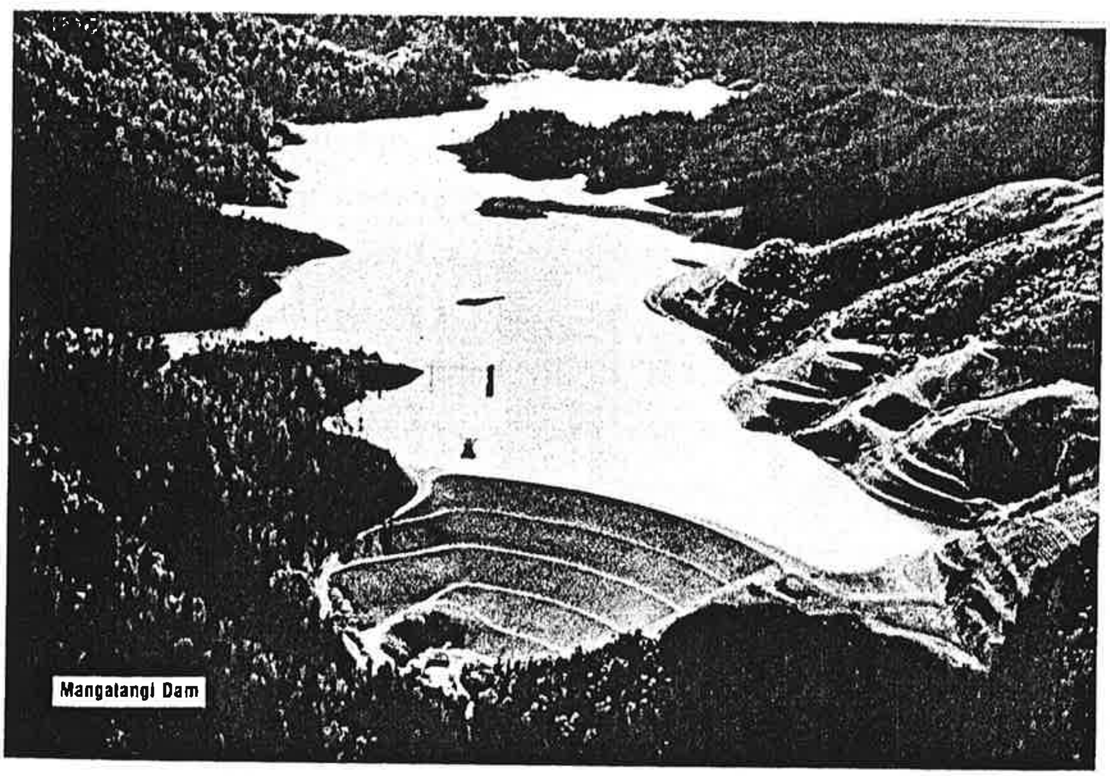

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1 SUMMARY

Summer water quality, in particular low oxygen and high temperature levels, limits trout habitat in all the Auckland Regional Council water supply reservoirs examined. This restriction will not limit the establishment of trout populations in the reservoirs, but can be expected to reduce growth rates. Fluctuations in water levels will also limit trout habitat and may hinder access to spawning streams. An examination of water level fluctuations over a ten year period showed that trout populations would be affected in drought years. Higher mortality rates for trout would have occurred in the Lower Huia, Lower Nihotupu and Wairoa Reservoirs had they been present. Growth rates would have been reduced in other reservoirs. Reservoir productivity, the relative size of feeding grounds for fish, and the fauna present indicate that moderate growth rates for trout can be expected. Spawning streams, particularly in the Hunua reservoirs contain adequate gravel sizes for egg laying and incubation. On the basis of the trout habitat variables examined the Managatangi Reservoir is the best environment for trout, however, the Upper Managatawhiri Reservoir is a close second.

The Upper Managatawhiri Reservoir already contains a self-recruiting trout population, and the limited data available on this indicates that growth rates and densities of fish would prove acceptable to many anglers in the Auckland region. It is concluded that while the ARC reservoirs in the Hunua Ranges could all support trout populations, densities and/or growth rates will

tend to be acceptable, only in the Mangatangi and Upper Mangatawhiri Reservoirs. The Waitakere Ranges reservoirs are not suitable environments for trout, except on a put-and-take basis.

There is a demonstrated need for additional freshwater angling in the Auckland region which could be met by the use of the ARC reservoirs as trout fisheries. However, it has been suggested that such use may jeopardize potable water supplies. The public health and water supply management implications of trout fisheries are discussed. Recommendations are offered for the establishment of trout fisheries, firstly on a trial basis in the Upper Mangatawhiri Reservoir, and ultimately in the Mangatangi Reservoir as well.

2 INTRODUCTION

2.1 Freshwater angling for trout in New Zealand and in the Auckland region.

Angling for freshwater fish is one of the most popular recreational sporting activities in New Zealand. Membership of angling organisations can be assessed from annual license sales and is estimated to be over 203,000 (Table 1). This can be compared with 200 000+ for the NZ Rugby Football Union and 110, 000+ for the NZ Netball Association.

Whereas angling is a NZ national pastime there are regional differences in its popularity. For example, angling is far more popular in the South Island than in the North. This situation reflects the abundance of good fishing waters in the South. In the North Island the most popular fishing region is the central North Island containing the Rotorua Lakes, Lake Taupo and Lake Waikaremoana. Because of this many Auckland anglers do not fish in the Auckland region and prefer to go south. It is estimated (Table 2) that there are at least 6,412 anglers in the Auckland region, but of these only 1,962 fish in the Auckland Acclimatisation Society District because of the lack of suitable angling waters. To put this into a national perspective 1.8% of adult males over 17 years and living in the Auckland Acclimatisation District are anglers. This compares with 6.2% in Hawkes Bay, 10.9% in the Central North Island and 13% for the South Island. (Teirney et al, 1982). Overall 6.2% of males,

Table 1: Importance of angling as a recreational pursuit in NZ. (Angling figures from annual fishing licence sales 1979 to 1981. Other figures from Order Paper No 87-1982 of the New Zealand House of Representatives).

Activity	Membership
Angling (all)	203 000
Angling (whole seasons)	101 040
NZ Rugby Football Union	200 000
NZ Netball Association	110 000
NZ Lawn Tennis Assn	60 900
NZ Bowling Assn	54 888
NZ Football Assn	52486
NZ Amateur Swimming Assn	37 887
NZ Rugby League	24 400
NZ Badminton Federation	19 500

Table 2: Auckland's angling population in relation to other NI districts and the South Island

District	Population total (1981)	Population (Males > 17 years)	Licence Holders (male > 17 years)	% of licence holders (males > 17 years
AUCKLAND	1 067 600	347 400	6 412	1.8
CENTRAL NI	233 900	74 600	8 153	10.9
TARANAKI	103 400	33 500	720	2.2
HAWKES BAY	139 100	43 300	2 702	6.2
WELLINGTON	532 100	178 200	4 651	2.6
NORTH ISLAND (total)		677 000	22 638	3.3
SOUTH ISLAND (total)		285 300	37 397	13.1
NEW ZEALAND (total)		962 300	60 035	6.2

Note: Potential Auckland anglers at 6.2% level 21 500 aged 17 years or older, hold whole season fishing licences in New Zealand. Many other people, including increasing numbers of tourists, fish for trout but do not purchase whole season licenses. These figures serve to illustrate the fact that approximately 70% of anglers in the Auckland Society district travelled outside the district to fish, because of the lack of suitable fisheries in the region. Based on national averages, there is a potential angling population of up to 21,500 people in the region who would fish there if suitable fisheries were available.

2.2 Actual and potential trout angling waters in the Auckland region

There are no major rivers in the Auckland Acclimatisation Society district capable of supporting high quality trout fishing comparable to that found in rivers such as the Tongariro, Mohaka, Rangitikei and Manganui-a-te-ao rivers further south.

The Lower Waikato River is larger than these other major North Island angling rivers, but trout fishing here is limited. Above Karapiro, hydro-electric reservoirs have replaced fishable waters in the river. Below Hamilton, the river becomes wide, shallow, sandy-bottomed, and fast-moving making it unsuitable for both trout and trout angling.

There are no rivers of national significance for trout angling in the region (Richardson et al 1985), but the Waihou river is the most popular trout fishing water. The Waipa river is the next most important river fishery, but is much further away from Auckland. Other rivers in the region support trout fisheries, but are generally very small in comparison with the Waipa and Waihou, or are further away (e.g. Awakino River). The Waihou, Waipa and Awakino Rivers were the only rivers classified as regionally important in the Auckland Acclimatisation Society district (Richardson et al. 1985).

The Auckland region is also poorly endowed with lakes and reservoirs that provide good trout fishing. Lakes of the Lower Waikato River (e.g. Waahi, Whangape) are too shallow and eutrophic to support trout populations. Trout fishing in the hydro-electric reservoirs of the Upper Waikato River is generally acceptable to local anglers. However, anglers from Auckland tend not to fish these waters as the central North Island lakes are just as far away, yet provide superior fishing opportunities.

Because of the lack of trout fishing opportunities near Auckland there are sporadic calls for the introduction of an alternative freshwater sports fish. In the 1950's the introduction of largemouth bass (Micropterus salmoides) was considered, and rejected, because of its likely interference with existing trout fisheries. Coho salmon (Oncorhynchus kisutch) were also considered because of their tolerance of warmer temperatures. More recently rudd (Scardinius erythrophthalamus) and tench (Tinca tinca) were illegally released into many northern waters to increase angling opportunities. The lack of freshwater recreational angling near Auckland will continue to lead to calls for the introduction of new species.

Many of the smaller lakes of the Auckland region would be suitable for perch (Perca fluviatilis) fishing. As these fish are already present in a number of northern waters, the Freshwater Fisheries Centre of MAFFish undertook an evaluation of the potential of perch fishing in the region between 1976 and 1979. (Graynoth 1978, Schipper 1980). The general conclusion arising from these investigations was that there was insufficient demand for this type of fishing to warrant further work. Despite growing interest in coarse fishing it is apparent that trout fishing is still the most popular form of freshwater angling at present, and will remain so for the foreseeable future.

Recognising this, and because of the pressure to expand angling opportunities, particularly for trout, the Auckland Acclimatisation Society has encouraged moves by MAFFish to improve or increase trout fishing waters in the Auckland region.

One approach adopted by MAF Fisheries involved habitat rehabilitation and fishery reconstruction in eutrophic lakes, where trout fisheries were once established, but had deteriorated. Work in this field began on L. Tutira (Hawkes Bay) where air guns were installed to break up water stratification and so improve the summer oxygen balance of the lake. More recently the twin problems of water weeds and rudd (noxious fish) were eliminated in L. Parkinson (Pukekohe), so paving the way for trout fishery reconstruction (now successfully completed). These experiences gained in fishery restoration may have application for L. Pupuke, a once important trout fishery in the Auckland region, now downgraded by water quality problems, aquatic weeds and possibly rudd and perch.

Another approach towards increasing angling opportunities has involved the stocking of trout into new waters. MAF Fisheries evaluated the effects of stocking Lake Ototoa with rainbow trout (Penlington 1985). This is now a moderately successful fishery.

There is clearly a demand for freshwater angling opportunities in the Auckland region. River fishing is limited and, apart from Lakes Pupuke and Ototoa, the Auckland Regional Council's water reservoirs in the Waitakere and Hunua Ranges (Fig 1) are the only large, high quality, static waters with the potential to sustain good trout fisheries near Auckland. However, public access to the reservoirs has been restricted since their commissioning.

2.3 Background to this investigation

The 1967 Act for the Conservation of Water and Soil in New Zealand promulgated a national policy for the multiple use of water resources. It provided the impetus for examining recreational use in water supply catchments, and in particular for water-based recreation in water supply reservoirs. The Forestry Council, and Forestry Development Conferences (1969 and

1975) have promoted increased recreational use of water supply catchments, mainly because many of these restricted-access catchments are in forests (NZ Forestry Council 1981).

The Auckland Acclimatisation Society has lost regionally important trout fisheries as a result of reservoir construction. For example, Hobbs (1936) stated that,

> "the trout fisheries in the Mangatangi and Mangatawhiri streams are the nearest to where the potential angling population is greatest and are therefore of especial interest".

Furthermore, he indicated that these streams might offer more extensive spawning areas than most others in the Auckland Acclimatisation Society area, and in comparison to other streams, were remarkable in that they were of a type in which trout were particularly easy to catch.

Auckland anglers have long been interested in obtaining access to the ARC water supply reservoirs for trout fishing. In 1975 the Auckland Acclimatisation Society obtained approval to determine the fish species present in both the Waitakere and Hunua Reservoirs. This survey work resulted in a series of reports (Thompson 1976 a,b,c,d,e,f). In January 1976, members of the Auckland Freshwater Anglers Club petitioned the Works Committee of the ARC to allow them access to the Hunua reservoirs for trout fishing. Their case was based on the need for compensatory

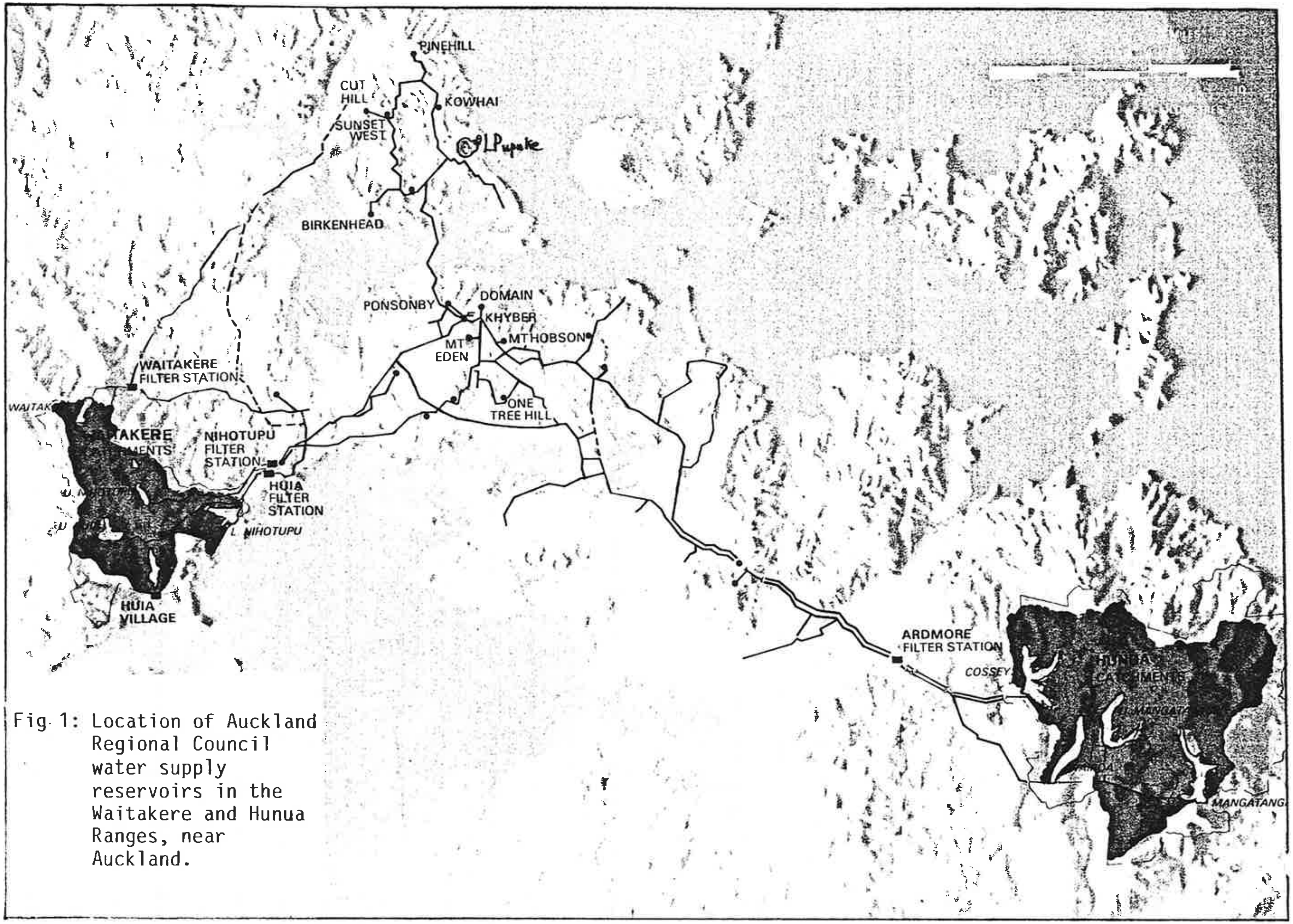

Fig. 1: Location of Auckland Regional Council water supply reservoirs in the Waitakere and Hunua Ranges, near Auckland.

angling opportunities, to replace fishing waters lost when the reservoirs were constructed. In response, the ARC commissioned a lengthy report on the potential for all types of recreation in the water supply catchments (Hill 1976). The Hill report expressed strong opposition to the opening up of water supply catchments to the public. In its case against fishing it mentioned a number of objections, specifically:

1. The lack of demand for angling in the Auckland region.
2. The need to remove coarse fish by rotenoning reservoir waters.
3. The introduction of small forage fish for trout which would block intake screens.
4. The danger to anglers of fishing from steep-sided, muddy slopes.
5. The effects of anglers on bank erosion and consequently turbidity levels.
6. The cost of providing facilities.
7. The precedent established with respect to claims by other recreational groups (e.g. sailing and canoeing).
8. The use of chemicals for weed control, which would harm trout.

As a consequence of the Hill report on recreational use of water supply catchments (Hill 1976), the ARC's policy of excluding the public was continued.

By 1981, three reports had been published indicating that limited public access to water supply reservoirs should be allowed. Firstly, the draft regional scheme for Auckland recommended that water supply catchments be progressively opened up for recreational use, 'where such use didn't compromise water supply functions'.

At the same time the Health Department proposed a recommended policy allowing consideration of recreational use in water supply catchments (N.Z. Health Dept., 1980). The policy indicated that the Medical Officer for Health would consider approving recreational use where:

(1) The water supply catchment assumed great importance as a recreational resource because of a shortage of similar facilities in reasonable proximity.

(2) The Health Department grading of the water supply remained at an A level. (The grading system took into account the quality of raw water, activities occurring in the catchment, and the level of treatment applied to the water).

The third report, from the Forestry Council, investigated the issue of public access to forested water supply catchments, using the Hunua reservoirs as one of its case studies (N.Z. Forestry Council, 1981). This report, by Dr Juliet Batten, concluded that:

there was no urgent need for water based activities in ARC reservoirs, except in the case of freshwater angling.

It identified the Mangatawhiri and Mangatangi Reservoirs as waters with some potential for trout fishing. Because of these 3 reports the ARC Works Committee reviewed its policy on public access to water supply catchments. In 1981 it proposed the further development of a network of walking tracks in the fringe areas of water supply catchments. It also recommended further investigations to determine the scope for recreational use in the catchments, and the impact of such activities on water supply.

In view of the ARC's proposed investigations, and the Forestry Council's conclusion that there was a case to be made for fishing in the reservoirs, a scientific investigation into the feasibility of establishing trout fisheries in the reservoirs was warranted. This would identify and rank the reservoirs in terms of their suitability for producing self-sustaining, or stocked, populations of reasonable sized trout. In addition it would examine the perceived problems raised in the Hill Report so that they could be discussed on a factual, scientific and objective background.

The Fisheries Research Centre of MAF Fisheries (Rotorua) obtained permission from the Water Supply department of the ARC to analyse data and report on the trout fishery potential of ARC water supply reservoirs (Plates 1,2,3). The Waitakere, Upper Huia and Upper Nihotupu reservoirs were excluded because of their unsuitability for trout angling. They are smaller, generally less accessible, and are characterised by greater fluctuations in water level than the other reservoirs.

2.4 Aims of the investigation

This report summarises the results of the investigation by the Fisheries Research Centre of MAF Fisheries (Rotorua) and the Auckland Acclimatisation Society. It analyses biological and limnological data available for the reservoirs and determines whether trout populations could survive, grow, and reproduce in the reservoirs. As such it is the first step in the scientific assessment of the reservoir's trout fishery potential.

In determining whether trout populations could survive, grow and reproduce in the ARC's water supply reservoirs four objectives were formulated:

(a) To determine which reservoirs contain suitable water quality habitat, in terms of oxygen and temperature levels, for trout survival and growth.

(b) To determine the relative biological productivity and potential food sources available to trout in the reservoirs.

(c) To determine whether water level fluctuations in the reservoirs would seriously reduce trout habitat, or compromise the food resources available to trout.

(d) To determine which reservoirs contain suitable tributary streams for trout spawning, and the subsequent rearing of juveniles, before they emigrate to the reservoirs.

Limnological data collected by the Water Supply Department of the Auckland Regional Council were made available to MAF Fisheries, and analyses of these data have enabled conclusions to be drawn concerning each of the first three aims above. In addition, field data collected by the Auckland Acclimatisation Society and MAF Fisheries has provided information on the fauna present in the reservoirs, and on the suitability of the tributary streams for trout spawning.

As a result of the conclusions concerning each of the four objectives, the reservoirs are ranked in terms of their overall potential for sustaining trout populations. Concerns over the implications of trout fishing for water quality management are addressed, and fishery management options that may arise in the future discussed.

This report cannot predict the viability of trout fisheries, should they be established. Trout anglers expect reasonable catch rates, and require fish of a reasonable size and condition. Limited data on density and size of trout in two of the reservoirs are available and provide, at best, a comparative guide to potential sizes and catch rates of trout. Other values are also important. For example, solitude, scenic attributes, ease of access, and social factors (eg. opportunity to link angling with family outings) can also influence whether or not a particular water is frequented. The viability of the reservoirs as trout fisheries can only be established *a posteriori*, by opening them to anglers on a trial basis.

This report does not examine use of the reservoirs for coarse fish angling, which although it is comparatively less popular than trout angling, is becoming steadily more popular in the Auckland region. Nevertheless, because trout and coarse fish populations are in general incompatible, reservoirs identified as being not suitable for trout may be more suitable environments for some coarse fish species.

3 WATER QUALITY IN RESERVOIRS AND THE PHYSICAL HABITAT AVAILABLE TO TROUT

3.1 Introduction

Oxygen and temperature levels in static waters, such as lakes and reservoirs, are the major components of water quality determining the physical space or habitat available to trout.

Trout are a cold water fish species. Adult rainbow trout have a preferred temperature of 12-13^{o}C, compared with 17^{o}C for juveniles, and thrive in relatively cold waters where the seasonal maximum is less than 18^{o}C. Temperatures over 21^{o}C occur in the surface waters of many North Island lakes. Such temperatures depress the depth distribution of rainbow trout, thereby restricting feeding on surface foods (Rowe 1984a). Relatively high water temperatures also limit their reproduction. Temperatures over 15^{o}C affect survival of rainbow trout eggs (D. Scott, pers. comm.) and, as this species spawns in spring, warm weather could reduce egg survival in exposed streams. Because of these temperature limitations, trout do not thrive in northern New Zealand and are near the limit of their latitudinal range.

Although high surface water temperatures set the upper limit to the depth distribution of trout in lakes, low oxygen levels often set the lower limit. Trout cannot survive in waters where oxygen levels are below 2.5-3mg/l, and have been observed to actively avoid such waters. They require oxygen levels over 5mg/l to maintain their normal swimming activity and stamina (Jones 1971). The depth range within which they can forage will therefore be limited to waters where oxygen levels are over 3mg/l. Foraging activity will be impeded between 3-5mg/l but not prevented. As a consequence I have used 4mg/l as the limit for determining the lower depth limit to trout habitat in lakes.

Oxygen levels near the bottom of lakes and reservoirs are reduced by nutrient enrichment (eutrophication) and, in lakes which stratify, the hypolimnion is usually anoxic. During summer months, trout depth distributions in many North Island lakes are compressed between the warm epilimnion and the anoxic hypolimnion. In lakes where the size of this habitable metalimnion is relatively small, growth of trout is restricted during summer months (Rowe 1984b, Rowe & Scott 1989). Nevertheless, the development of successful trout fisheries, based on stocked fish in Lake Ototoa (South Kaipara Head), and Lake Taharoa (north of Dargaville), and more recently in L. Ngatu (North of Kaitaia), indicates that rainbow trout fisheries can be established in some northern New Zealand waters, even though water quality limits habitat and growth rates. As water quality is one of the major factors limiting habitat of trout in lakes and reservoirs, oxygen and temperature levels need to be considered when determining the feasibility of northern New Zealand waters for trout populations.

In small lakes thermal stratification (and low oxygen levels in bottom waters) can be very temporary, whereas in large lakes such conditions may persist for months. Thus, a measure of the amount of time over which limiting temperatures and oxygen occur at various depths, is also needed.

3.2 Methods and Analysis

Monthly oxygen and temperature levels, recorded between January 1981 and March 1982, at various depths below TWL (top water level mark) were examined to determine the extent of water quality restrictions on trout habitat. The depths, below TWL, of the $21^{o}C$ isotherm, and the 4ppm oxygen isopleth, were plotted for each reservoir and show seasonal changes in the depth range of trout habitat. Although trout can survive outside these oxygen and temperature limits, their distribution, and to a large extent their movement and feeding, will be confined to waters within them. The 1 ppm oxygen level was also plotted to indicate the depth at which other life, particularly benthic food sources for trout, would be absent (See 5.3.4).

The extent of restrictions on trout distribution in terms of both depth and time were calculated for each reservoir. The reservoirs were then ranked in terms of the depth range for trout habitat during summer months. I also examined depth profiles of oxygen for the year 1988/89 to determine whether there had been any significant changes with time.

3.3 Results and Conclusions

Results are presented graphically in Figures 2 to 7, and Table 3. The reservoirs are artificially aerated to maintain oxygen levels above 5mg/l (Ashton 1989). However, it is apparent that oxygen levels can decline to lower levels than this before aeration is initiated, and they are restored.

The only reservoir where bottom oxygen and surface temperature limits for trout overlapped was the Lower Nihotupu (Fig 3). Here, trout, had they been present, would have been severely constrained in distribution over summer, and in March 1981, would have been stressed by the lack of habitable water. Under such conditions trout will often concentrate in the cool waters near stream mouths. Results from all other reservoirs (Fig 2, 4, 5, 6, 7) showed that while oxygen and temperature limits did not overlap, trout would have been constrained within a relatively narrow depth range over summer months.

In 1980, the Wairoa Reservoir provided the largest depth zone of habitable water for trout, allowing access to more than 4m of water throughout the year (Table 3). In comparison with other reservoirs the 21^{o} isotherm in the Wairoa Reservoir was the shallowest (6 m) and the depth of the 1 ppm oxygen level approached 17 m, which compares favourably with 18 m, the upper limit for deoxygenated waters in the Mangatangi Reservoir. The Wairoa Reservoir therefore provided the best water quality environment for trout over the summers of 1980/81 and 1981/82.

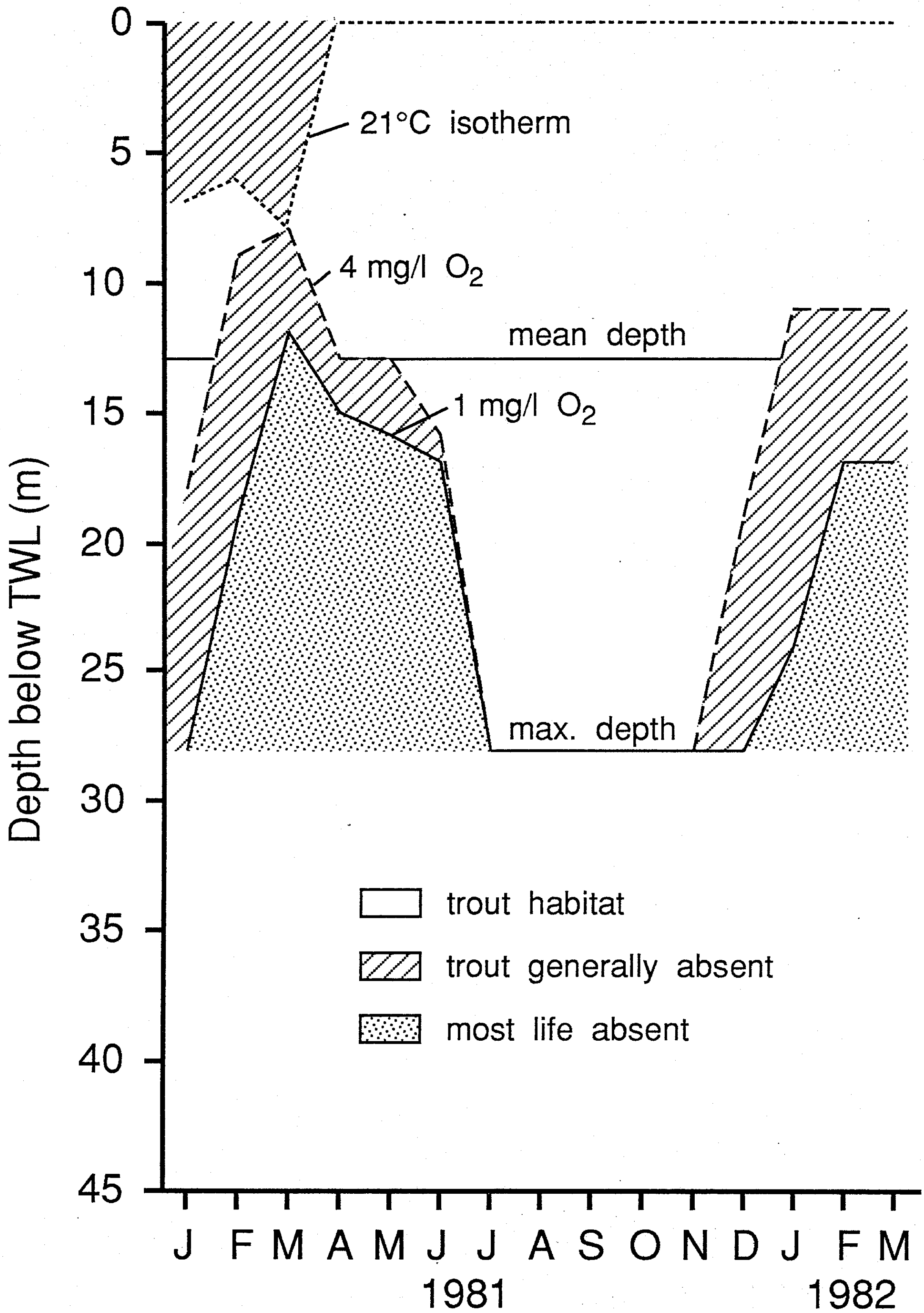

Fig. 2 : Effects of seasonal oxygen and temperature limits on trout habitat in the Lower Huia Reservoir, 1981-82

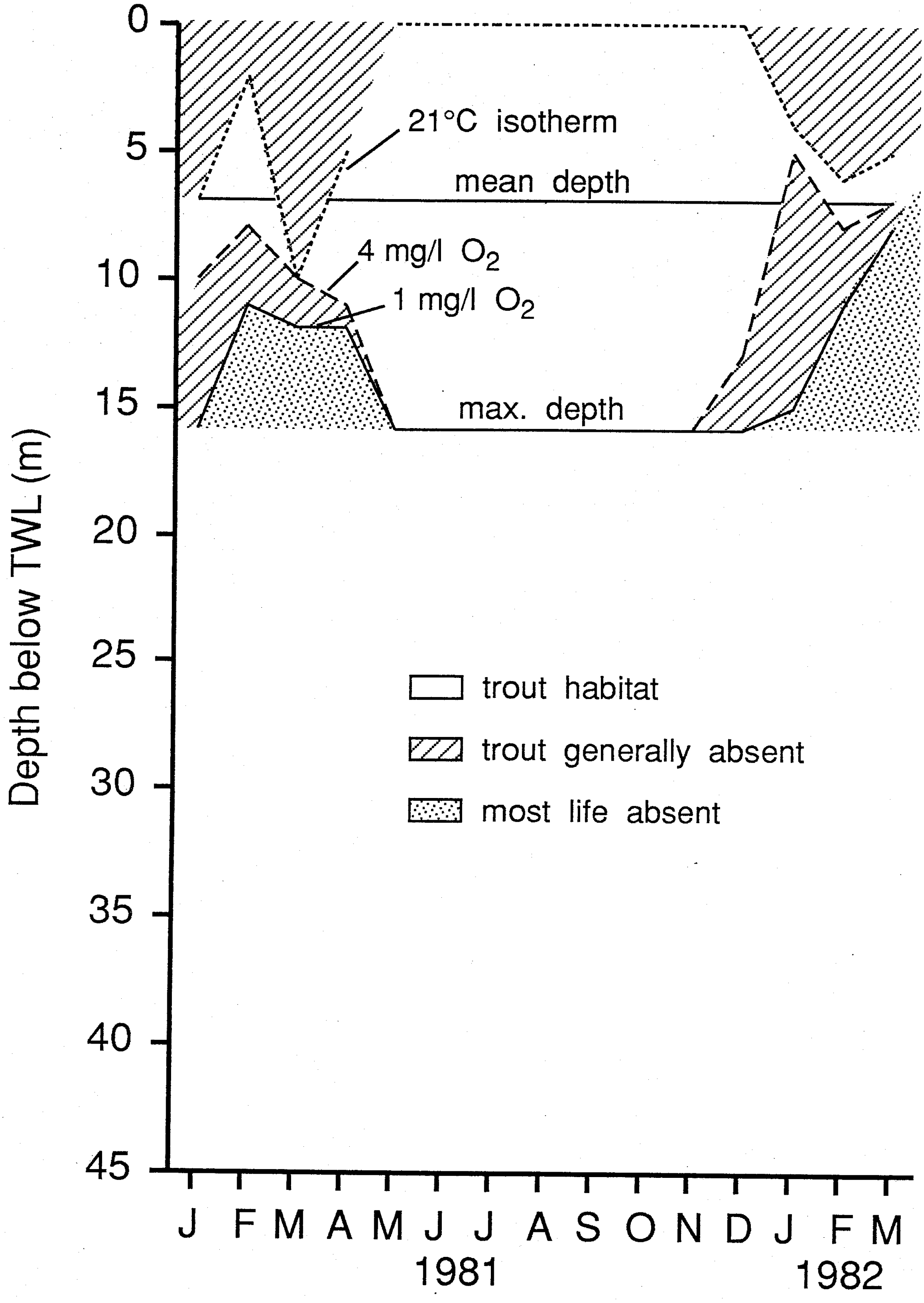

Fig. 3 : Effects of seasonal oxygen and temperature limits on trout habitat in the Lower Nihotupu Reservoir, 1981-82

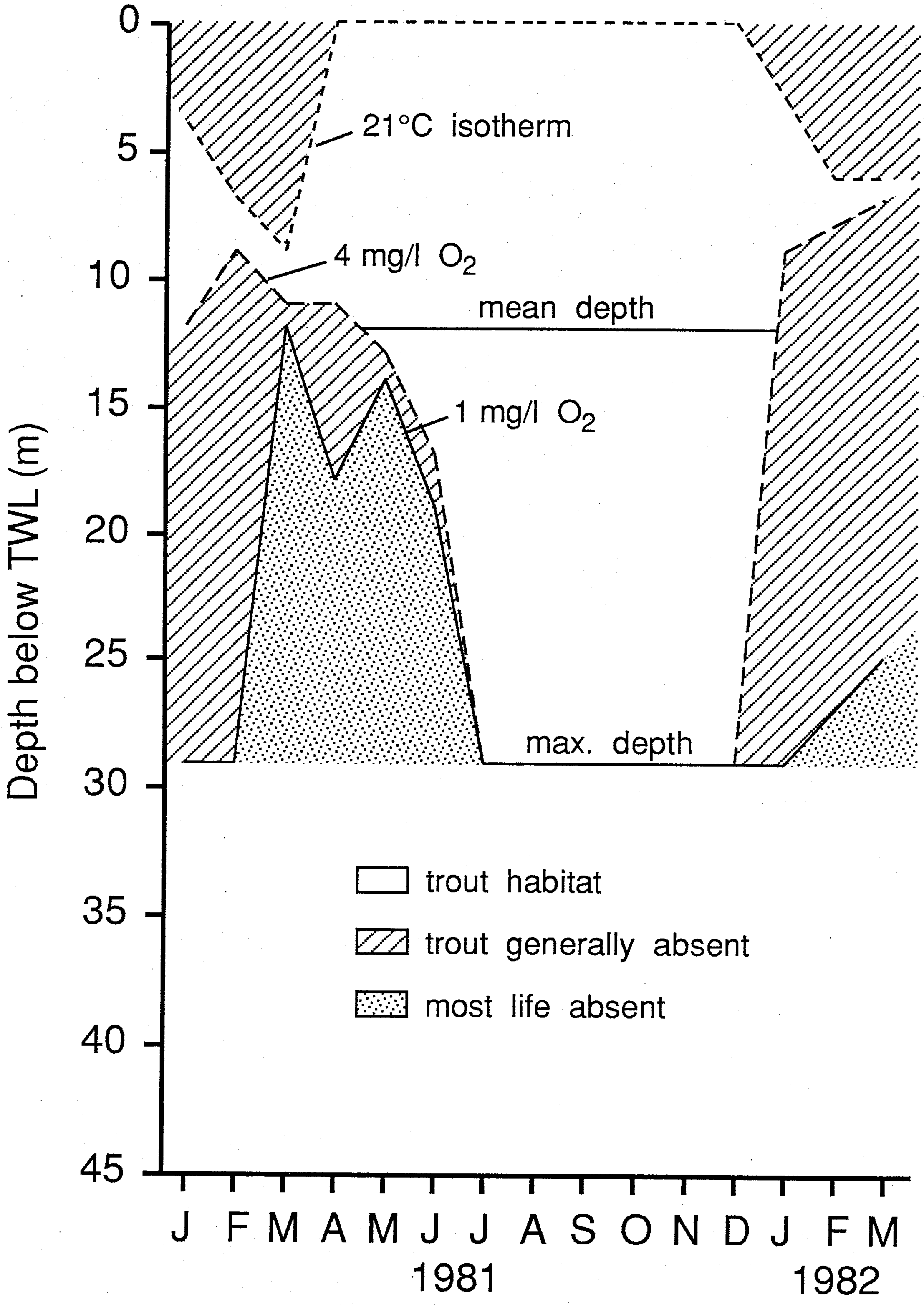

Fig. 4 : Effects of seasonal oxygen and temperature limits on trout habitat in the Cossey's Creek Reservoir, 1981-82

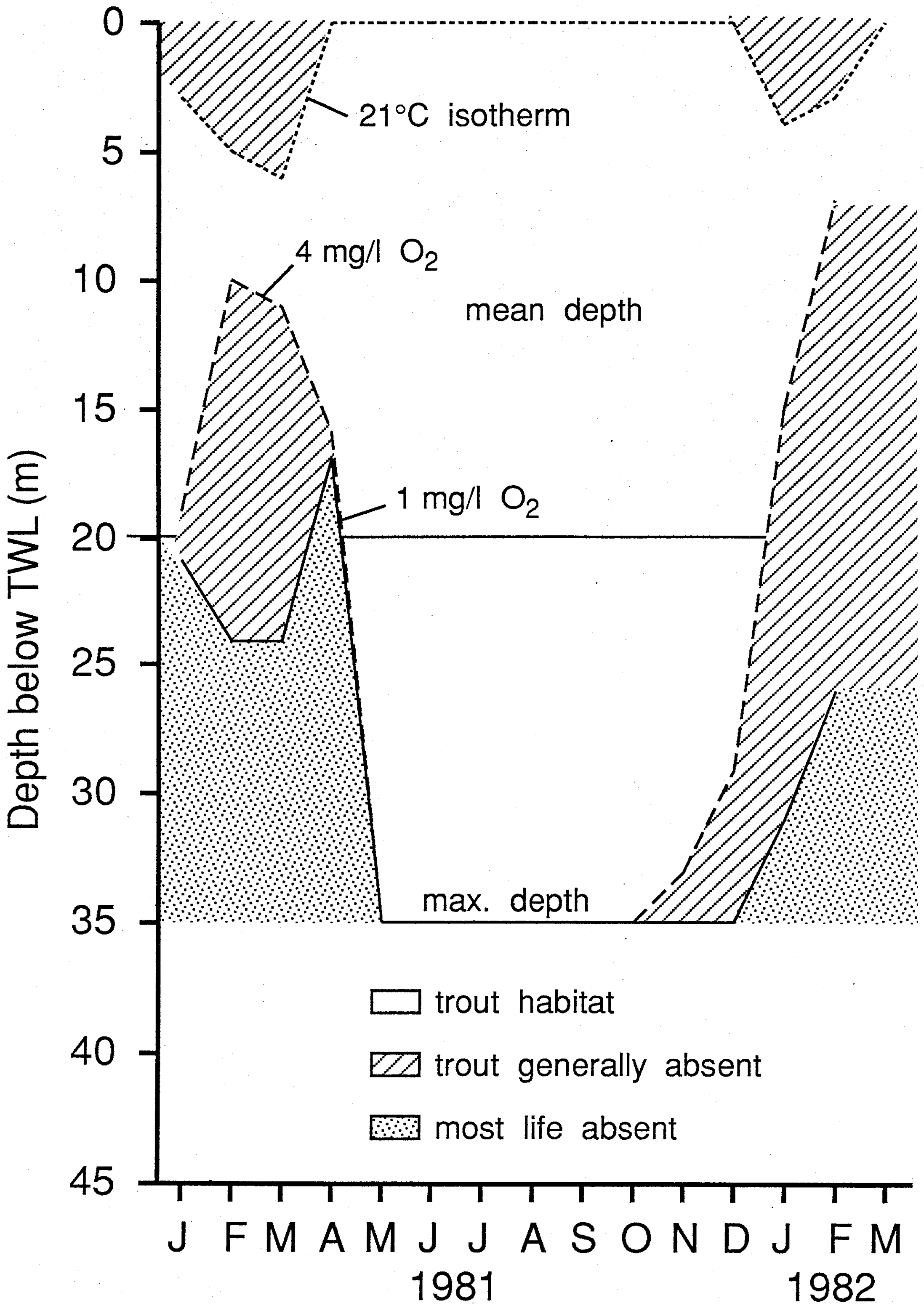

Fig. 5 : Effects of seasonal oxygen and temperature limits on trout habitat in the Wairoa Reservoir, 1981-82

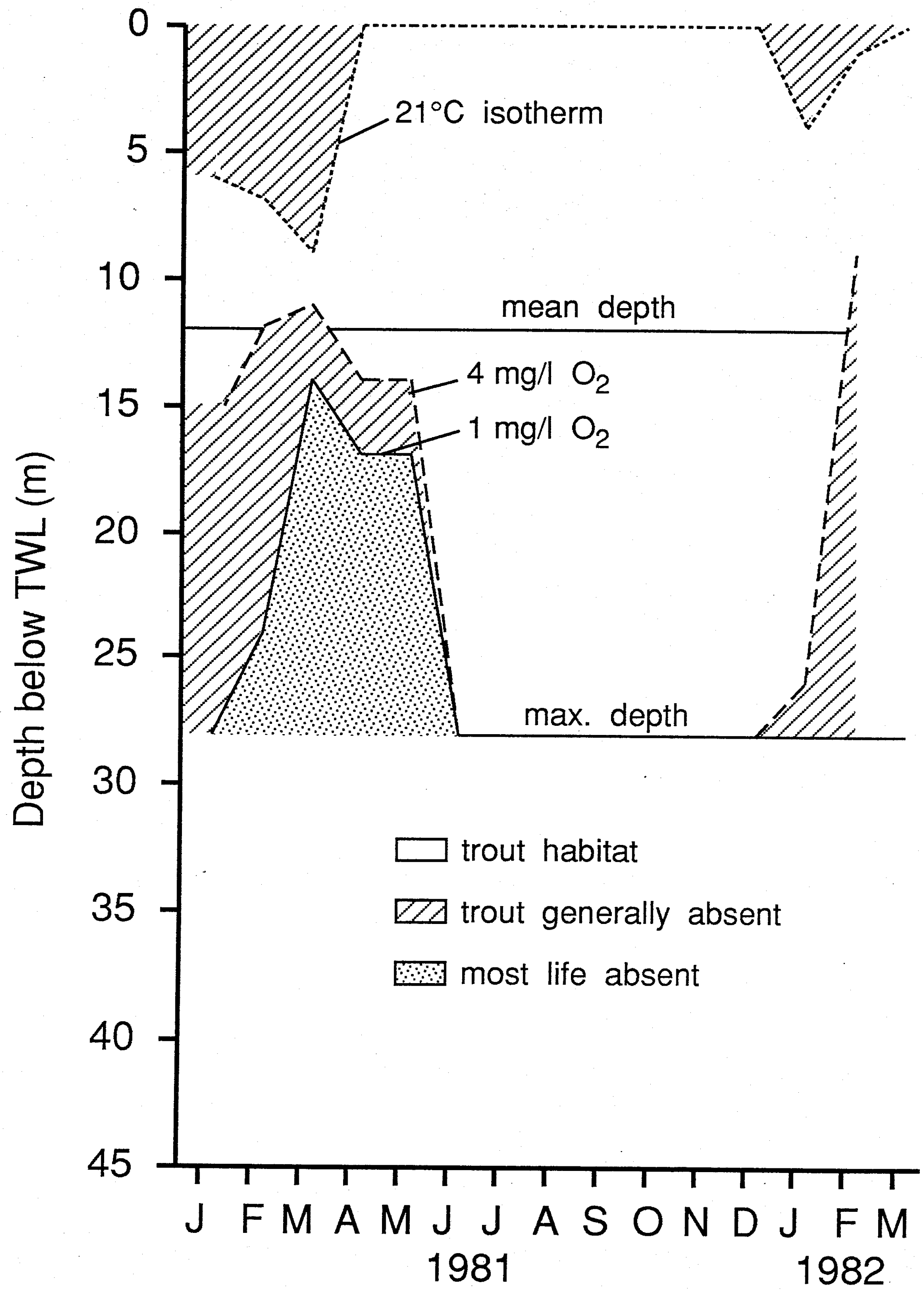

Fig. 6 : Effects of seasonal oxygen and temperature limits on trout habitat in the Upper Mangatawhiri Reservoir, 1981-1982

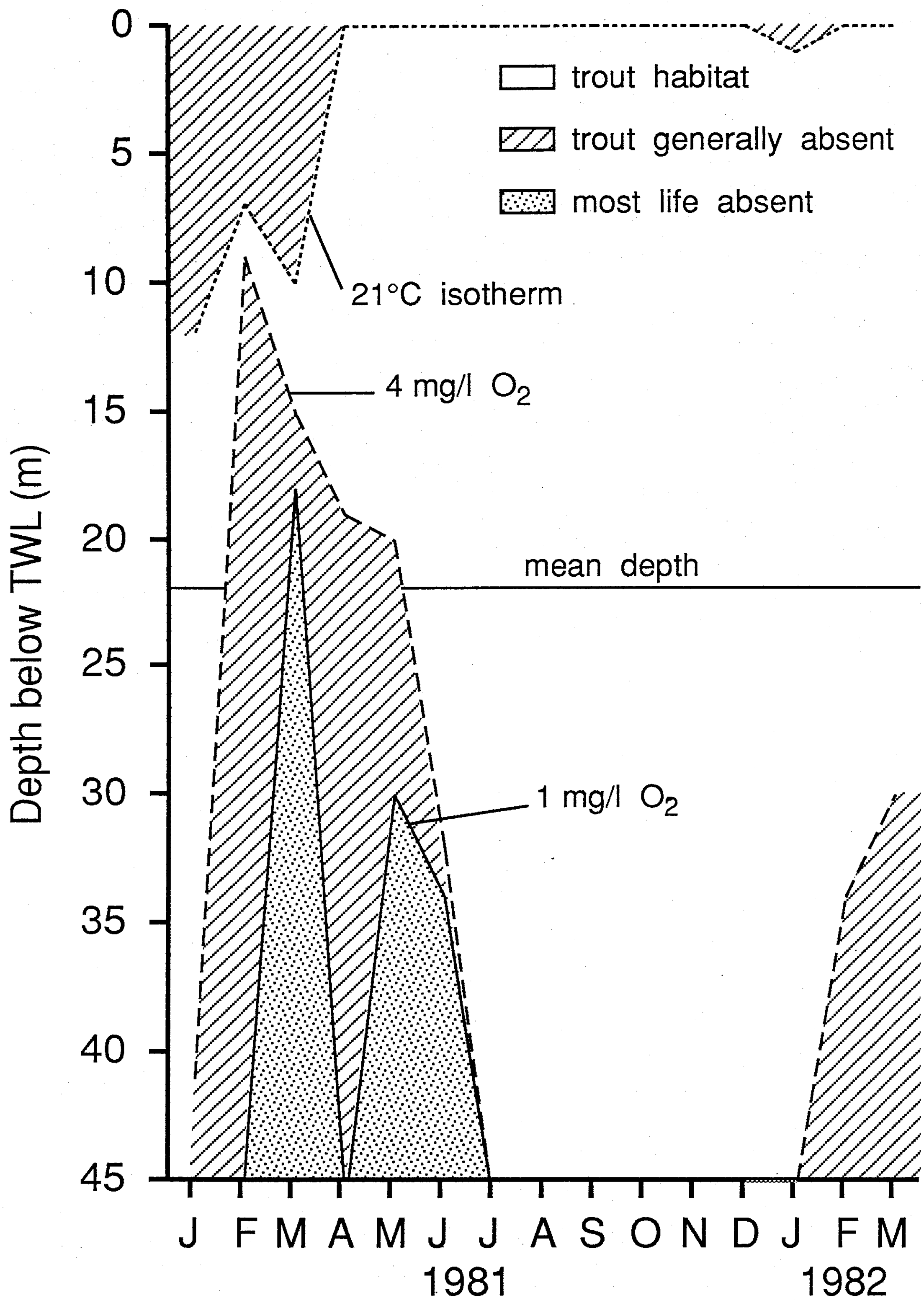

Fig. 7 : Effects of seasonal oxygen and temperature limits on trout habitat in the Mangatangi Reservoir, 1981-82

Table 3: Summary and ranking of the effects of oxygen and temperature on trout habitat in ARC reservoirs

Reservoir rank		Months/annum when trout restricted to a 4 m or less column of water	Shallowest depth (m) of the 1 ppm oxygen level below TWL	Maximum depth (m) of 21° isotherm below TWL	Months/annum when top 2m of water exceeded 21°C
1	Wairoa	0	17	6	5
2	Mangatangi	1	18	12	3
3	Mangatawhiri	1	14	9	4
4	Lower Huia	2	12	8	3
5	Cosseys	2	12	9	6
6	Lower Nihotupu	5	11	10	6

Of the remaining four reservoirs the Upper Mangatawhiri and Mangatangi, both in the Hunua ranges, provided better habitat for trout than the Lower Huia or Cosseys Reservoirs. Of the two Waitakere Ranges reservoirs, the Lower Huia contained significantly more water quality habitat for trout than did the Lower Nihotupu.

These conclusions are based on data for the summers of 1980/81 and 1981/82 and may not reflect the current situation. An examination of water temperatures and mid-depth oxygen levels in each reservoir between 1986 and 1989 was carried out by the ARC. Oxygen levels were generally lower during 1988/89 than during the previous two years (Ashton 1989). Monthly depths of the 4mg/l oxygen isopleth for 1988/89 were therefore compared with those obtained in 1980/81. The shallower depth of the 4mg/l isopleth in the Lower Huia and Lower Nihotupu Reservoirs during 1988/89 indicates that trout habitat in the two Waitakere Ranges reservoirs has decreased. However, in the Hunua reservoirs it has increased.

Rankings of the reservoirs in terms of restrictions in depth for trout imposed by oxygen levels remains virtually unchanged (Table 4). The Wairoa, Upper Mangatawhiri and Mangatangi Reservoirs still provide comparatively more trout habitat than the Lower Huia, Lower Nihotupu and Cosseys Reservoirs. The main difference has been the improvement in oxygen levels in the Mangatangi Reservoir. It was still filling in 1980 and new reservoirs usually experience several years of increased biological

Table 4: Means of monthly oxygen levels (mg/l) recorded between June 1988 and August 1989 in ARC reservoirs. Reservoirs are ranked left to right in terms of increasing depths of oxygenated water (the staggered solid line represents depth limits for the 8mg/l level).

Depth (m)	Lower Huia	Lower Nihotupu	Cosseys	Upper Mangatawhiri	Wairoa	Mangatangi
0	8.66	8.77	8.89	9.17	9.03	9.06
3	8.40	8.57	8.73	8.98	8.97	9.04
6	7.90	8.03	8.34	8.71	8.72	8.79
9	7.74	7.47	8.03	8.39	8.57	8.44
12	7.68	7.23	7.97	8.19	8.45	8.33
15	7.50	7.03	7.89	8.06	8.26	8.17
18	7.24		7.86	7.96	8.10	8.08
21	7.10		7.83	7.80	8.08	8.13
24	6.99		7.75	7.72	8.05	8.16
27	6.81		7.60	7.28	7.88	8.14
31					7.54	8.07
35					7.41	8.02
39					7.34	7.98
43						7.92
47						7.76
53						7.65

production before they mature. Oxygen levels during 1980/81 and 1981/82 were probably influenced by this and have since improved. As a consequence the Mangatangi Reservoir now provides more trout habitat in terms of the depth of water available to trout than the Wairoa Reservoir.

The greater depth of oxygenated water for trout in these two reservoirs is associated with their comparatively deeper maximum depth and lower ratios of mean depth to maximum depth, reflecting basin form (Table 7).

4 IMPACTS OF WATER LEVEL FLUCTUATIONS ON TROUT HABITAT AND SPAWNING IN THE RESERVOIRS

4.1 Introduction

Water level fluctuations in water supply reservoirs are an integral part of reservoir management but can have a significant effect on the depth and volume of water available to fish. Reductions in water level can also directly affect access to spawning streams during the annual spawning migration of trout. Secondary or indirect effects of water level fluctuations on trout occur as a result of impacts on water quality, on biological production, and on the littoral and benthic food-producing areas of reservoirs. In some cases these secondary effects can be more serious than loss of space or access to spawning streams. Nonetheless, the effects of reservoir drawdown on habitat available to trout need to be examined first. Effects of secondary impacts will be examined later (See 5.3.4).

At present, reservoir drawdown is controlled by computer program (HUDAT) which regulates flows from each reservoir so that they all fill, or empty (during a prolonged drawdown), at the same time. However, because of the differing sizes and shapes of the reservoirs, water levels can be expected to drop at different rates. Thus impacts due to water level fluctuations will be more severe in some reservoirs compared with others.

Impacts due to reservoir drawdown will also vary on a seasonal and annual basis, depending on the relationship between supply and demand. Water supply to the reservoirs is largely controlled by rainfall and catchment size, and varies both seasonally and annually. In comparison, the overall demand for water is related mainly to the growth in population size of Auckland City. The timing and extent of future reservoir drawdowns is therefore difficult to predict. At worst, a one-in-a-hundred year drought would necessitate a complete drawdown of all reservoirs during summer months, and would last several years (pers. comm., P. Thomas). This would cause a high, if not complete, mortality of adult trout in all reservoirs. Such an extreme drought would eliminate angling for several years. However, lesser droughts, while seriously reducing trout habitat, may not result in mortalities, and therefore would not prevent use of the reservoirs as fisheries. Annual variations in drawdown therefore need to be considered to assess the impacts of moderate droughts on trout habitat. In addition relative differences in the extent and rate of drawdown between the reservoirs will determine which, if any reservoirs, are better suited as environments for trout.

The simplest way to guage the extent and frequency of impacts due to reservoir drawdown is to examine actual changes in water levels over an extended time for each reservoir. Examination of water level fluctuations over a period of ten years, including at least one dry period, is likely to reflect important patterns in drawdown between the reservoirs.

4.2 Methods and Analysis

Fortnightly measurements of reservoir water level below TWL were obtained from the ARC for the years 1977 to 1987 inclusive (1977 to 1982 for Waitakere Ranges Reservoirs). These were plotted and show differences in the rate of drawdown in water level, as well as seasonal changes in water level fluctuations, between the reservoirs.

4.3 Results and conclusions

There was a tendency for drawdowns to occur during late summer/autumn each year, with water levels reaching a minimum during April (Figs. 8-13). Greatest drops in water level occurred in 1978 and 1983, with the effects of the 1983 drought extending throughout 1984. In comparison 1979, 1980, 1985, and 1986 were years of comparatively minimal drawdown. Data summarising water level fluctuations in the reservoirs are presented in Table 5 and provide a basis for ranking the reservoirs in terms of potential impacts on trout.

During drought years (1978, 1983) the mean depth of reservoirs was reduced by 58-91%. The mean depth of water remaining in the Lower Huia, Lower Nihotupu and Wairoa reservoirs was less than 2m. Although this minimum depth occured during June/July, when water quality would not restict trout habitat, the 3-4 month long duration of low water levels would combine with reduced feeding and increased predation to cause high mortality of trout.

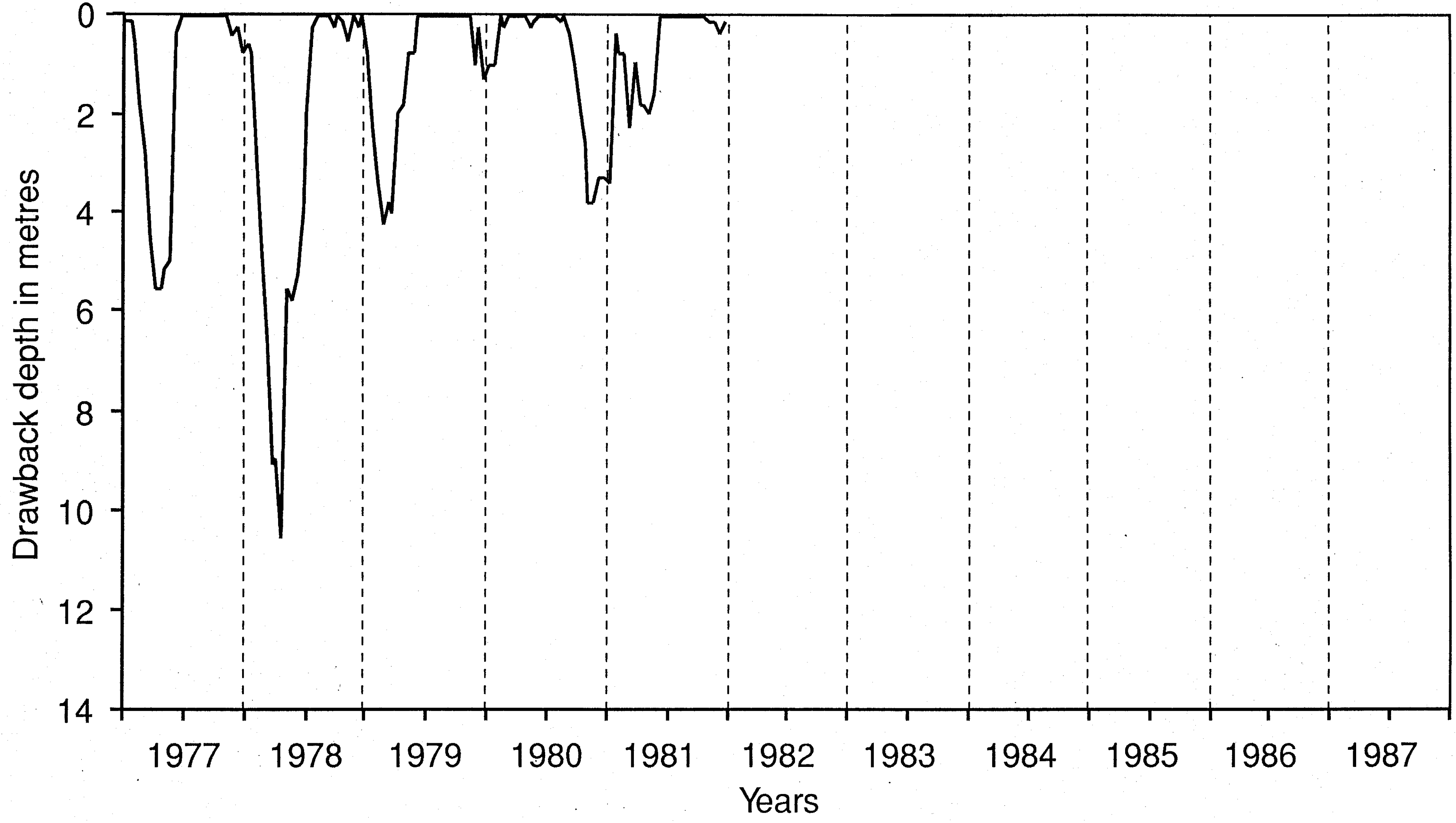

Fig. 8 : Water level fluctuations in the Lower Huia Reservoir

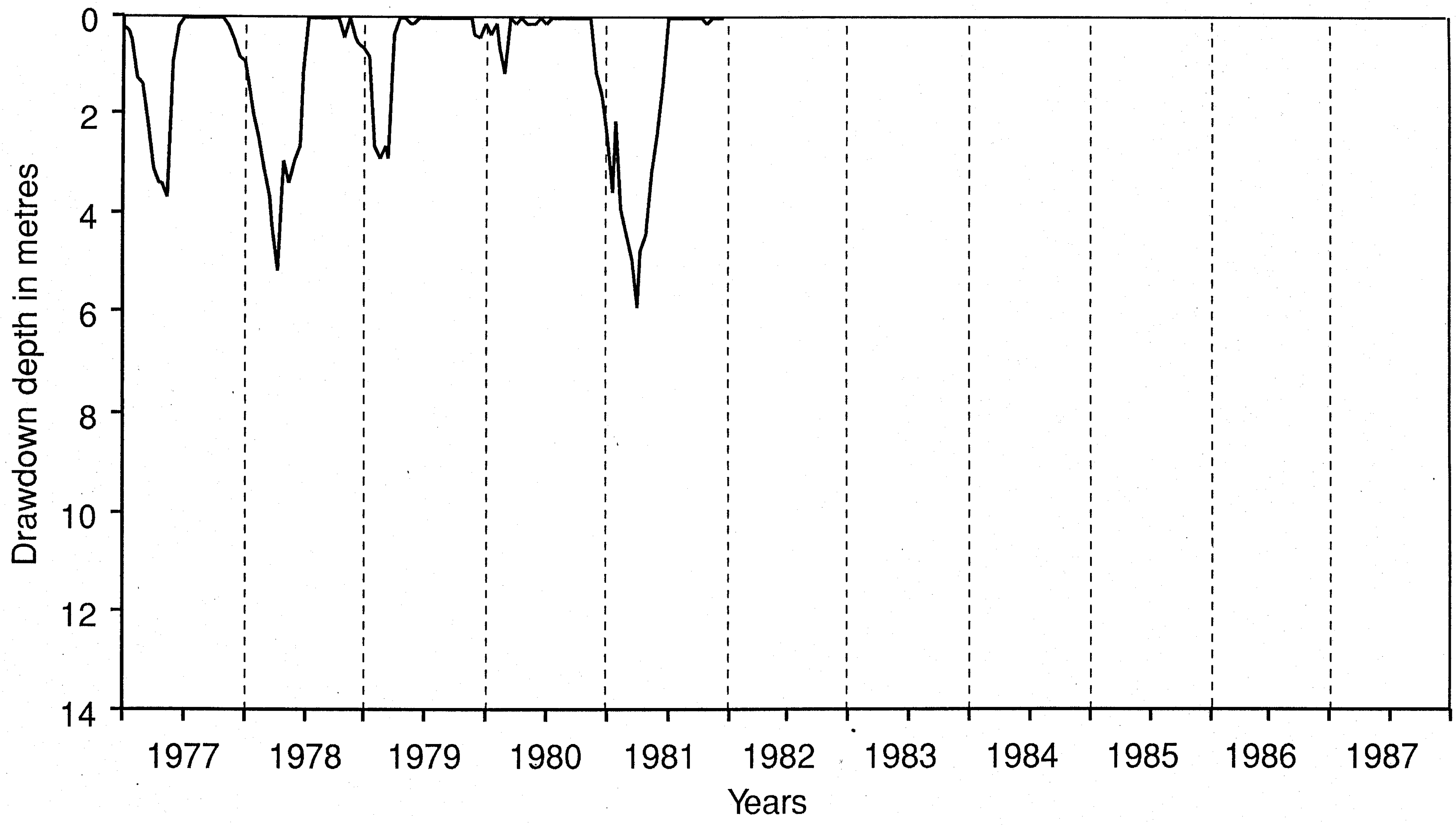

Fig. 9 : Water level fluctuations in the Lower Nihotupu Reservoir

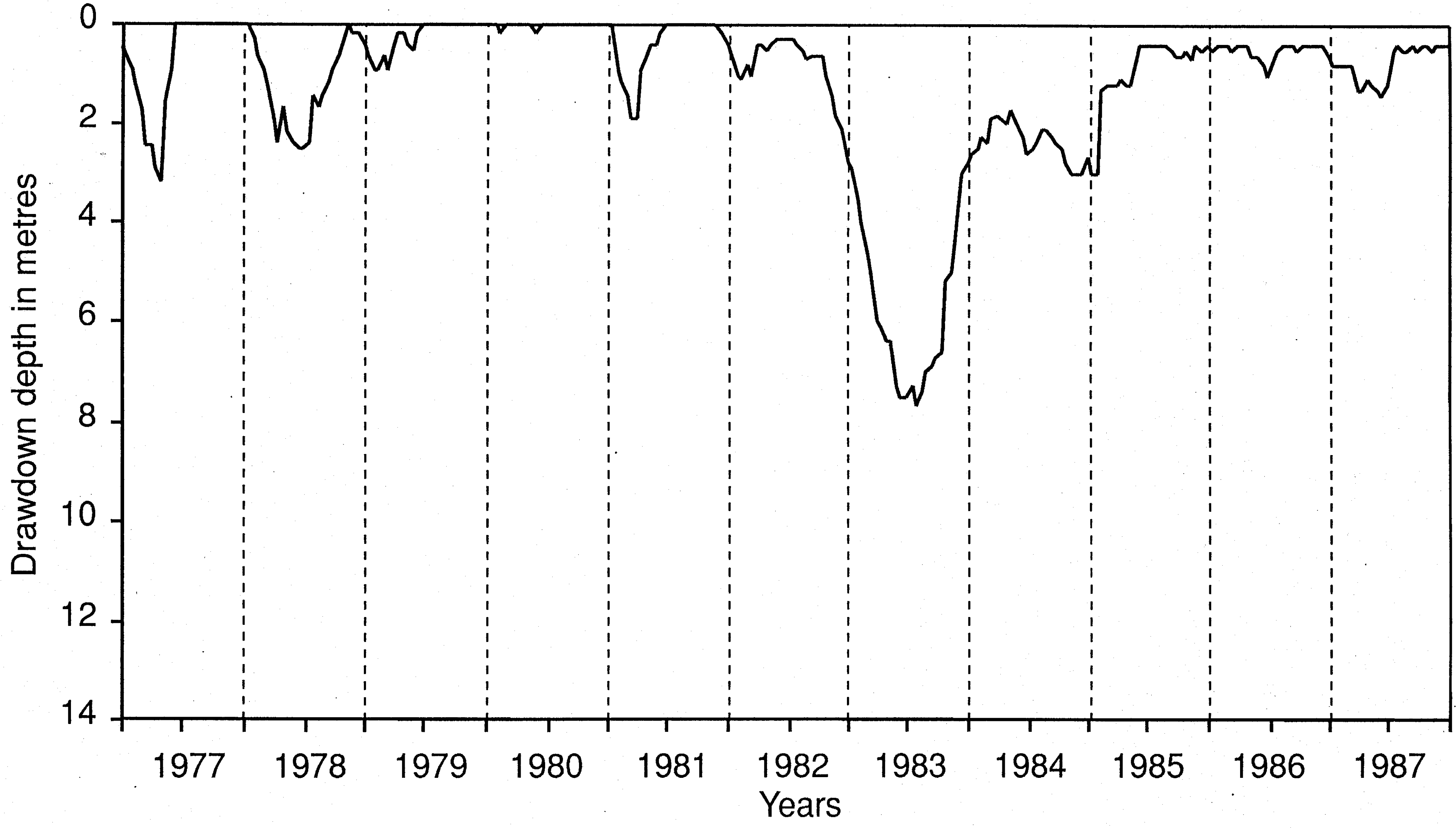

Fig. 10 : Water level fluctuations in Cossey's Creek Reservoir

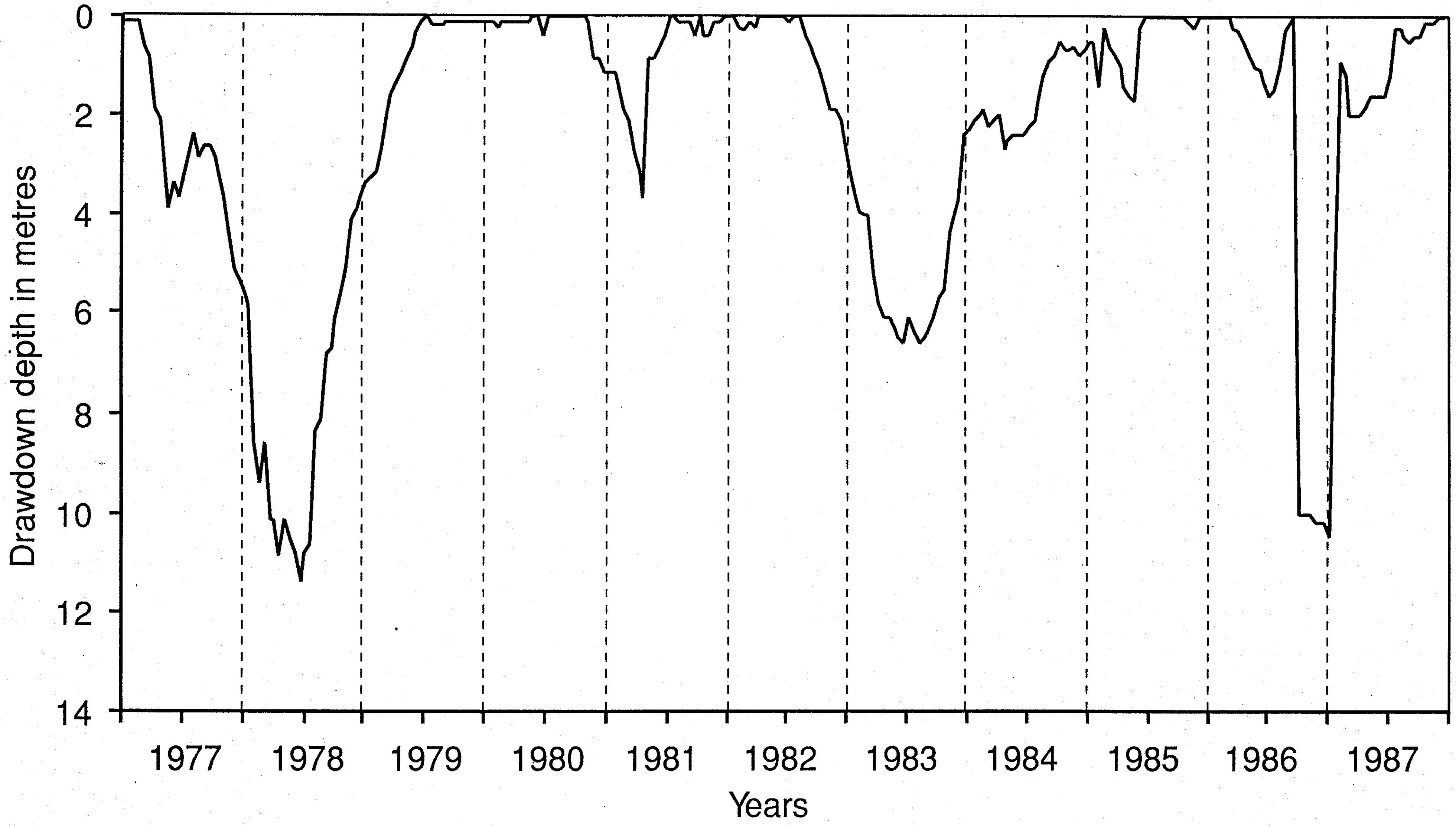

Fig. 11 : Water level fluctuations in the Wairoa Reservoir

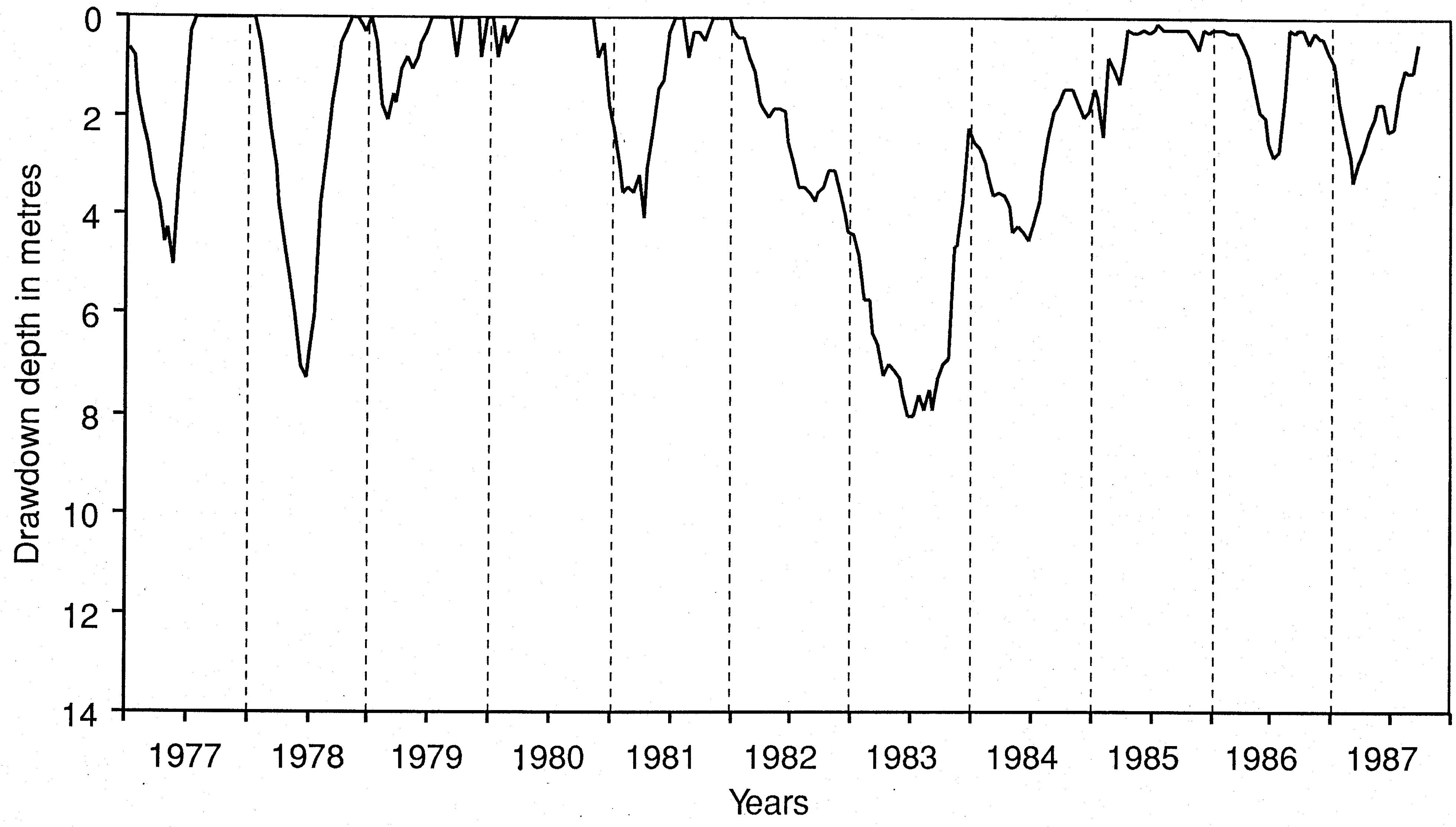

Fig. 12 : Water level fluctuations in the Upper Mangatawhiri Reservoir

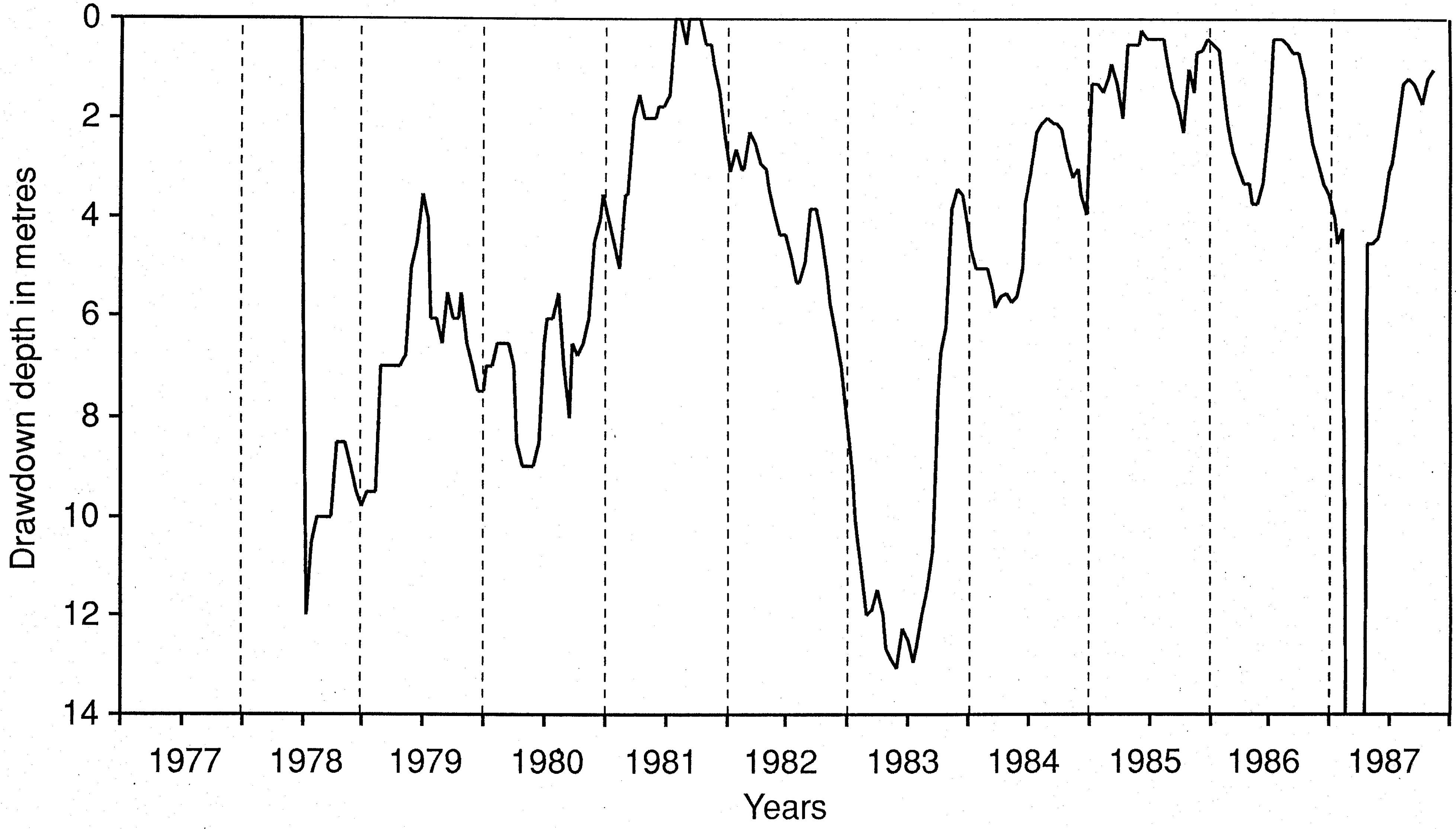

Fig. 13 : Water level fluctuations in the Mangatangi Reservoir

Drought conditions in the other reservoirs were less severe, particularly so in the Mangatangi Reservoir. Here, mean water depth remained above 8m and the absolute volume of remaining water was double that in other reservoirs. Mortality of trout is unlikely under such conditions, but growth rates can be expected to be reduced.

Non-drought drawdowns tended to occur during late-summer/autumn when water quality limits the depth distribution of trout. As a consequence reductions in water depth are of more concern during non-drought years than reductions in overall volume. Mean depths for these years were reduced by more than 30% in the Waitakere Ranges reservoirs and by 27% in the Upper Mangatawhiri Reservoir (Table 5). Loss of habitat in terms of reductions in mean depth of water available to trout was least in Cosseys Reservoir (14.8%). However, although mean depth was reduced by 20% in the Mangitangi Reservoir, the depth of water remaining for trout was greatest (17.3m compared with 10.4m in Cosseys reservoir).

Effects on trout habitat

It can be concluded that trout in the Mangatangi Reservoir would be less vulnerable to loss of habitat from drawdowns than trout in other reservoirs. In addition they would be expected to survive drought conditions of less than one-in-a-hundred year magnitude. Although trout in Cosseys, Wairoa, Upper Mangatawhiri and the Lower Huia Reservoirs would also have adequate habitat during non-drought years (mean depths of 10.4, 9.7, 8.7 and 8.8m

Table 5: Differences in water level fluctuations for ARC water supply reservoirs during the period 1977-1987

	At maximum drawdown[1]				Non-drought drawdowns[2]		Rate of drawdown		
	Water depth(m)		Volume						
	Below TWL	Remaining	(% of full)	($m^3 x 10^6$)	Avg. depth below TWL(m)	Depth as % of z	Maximum (m/day)	Year	Frequency[3] (No./annum)
Lower Huia	(10.5)	2.0	31.1	2.0	3.7	29.6	0.157	1977	1.00
Lower Nihotupu	(6.0)	0.7	41.7	2.0	3.3	49.3	0.086	1979	0.33
Cosseys	7.5	4.7	52.4	7.5	1.8	14.8	0.071	1981	0.27
Wairoa	11.0	1.1	32.1	3.9	2.4	19.8	0.186	1978	0.27
U. Mangatawhiri	8.0	4.1	46.7	7.8	3.3	27.3	0.086	1979	0.45
Mangatangi	13.0	9.4	48.8	19.0	4.5	20.1	0.093	1982	0.57

1 Data for 1983 not available for L. Huia and L. Nihotupu
2 Excludes drawdowns in 1978, 1983 (drought years)
3 Of drawdowns greater than 1 m per fortnight

respectively), salmonids in the Wairoa and Lower Huia Reservoirs would suffer a high mortality during drought years. The Lower Nihotupu Reservoir would be the least suitable environment for trout.

Effects on spawning migrations

Rainbow trout spawning migrations in N.I. lakes can occur in all months of the year, except November and December. However, large runs are generally restricted to late winter and early spring (July to October with a main peak in September). Runs are often asssociated with increased flows and are rare when flows are decreasing.

The major drawdown of water levels in 1978 was associated with reduced rainfall and stream levels. However, access to spawning streams would not have been greatly affected, except in the Wairoa Reservoir. Here water levels during September to October were still 5-6m below TWL. Water levels were increasing, and all within 2m of TWL in all other reservoirs. In comparison with 1978, access to streams in the Mangatangi and Upper Mangatawhiri Reservoirs would have been prevented during spring 1982. Water levels in these reservoirs were low (4m below TWL), and falling. Access to all reservoirs would have been inhibited, but not prevented, by the drought of 1983. Although all reservoirs were filling by September, water levels were still 4-5m below TWL by November. The degree of restriction would depend on the height of sills between the reservoir and stream mouths. Spawning migrations would not have been affected during non-drought years.

Restricted access to spawning streams during some drought years could result in reduced recruitment the following year, and decreased catch rates in subsequent years. This would not be catastrophic as rainbow trout can live up to age 5+, resorbing gonad material when spawning is inhibited, and regenerating new ones during the next summer. Droughts would need to restrict spawning for 4 or more years in succession before trout populations would be in danger of extinction.

5 RELATIVE PRODUCTIVITY OF THE RESERVOIRS AND FOOD SOURCES FOR TROUT

5.1 Introduction

Insect larvae, particularly chironomids, will be found in all reservoirs, and can form a significant part of trout diet in reservoirs and lakes. Together with terrestrial insects, which are important mainly during summer months, they are often sufficient on their own to support trout fisheries. However, growth rates of trout in such waters are generally unspectacular, and other food sources, such as forage fish and large crustacea are usually needed to support the larger trout associated with high quality fisheries.

Major foods for trout known to be present in the ARC reservoirs include small galaxiid fish, bullies, freshwater crayfish (koura), planktonic crustacea (daphnia), and snail and insect larvae (Table 6).

Main feeding grounds, or zones, for trout in lakes include the littoral zone (around shorelines), the limnetic zone (open water), the lake surface and the sublittoral, benthic zone. Whereas terrestrial (winged) insects will be found near the water surface, aquatic insects, particularly larvae of midges (Chironomidae) and dragonflies (Odonata), will be found, along with most other aquatic foods, on the lake bottom, in or near the littoral zone. Galaxiids, larval bullies, and small planktonic crustacea occur mainly in the limnetic zone.

Although smelt are now the main limnetic prey for trout in lakes of the Central North Island, this position was historically occupied by galaxiids. Galaxiids also occur in the ARC reservoirs, but in general the limnetic food base is likely to be less important than the littoral one. Even where substantial limnetic food resources exist, such as in the Rotorua Lakes, the biomass and production of trout has been more closely correlated with length of shoreline (and hence littoral zone) than with surface area of lakes (Fish 1968). In addition there is a strong correlation between the growth rates of hatchery trout and the size of littoral zones for the Rotorua lakes (unpublished data).

The size of the feeding grounds for trout in each of the ARC reservoirs will be related mainly to the size of the littoral zone, but production will be linked to reservoir productivity. For example, Jones & Hoyer (1982) used summer chlorophyll-a concentrations to predict harvest of sportsfish in mid-western lakes and reservoirs in the USA. However, reservoir or lake specific attributes such as the type, size, density and distribution of the food species present are also important, as is the availability of particular foods to trout. For example, rainbow trout are visual feeders and their retinas are adapted for feeding in surface waters. Extensive vegetative cover, or high levels of turbidity, can decrease the efficiency of predation on some limnetic foods, despite their high density.

Table 6: Fish, crustacea and molluscan species in ARC water supply reservoirs (+ - present, nil - absent, - status unknown).

	Waitakare	Lower Huia	Lower Nihotupu	Cosseys	Wairoa	Upper Mangatawhiri	Mangatangi
<u>Pisces</u>							
Eels[1]	+	+	+	+	+	+	+
Bullies[2]	-	+	+	-	Nil	a,b	b
Galaxiids[3]	+	+	+	a	a,b	a,b	Nil
Rainbow trout	Nil	Nil	Nil	+	Nil	+	+
Rudd	+	+	+	+	Nil	Nil	Nil
Tench	-	-	+	-	-	-	-
Perch	+	-	-	+	+	-	-
<u>Crustacea</u>							
Crayfish	+	+	+	+	+	+	+
Shrimps	-	+	-	-	-	Nil	Nil
<u>Mollusca</u>							
Gastropods[4]	-	+	+	-	Nil	b	a

[1] Species unknown but most probably longfinned (Anguilla dieffenbachii)
[2] Species unknown, otherwise; (a) <u>Gobiomorphus cotidianus</u> (b) <u>Gobiomorphus basalis</u>
[3] Species unknown, otherwise; (a) <u>Galaxias fasciatus</u> (b) <u>Galaxias brevipinnis</u>
[4] Species unknown, otherwise; (a) <u>Potamopyrgus sp.</u> (b) <u>Planorbis sp.</u>

The importance of lake specific factors for trout feeding efficiency means that an assessment of the potential for each reservoir to support large, fast-growing trout populations is complex. It involves the integration of variables relating to lake morphometry, biological productivity, water quality and the fauna of the reservoirs. Adequate data is rarely available on each of these factors. Nevertheless, a comparative assessment of relative potential is possible both among these reservoirs, and with other similar reservoirs and lakes already known to support trout.

5.2 Methods and Analyses

The complexity of assessing the size of food resources for trout reflects the fact that trout are predators. They are far removed from the level of primary production, which is the main determinant of reservoir or lake productivity. Despite this, primary production can, within limits, provide an indication of the order of secondary or tertiary production to be expected.

Carbon 14 assessments of primary production are not available for ARC reservoirs, but other less precise indicators of relative production include biomass estimates such as microbial carbon (e.g. Pridmore et al 1984) and phytoplankton densities. Secchi disc measurements also correlate with the trophic status of the reservoirs and provide a basis for assessing their general level of productivity.

Aquatic weeds are minimal in the ARC reservoirs because of their steep sides and water level fluctuations (Ronberg 1989), so primary production will be dominated by phytoplankton. However, reservoirs are not typical lake environments. They are often subject to large flow-throughs of water which 'flush' plankton in surface waters across spillways. In this sense, reservoirs are intermediate ecosystems, between lakes and rivers. Estimates of production, or trophic level, based on plankton or phytoplankton biomass can be underestimated because of such flushing effects. Therefore the residence time, or rate of water renewal, in reservoirs needs to be considered, because plankton population densities in lakes tend to be high and stable when flushing effects are minimal (Bayly and Williams 1973). An examination of the temporal stability of phytoplankton in reservoirs is used here to indicate the degree to which each reservoir is functioning as a lake ecosystem.

Although microbial carbon concentrations, phytoplankton levels and an analysis of secchi disc values indicate the general trophic level of the reservoirs, and enable comparisons with other productive waters known to support trout fisheries, such indicators are too coarse to permit a ranking of the productivity of each reservoir. In general, phytoplankton production is determined mainly by the concentrations of nitrogen and phosphorus in the water. Consequently nutrient concentrations measured by the ARC in the surface (0-9 m) water of the reservoirs are compared to determine any differences in relative concentrations. Differences in the mean concentrations of total phosphates and combined nitrogen between reservoirs are used as a basis for assessing relative productivity, and for comparing this with the estimated trophic status of the reservoirs gauged by other indicators of productivity.

Relative trophic status and biological productivity of these waters will reflect broad differences in potential fish production, but the size of the food resource actually available to trout is likely to be related more directly to the size of the littoral zone. Large differences in the size of the littoral zones between the ARC reservoirs will therefore indicate differences in potential trout production.

The length of the littoral zone is usually related to the length of shoreline (Table 7), but its width, or distance from shore is ultimately determined by the interaction of reservoir morphology with light penetration. Littoral zones will be limited in deep reservoirs with steeply sloping sides, or turbid waters, because the area of bottom exposed to adequate light for photosynthesis will be minimal compared with reservoirs containing extensive areas of shallows, or comparatively clear waters. A biological indicator for the lower limit to the photic zone, and hence for the littoral zone, is often provided by the lower depth limit for rooted macrophytes. However, because of water level fluctuations, these are generally lacking in reservoirs. Secchi disc measurements, reflecting water transparency provide an alternative means of estimating the depth of the photic zone. Knowing this, the size or area of littoral based trout feeding

Table 7: Physical characteristics of the A.R.C. water supply catchments investigated.

	Catchment area (ha)	Avg. ann. rainfall (mm)	Reservoir characteristics						
			Area (ha)	Volume ($m^3 x 10^6$)	Max. depth Zm (m)	Mean depth[1] $\bar{z}$ (m)	$\bar{Z}$:Zm[2]	Shoreline length (km)	D_L[3]
Lower Huia	1430	1958	56	7.0	28	12.5	0.45	9.0	3.40
Lower Nihotupu	1300	2000	72	4.8	16	6.7	0.42	10.9	3.67
Cosseys	2200	1811	119	14.5	29	12.2	0.42	39.0	10.09
Wairoa	1300	1889	100	12.1	35	12.1	0.35	16.7	4.71
Upper Mangatawhiri	2580	2198	136	16.5	27	12.1	0.45	14.8	3.58
Mangatangi	3940	2186	179	39.0	54	21.8	0.40	33.9	7.14

1. $\bar{z} = \frac{V}{A}$
2. ratio of mean depth to max. depth is a measure of basin form (i.e. $\bar{z}$: Zm>0.5 for shallow, flat-bottomed lakes $\bar{z}$: Zm<0.3 for deep, narrow lakes).
3. Shoreline development (D_L) is ratio of shoreline length to circumference of circle of equal area to reservoir

grounds can be estimated from reservoir bathymetries.

5.3 Results

5.3.1 Phytoplankton and microbial carbon levels

The main species of phytoplankton for 1980-1981 are listed (Table 8) and the number of months/annum over which they were dominant or co-dominant in the plankton biocoenosis of each reservoir noted (Fig 14). Although Cosseys Reservoir contained four dominant species over 1981, one of these was present for ten months and another for six months of the year. In comparison the Mangatangi Reservoir contained five dominant species, only one of which was present for more than four months. These two reservoirs display two extremes in relative phytoplankton stability, and reflect the rate of change in the succession of various species of phytoplankton. A direct measure of the rate of change in phytoplankton succession or of the stability (S) of phytoplankton biocoenosis is provided by:

$$S = \sum_{i=1,n} \frac{m_i}{n_i}$$

Where i — is the rank for each of 'n' species determined by the time in months during which they were either dominant or co-dominant.

m — is time in months/annum for which a species of rank 'i' was dominant/codominant.

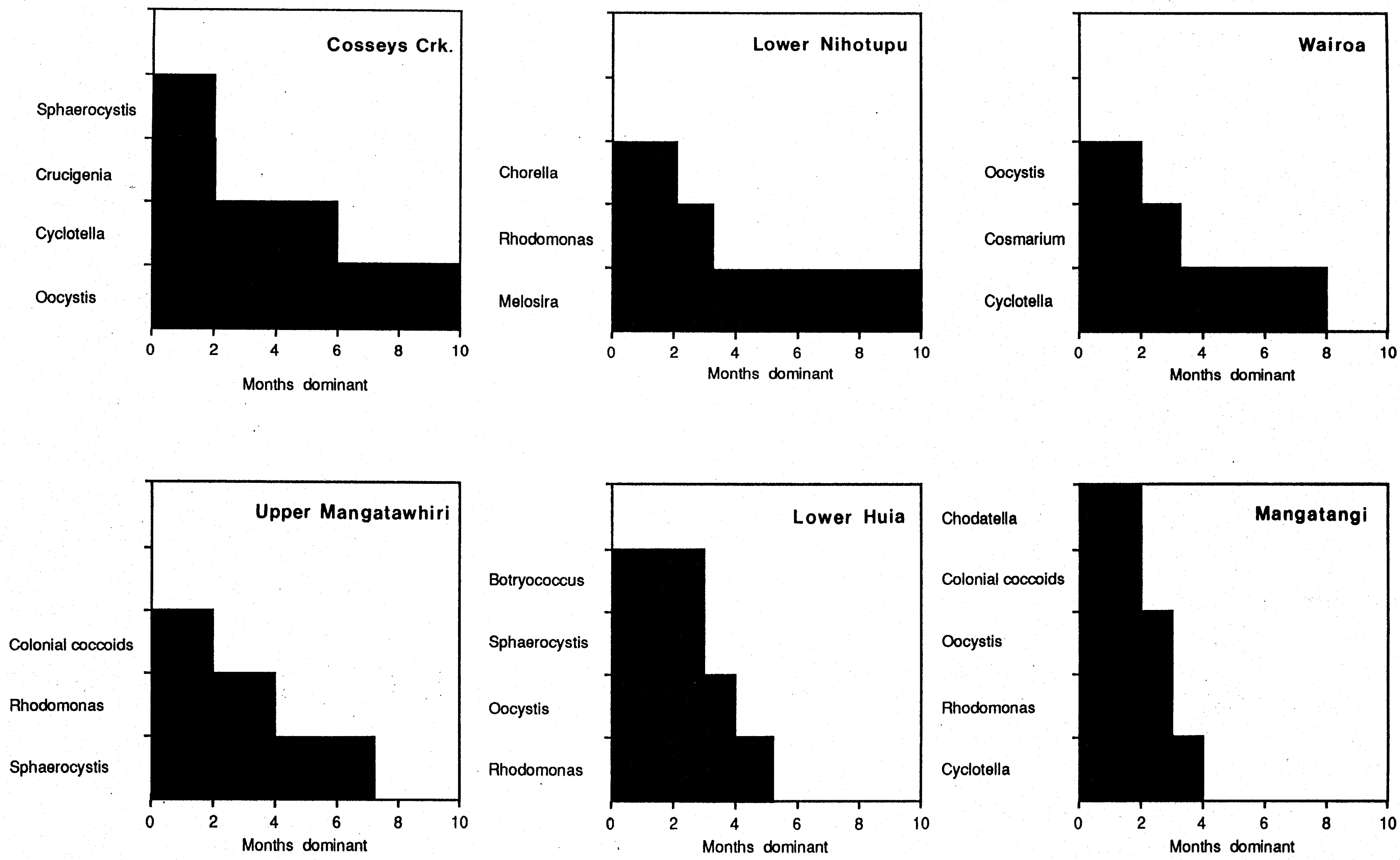

Fig. 14 : Duration of dominance by phytoplankton species in ARC water supply reservoirs during 1981/82

Values for S are indicated in Table 8 along with other characteristics for each reservoir's phytoplankton populations. A range of values for S occur, but all reservoirs contained species that were dominant for four or more months. In addition phytoplankton cell densities in all reservoirs, except Cosseys showed a distinct summer maxima over both 1981 and 1982. (Cosseys had a spring maxima). These results indicate that the phytoplankton assemblages were relatively stable, and that flushing effects associated with fast drawdown and/or low water retention rates were not a major factor influencing primary production.

This result is supported by an analysis of water retention rates which can be gauged from the relationship between reservoir volume and mean daily water yield (Table 9). As the Mangatangi Reservoir was new, and only just full in 1981, its plankton would be expected to be new and changing. The lowest value for phytoplankton stability reflects this, but its ratio of water yield to volume is comparatively low indicating a relatively high rate of water retention (Table 9). Once this reservoir matures its phytoplankton stability can be expected to increase. Comparatively low values for phytoplankton stability occurred for the Lower Huia and Upper Mangatawhiri Reservoirs (Table 8), and are related to their comparatively low water retention rates. In comparison, Cosseys and Wairoa Reservoirs had comparatively high values for plankton stability, and high water retention rates. The Lower Nihotupu was the exception to the generalisation, and

Table 8: Characteristics of phytoplankton populations in ARA water supply reservoirs over 1980, 1981

	Average Density (range) cells/ml	Summer Maxima	Main summer genera (1981)	Main winter genera (1981)	Temporal Stability of phytoplankton 1981 (S)
Lower Huia	641 (90-1240)	Yes	Botryococcus (chlorophycae) Oocystis (Chlorophycae)	Rhodomonas (Cryptophycae) Sphaerocystis (Chlorophycae)	8.8
Lower Nihotupu	664 (160-1720)	Yes	Melosira (diatom) Chlorella	Melosira (diatom) Rhodomonas (Cryptophycae)	12.2
Cosseys	1013 (190-2990)	No (Spring Maxima)	Cyclotella (diatom) Oocystis (Chlorophycae)	Oocystis (Chlorophycae) Cyclotella (diatom) Crucigenia (Chlorophycae)	14.2
Wairoa	1466 (170-10,040)	Yes	Cyclotella (diatom) Cosmarium (chlorophycae)	Oocystis (Chlorophycae)	10.2
Upper Mangatawhiri	1500 (290-7930)	Yes	Sphaerocystis (chlorophycae) Colonial coccoids -	Rhodomonas (Cryptophycae)	9.7
Mangatangi	1372 (140-4940)	No (Spring)	Cyclotella (diatom) Chodatella Colonial coccoids -	Rhodomonas (Cryptophycae) Oocystis (Cholorophycae	7.4
				MEAN =	10.38

Note: Temporal stability of phytoplankton calculated as $S = \sum_{i=1,n} \frac{M_i}{n_i}$

Where M is the number of months for which a species was dominant or co-dominant per annum, and 'i' is the rank of that species determined from a ranking of the species according to the number of months/annum for which they were dominant or co-dominant.

Table 9: Ratios of water yield to reservoir volume (water retention index) for ARC water supply reservoirs

Reservoir	Water Yield (m^3/day x 10^3)	Reservoir Volume (m^3 x 10^3)	Ratio (Yield/Volume)[1]
Lower Huia	36.4	7.0	5.2
Lower Nihotupu	27.2	4.8	5.7
Cosseys	40.8	14.5	2.8
Wairoa	26.3	12.1	2.2
Upper Mangatawhiri	66.7	16.5	4.0
Mangatangi	101.1	39.0	2.6

[1] Ratio of 5.0 represents low water retention
Ratio of 1.0 is relatively high water retention

had a low water retention rate, but a high value for plankton stability. However, this is likely to reflect the comparatively large drawdown in this reservoir that occurred in 1981, and which may have had a relatively greater effect on the plankton biocoenosis.

The relationship between water retention rates and relative plankton stability reflects the riverine nature of the reservoirs, but the overall stability of the plankton assemblages, together with the fact that distinct summer (or spring) maxima occur (Table 8), indicates that the reservoirs have a significant affinity with lake ecosystems. As a consequence estimates of plankton cell abundance are likely to be useful indicators of plant biomass and the magnitude of primary production in these reservoirs.

Average phytoplankton cell counts given in Table 8 range between 500-1500 cells/ml, with maximum counts ranging from 1240 cells/ml in the Lower Huia Reservoir, up to 10,040 cells/ml in the Wairoa Reservoir. Green (1976) ranked a number of New Zealand lakes for which maximum phytoplankton cell densities and trophic states were known and found that densities of less than 800 cells/ml were associated with oligotrophic to mesotrophic waters. Densities over 5000 cells/ml were associated with eutrophic waters. Cell counts of the Waitakere Range reservoirs are in the mesotrophic range and are significantly lower than those of the Hunua reservoirs. Of the Hunua reservoirs, cell counts in Cosseys were in the upper mesotrophic range and those of the

Wairoa, Upper Mangatawhiri and Mangatangi Reservoirs were in the eutrophic range. Maximum cell counts for Lake Rotorua, known to be a relatively productive trout fishery, are in the vicinity of 4550-5000 cells/ml, and are comparable with those found in the Mangatangi Reservoir, but are less than in the Mangatawhiri (7,930 cells/ml) and Wairoa Reservoirs (10,040 cells/ml), which maybe more productive than Lake Rotorua.

Phytoplankton are usually the major component of total microbial biomass, but bacteria can also be a significantly large fraction at times. Pridmore et. al.(1984) found that bacterial biomass in the Cosseys, Mangatangi, Mangatawhiri and Wairoa Reservoirs respectively, averaged 23%, 82%, 57% and 36% of total microbial biomass. The Mangatangi Reservoir was first filled in 1981 and decomposition of inundated terrestrial, organic matter probably accounts for the relatively high bacterial populations measured in this reservoir in 1981/82. However, bacterial biomass is still an important component of total microbial biomass, which itself provides a better indicator of biomass and general trophic status than phytoplankton cell densities. Measurements of microbial carbon in the Hunua reservoirs ranged from approximately 25 $mg.m^{-3}$ in the Mangatawhiri Reservoir to just over 200 $mg.m^{-3}$ in the Wairoa Reservoir. In comparison, microbial carbon levels in Lake Karapiro, a reservoir known to support a rainbow trout fishery, ranged from 200-800 $mg.m^{-3}$ (Pridmore et al 1984).

In general, variation in both mean phytoplankton cell densities and mean microbial carbon levels in the Hunua Reservoirs was minimal compared with differences in these parameters between the reservoirs and other water bodies. As a result differences in productivity between the Hunua reservoirs cannot be determined on the basis of phytoplankton cell counts or microbial carbon levels. But it can be stated that the reservoirs are comparable to other relatively enriched waters known to support trout fisheries. The major disadvantages of high productivity or eutrophication in reservoir waters to trout are the risks of high water temperatures and low oxygen levels in summer (See Section 3). In addition, high turbidity can deleteriously affect trout feeding (Rowe 1984a).

5.3.2. Secchi disc values

Secchi disc values measure water transparency and can provide a coarse, but useful, means for estimating plankton densities. As such, secchi disc values have been correlated with trophic status (McColl 1972), and can provide a useful measure of relative productivity. They also provide a measure of water transparency that is related to trout feeding patterns. Trout feeding on smelt in surface waters is reduced by low water transparency, and feeding on bullies near the bottom predominates when secchi disc values are less than 3m (Rowe 1984a). Mean values and ranges for secchi disc depths taken between October 1982 and August 1983 are shown in Figure 15. Mean values for the period June 1988 to August 1989 are contrasted with these to show changes with time.

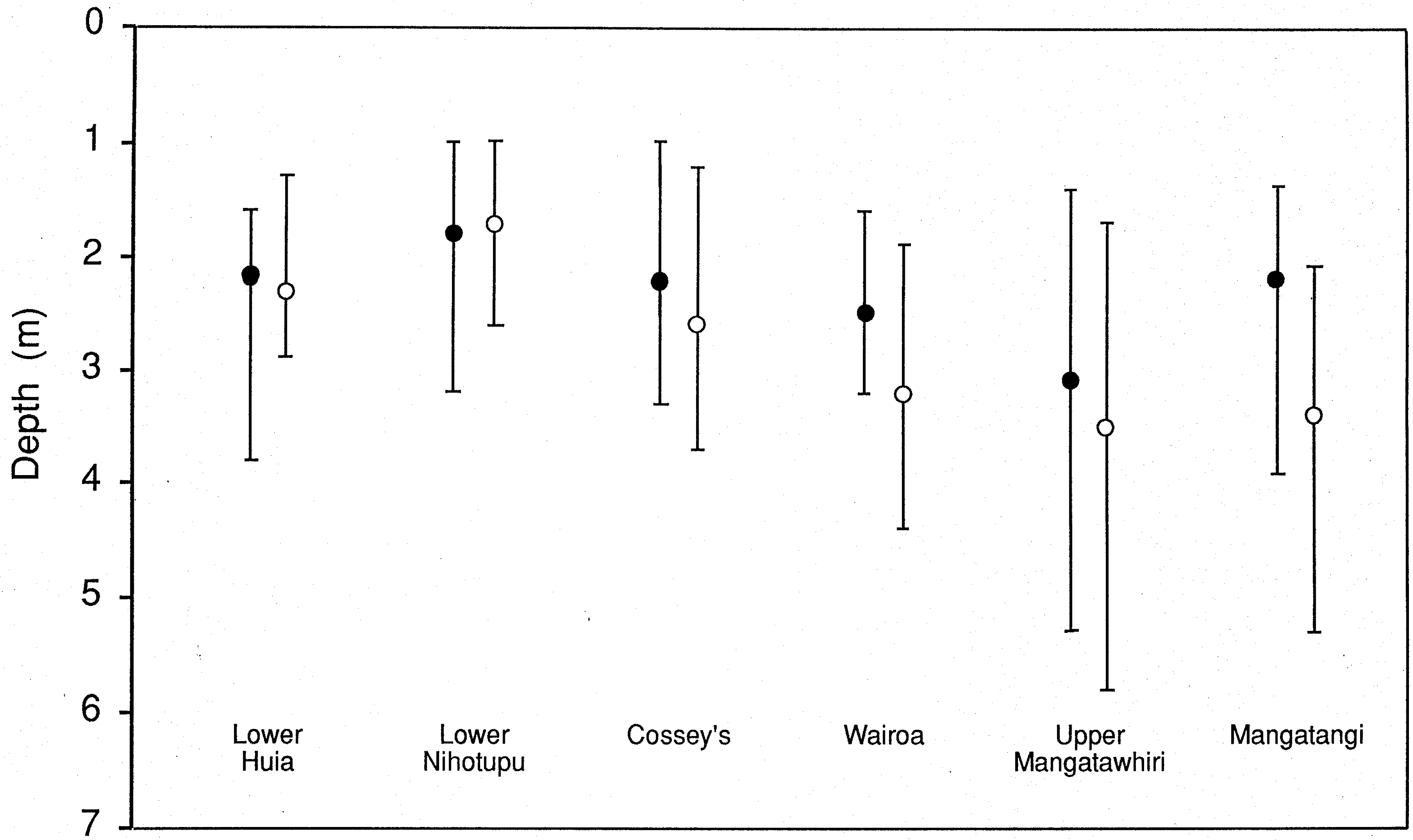

Fig. 15 : Means and ranges for secchi disc readings in ARC reservoirs for (●) 1981/82 and (○) 1988/89

Greatest water transparency occurred in the Upper Mangatawhiri Reservoir (>3m) while lowest transparency occurred in the Lower Nihotupu Reservoir (<2m). Secchi disc values also varied greatly in the Upper Mangatawhiri Reservoir (range 4m), compared with other reservoirs (ranges 2-3m). In general values for 1982/83 were similar to those for 1988/89. Water transparency appears to have deteriorated slightly in the Waitakere Ranges reservoirs and improved in the Hunua Ranges ones. However, the differences in annual means are less than the annual range in values. The improvement in secchi disc values for the Managatangi Reservoir is probably related to its decreased productivity since filling in 1981.

Mean secchi disc depths for the ARC reservoirs were in general greater than mean values for eutrophic lakes reported by McColl (1972), but were shallower than mean values for mesotrophic lakes. The ranges were comparable with ranges reported for other productive waters, containing trout fisheries, such as Lake Rotorua (Jolly 1968) and the Waikato River reservoirs, apart from Aratiatia (Magadza 1973).

These results support the general conclusions obtained from phytoplankton cell counts and microbial carbon levels, and further indicate that the reservoirs are all relatively productive, and on the border of mesotrophy to eutrophy. The results also indicate that water transparency in the reservoirs will result in trout feeding mainly on bottom-living organisms such as bullies, freshwater crayfish and chironomid larvae, rather than on limnetic foods. Nonetheless, some seasonal feeding on galaxiids can be expected, particularly in the Wairoa, Upper Mangatawhiri ~~and Mangatangi~~ Reservoirs, where mean secchi disc values exceeded 3m.

5.3.3 Nutrient concentrations

Differences in productivity between the reservoirs cannot be distinguished on the basis of phytoplankton cell counts, microbial biomass or secchi disc data. They are all mesotrophic to eutrophic. Nutrient concentrations may provide a more direct basis for comparing the relative productivity of the reservoirs.

Total phosphate concentrations were lower in 1988/89 compared with 1980/81, except in the Wairoa Reservoir (Table 10). The concentrations are generally high for all reservoirs, being close to, or over 20 $mg.l^{-1}$, the limit set for eutrophic waters in lakes (Vant 1987). Combined nitrogen levels were generally higher than total phosphate values and N:P ratios were all less than 10.0 (Table 10). This indicates that chlorophyl-a production is likely to be nitrogen limited (Vant 1987). On this basis the Wairoa Reservoir had consistently higher nitrogen levels than all other reserviors and would be the most productive reservoir. This conclusion is in agreement with its generally higher phytoplankton cell count. Similarly, the Waitakere Ranges Reservoirs had comparatively lower levels of nitrogen, particularly in 1988/89, and lower phytoplankton cell counts.

Table 10: Mean concentrations of total phosphorous and nitrogen ($mg.l^{-1}$), and N:P ratios[1] in ARC reservoirs during 1980/81 and 1988/89

	1980/81			1988/89		
	P	N	N:P	P	N	N:P
L. Huia	.036	.036	1.0	.018	.034	1.9
L. Nihotupu	.034	.043	1.3	.022	.029	1.3
Wairoa	.019	.111	5.8	.022	.125	5.7
Cosseys	.024	.048	2.0	.020	.082	4.1
U. Mangatawhiri	.033	.145	4.4	.016	.061	3.8
Mangatangi	.029	.038	1.3	.016	.066	4.1

1. N:P ratios less than 10 are indicative of N limitation

5.3.4 Trout foods available and sizes of feeding areas

Whereas the extent of primary productivity reflects the potential level of trout production, actual trout production will be determined by the size of the littoral zone, and by the type, density and seasonal distributions of food organisms present there.

Table 6 lists the macro-fauna known to be present in the reservoirs. Small forage fish (bullies, galaxiids) and crayfish are important trout foods known to be associated with viable trout fisheries in other New Zealand lakes and reservoirs. Most reservoirs (Lower Huia, Lower Nihotupu, Cosseys, Wairoa and the Upper Mangatawhiri) contain populations of galaxiids, but bullies only occur in the Lower Huia, Lower Nihotupu, Upper Mangatawhiri and Mangatangi Reservoirs. Relatively high densities of crayfish have been observed on the bottom of the Wairoa Reservoir (Thompson 1976c). The Upper Mangatawhiri has the highest number of potential trout foods (4 species of forage fish, plus crayfish) and, at present, is unlikely to contain other fish species (eg. perch), which may compete with trout. In comparison the Mangatangi Reservoir lacks galaxiids and the Wairoa lacks bullies. Both the Wairoa and Cosseys Reservoirs contain perch, while the Waitakere Ranges reservoirs contain rudd. Rudd can create problems for trout fisheries, not so much because they compete with trout for food, but because they affect angling efficiency. It is difficult to place lures in waters frequented by trout because rudd take them first.

Although the reservoirs contain galaxiids, only G. brevipinnis may be suitable as a forage species. Studies of rainbow trout in lake Ototoa (Penlington 1985) showed that the land-locked galaxiids there (G. fasciatus) formed an insignificant part of trout diet. This species may not be as useful a forage food as other galaxiid species (eg. G. brevipinnis, G. gracilis) known to be readily preyed on by trout in other lakes. If so, the Upper Mangatawhiri reservoir stands out, as it contains both G. brevipinnis and two species of bullies. None of these native freshwater fish species are rare, or endangered.

Major concentrations of the principle food organisms for trout will be associated with the littoral, and parts of the sublittoral zone of the reservoirs. A useful indicator of the depth of this zone is provided by the lower limit to the photic zone. As a rule, two and a half times the mean secchi disc depth approximates the lower depth limit of the photic zone (Biggs et al. 1983). The area of lake bottom shallower than the euphotic depth is calculated by measuring percentage surface areas of reservoirs above the depth of photic zone and subtracting this from total suface area. Figure 16 shows the respective changes in surface area with depth, for each of the reservoirs apart from the Wairoa (data not available).

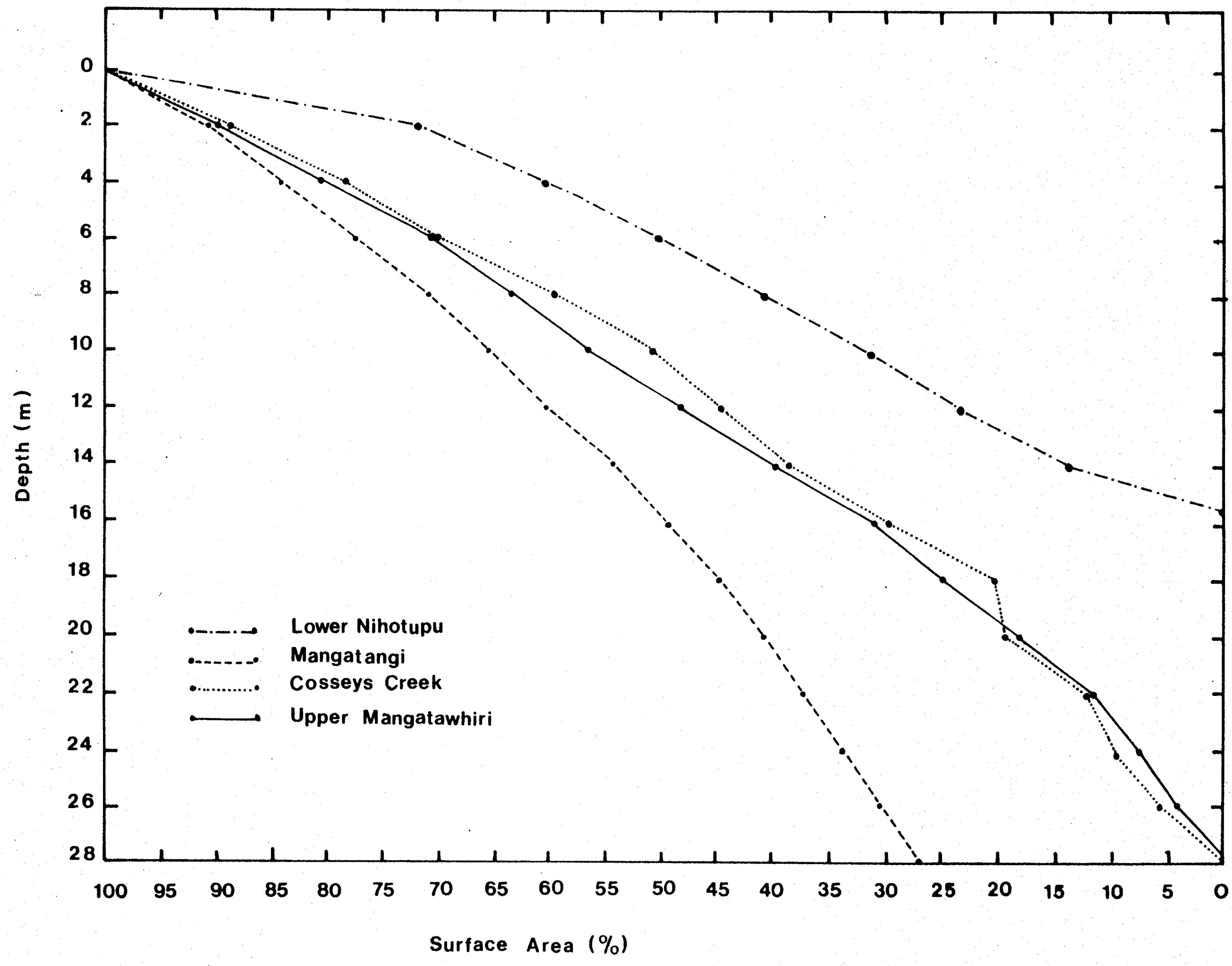

Fig 16: Surface area versus depth curves for ARC reservoirs (Note: Curves for the Lower Huia and Cosseys reservoirs were identical down to 10m, and differred marginally below this.)

5.4 Conclusions

Table 11 ranks the reservoirs in terms of the sizes of the feeding areas for trout. This is considered to be the major factor affecting potential trout production, as the order of primary productivity (i.e. trophic status) is much the same in all reservoirs. Changes in water level are unlikely to be a major factor in determining differences in productivity between reservoirs. This is because the extent of drawdown in average years is similar, and because the rate of decline in water level is slow enough to allow most mobile invertebrates to adapt to the changing level. For example, the maximimum drawdown rate (approx. 0.186m/day) represents a drop of around 3mm per hour (Table 5). Nevertheless, in drought years the extent of drawdown (eg. more than 3 m) will reduce littoral habitat in all reservoirs.

Although the Mangatangi has the largest feeding grounds in absolute terms, The Upper Mangatawhiri Reservoir has the largest area of feeding grounds in proportion to its size. As this reservoir also contains the highest number of forage species for trout it is clearly the best reservoir in terms of potential trout production at present. Furthermore, water transparency, which when low constricts trout feeding patterns, is high in this reservoir.

Sizes of potential feeding grounds in the Mangatangi, Cosseys, and Lower Nihotupu are all similar ($27-30 m^3 \times 10^4$), but shoreline development ratios (D_L) are relatively high in Cosseys and the

Table 11: Potential sizes of trout feeding grounds in ARC water supply reservoirs

Reservoir	Depth of photic zone[1] (m)	% of lake S.A. shallower than euphotic depth	Size of feeding grounds ($m^3 \times 10^4$)
Mangatangi	8.5	30.0	53.7
U. Mangatawhiri	8.1	36.5	49.6
Wairoa	7.1	----	----
Cosseys	6.3	32.0	38.1
L. Nihotupu	4.4	41.5	29.9
L. Huia	5.5	28.5	16.0

1. Euphotic depth ($z_{eu} = 2.5 * z_{SD}$)

Mangatangi Reservoir (Table 7). This indicates comparatively greater areas of shallower (0-2m) littoral zone than in other reservoirs.

Of the two Waitakere Ranges reservoirs, the Lower Nihotupu shelves relatively shallowly and, considering its size, has a relatively large littoral zone. Whereas this would indicate a high potential for trout production relative to reservoir size its mean secchi disc depth is low (1.8 m), and it is doubtful whether rainbow trout would feed efficiently on surface foods in such turbid waters.

6 TROUT SPAWNING IN THE RESERVOIR'S STREAMS

6.1 Introduction

Rainbow trout spawn in streams (preferred habitat), and on shorelines of lakes where coarse gravels occur in shallow waters (Penlington 1983). However, shore-line spawning in reservoirs with steep sides and fluctuating water levels is improbable. Spawning in reservoirs will occur in the streams draining the reservoir's catchments.

Self-recruiting rainbow trout populations are known to exist in Cosseys, the Upper Mangatawhiri and Mangatangi Reservoirs. Surveys by Thompson (1976b,a) revealed suitable conditions for trout spawning in the inlet tributaries of Cosseys and the Upper Mangatawhiri Reservoir. Other surveys in the Wairoa, and in the two Waitakere reservoirs (Lower Nihotupu, Lower Huia), which do not contain trout, were also carried out (Thompson 1976c,d,e). Whereas suitable conditions for trout spawning occurred in all three of the existing Hunua reservoirs (the Mangatangi was not completed in 1976), and one of the Waitakere reservoirs, the extent or size of spawning grounds in the areas surveyed was not determined.

The size of spawning grounds is important as they should be large enough to support the recruitment of a large trout population needed to sustain a trout fishery. Supplementary stocking, as occurs in several Rotorua lakes, would be needed if the size of spawning grounds was too small, but this would be expensive and could mitigate against the development of an economic fishery.

6.2 Methods and analyses

Thompson (1976a,b,c,e) surveyed the main tributaries of the Upper Mangatawhiri, Cosseys, Wairoa, and Lower Huia Reservoirs. He established locations in the streams which were suitable for trout spawning, and determined where barriers prevented the upstream migration of trout. Further surveys were carried out by MAF Fisheries to complement Thompsons observations, and to survey the major tributaries of the Mangatangi reservoir. Observations were made on the average width and depth of streams, the suitability of substrates for trout spawning, the length of spawning grounds, any barriers to the movement of adult fish, and the suitability of the streams (food, shading, water depth and flow) for juvenile trout.

6.3 Results and Conclusions

Data from the surveys of spawning grounds in each of the main tributaries is summarised in Table 12. Suitable gravels for trout spawning occurred in most streams, but were only abundant and relatively devoid of fine sand (which reduces egg survival by restricting water flow and oxygen supply), in the Hunua Reservoirs. The Huia stream in the Lower Huia Reservoir would support some trout spawning, but this is unlikely to be sufficient for the production of a large fishable trout

TABLE 12. Size of spawning grounds for rainbow trout in the ARA reservoir inlet streams

Reservoir	Tributary Stream (name)	Length of stream surveyed (m)	Average width (m)	Average depth (m)	Quality of spawning gravels (score)[1]	Length of spawning grounds (m)	Barriers to trout movement
Cosseys	Cosseys N.	200	-	-	0	0	-
	Cosseys E.	800	-	-	1	300	stm gradient increases at 800 m
Wairoa	Wairoa	1500	2.5	15	2	450	shallow water throughout
Mangatawhiri	Mangatawhiri W.	1000	-	-	1	300	rapids & fall at 300 m
	Mangatawhiri E.	1500	2.5	30	2	350	large boulders at 1800 m
	Lilburne	800	1.0	30	0	0	-
Mangatangi	Mangatangi	3500	8.0	25	3	2000	none seen
	Konini	1100	3.0	40	3	1000	log jam at 1100m
Lower Huia	Huia	400	-	-	1	-	-
Lower Nihotupu	Nihotupu	300	-	-	0	0	-

Note 1: 0 = not suitable
1 = fair
2 = good
3 = excellent

population. In the Hunua reservoirs the Mangatawhiri Reservoir contained approximately 650 m of tributary stream suitable for trout spawning. Trout are present in this reservoir and over 30 redds were observed in the Mangatawhiri stream (11 above the confluence of east and west forks). When one of these was excavated, eyed ova were found. One pool (Plate 4) contained 10 redds, the highest density seen in this survey. Trout fry were common in the Mangatawhiri Stream, but no trout or redds were observed in the Lilburne Stream.

One tributary of Cosseys Reservoir, which also contains a self-recruiting trout population, contained good gravels over a distance of 300 m but the trout population in this reservoir is small.

The quality of gravels (size, mix and absence of fines) in the Mangatangi Reservoir tributaries was better than in tributaries of other reservoirs, and the length of spawning grounds in the two main tributaries of this reservoir was, at 3000 m, nearly five times longer than in other reservoirs.

Although the Mangatawhiri Stream provides suitable spawning and rearing grounds for a good sized rainbow trout population, the Mangatangi and Konini Streams (Plate 4) of the Mangatangi Reservoir contain larger areas of better spawning ground, and are likely to contain better rearing habitat.

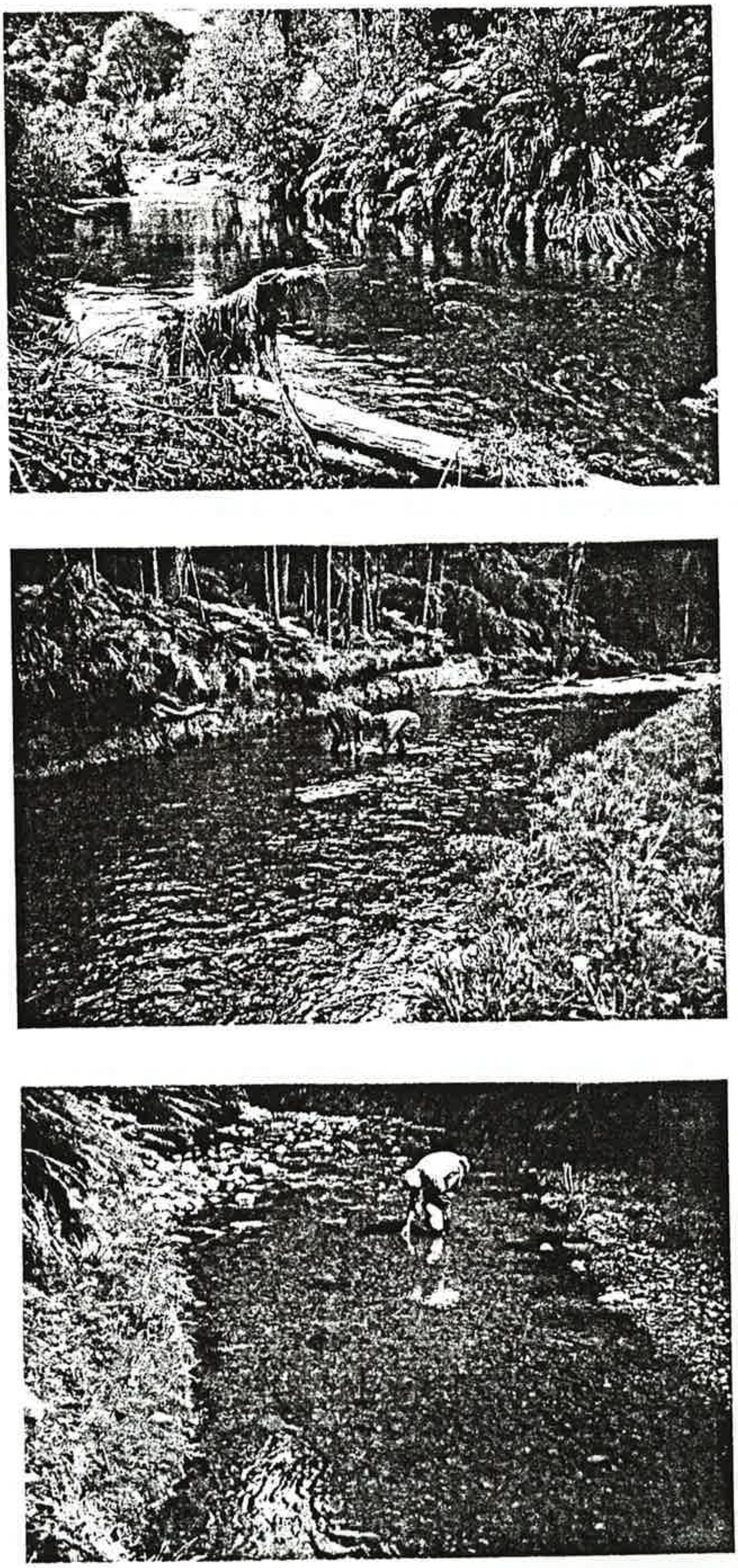

PLATE 4: TROUT SPAWNING AREAS IN THE MANGATAWHIRI STREAM (TOP), WHERE TEN REDDS WERE OBSERVED, AND POTENTIAL SPAWNING AREAS IN THE MANGATANGI (MIDDLE) AND KONINI STREAMS (BOTTOM) OF THE MANGATANGI RESERVOIR.

7. DISCUSSION AND GENERAL CONCLUSIONS

7.1 Trout fishery potential of the reservoirs

Although the Hunua and Waitakere Ranges water supply reservoirs investigated are all relatively eutrophic, water quality is still at a sufficiently high standard to permit both trout survival and growth. The artificial aeration of reservoirs to maintain oxygen levels above 5mg/l suppresses low oxygen levels in bottom waters during summer months. The depth of water for trout is increased by this. Aeration is thus a major factor in the maintenance of trout habitat in the reservoirs. Nevertheless, depth distributions of trout would still be restricted in all reservoirs over summer months. In particular, habitat will be reduced by warm temperatures in surface waters during summer, and this restriction can be expected to slow trout growth rates. The limitations on trout depth distributions will be temporary, and are not as extensive as occur in some of the Rotorua lakes, or in Lake Ototoa (South Kaipara Heads). These lakes support valued rainbow trout fisheries despite warm surface waters during summer months.

Restrictions on trout depth distribution were least in the Mangatangi Reservoir. Absolute physical habitat for trout is greatest in this reservoir, and drawdowns during drought years would not compromise trout habitat in the Mangatangi Reservoir as much as in other reservoirs. In addition, this reservoir contains comparatively larger areas of spawning grounds and rearing areas for trout.

However, the Upper Mangatawhiri Reservoir contains a greater diversity of food organisms, and has the largest area of feeding grounds for trout in proportion to its size. It is apparent that although the physical habitat for trout will be greatest in the Mangatangi Reservoir, the relative density of feeding areas and hence foods will be greater in the Upper Mangatawhiri Reservoir.

Thompson (1976a) obtained a sample of rainbow trout from the Upper Mangatawhiri Reservoir. Length frequency data indicates a minimum growth rate of 10 cm/year for 1+ fish. This is comparable with an average rate of 12 cm/year for rainbow trout in Lake Parkinson, which provided good trout fishing prior to 1976 (Rowe 1984b). But it is less than the 15-20cm/yr for stocked trout in L. Pupuke and L. Ototoa (unpublished data, Penlington 1985), and for the 30-40cm/yr attainable in central N.I lakes. A catch rate of 20 trout.net^{-1}.day^{-1}, recorded by Thompson (1976a) compares favourably with rates of 5-12 trout.net^{-1}.day^{-1} obtained in other N.I. lakes (Rowe 1984b, Penlington 1985). Mean size of trout caught was 45 cm and 1.2 kg in weight, with an average condition factor of 40.2, slightly less than for rainbow trout in L. Ototoa (Penlington 1985).

The Mangatangi Reservoir contains more physical habitat for trout and a greater area of spawning grounds. It can therefore be expected to support a larger, self-recruiting trout population. Rainbow trout are now present in this reservoir (Slaven, pers.

comm.) but there is no data on growth rates or densities. On the basis of its proportionately smaller feeding areas and larger potential for recruitment, this reservoir could be expected to produce higher densities of smaller sized trout than the Mangatawhiri Reservoir. This assumes mortality rates of trout will be similar in both reservoirs.

Wairoa and Cosseys Reservoirs would also support trout populations (they already exist in Cosseys Reservoir), but these would be limited in their suitability as fisheries. Both reservoirs contain perch which are believed to compete with trout for food. Reduced water quality and restricted spawning grounds both limit habitat in Cosseys Reservoir and catch rates of 0.2 $trout.net^{-1}.day^{-1}$ (Thompson 1976b) compare poorly with rates of 5-12 for other lakes.

Of the two Waitakere Ranges Reservoirs investigated, the Lower Huia would support trout, but annual stocking would probably be needed. Management will be difficult because of the difficulty in achieving balance between numbers of trout stocked and growth rates. Both reservoirs would be more suitable for coarse fish angling than for trout.

In summary, the Hunua reservoirs are better suited to trout populations than the Waitakere Ranges Reservoirs. The Upper Mangatawhiri and Mangatangi Reservoirs offer more potential than Wairoa or Cosseys. The Upper Mangatawhiri reservoir already contains an established self-recruiting stock of rainbow trout, which are in sufficient number and of sufficient size to be acceptable to many anglers at present. In time the Mangatangi Reservoir can also be expected to sustain a comparatively larger population of trout with moderate, but acceptable growth rates.

7.2 Potential problems and management issues

One of the major concerns with 'opening-up' water supply reservoirs is impacts to water quality and possible increases in treatment costs. The New Zealand Department of Health policy recommended to water supply authorities indicates that the existing 'A' grading of the ARA water supply reservoirs would be unchanged if angling was permitted in them (Appendix 1). Nevertheless there is little sense in downgrading an existing high quality source of water unless the demand for recreation is high, and cannot be met by other areas, which are reasonably convenient and available to the public. In the specific case of freshwater angling 'other' areas of static water available near Auckland for trout fishing purposes are minimal compared with other parts of the country, and there is clearly a demand for freshwater angling in the Auckland district.

The concern that trout angling will downgrade water quality is not borne out by experience in New South Wales, Britain or Sweden. These countries are topographically, or climatically similar to New Zealand and contain trout fisheries in reservoirs. The Ministry of Agriculture and Fisheries and Food Principal Scientific Officer in Whitehall, London, advises that trout fisheries in water storage reservoirs are seen as an unmitigated benefit (Appendix 2). In some reservoirs anglers carry out sterilizing procedures, however, in general, recreation at reservoirs is well accepted. Water authority personnel spoken to in the United Kingdom indicated that they had never heard of trout fisheries causing deleterious effects on water quality, and regarded a trout fishery as a valuable, early-warning indicator of trouble with water quality in reservoirs. The Director of the Institute of Freshwater Research in Drottningholm, Sweden also indicated that fisheries have very little effect on water quality and that rod and line (versus trap and net) fisheries for salmonids never affect water quality (Appendix 3). He indicated that the Institute had much experience with developing fisheries in reservoirs and lakes and advised us to check that oxygen and temperature limits for trout were acceptable, and that there were no native species of fish which need special protection in the reservoirs. Both these conditions are satisfied in the case of the ARC reservoirs. Trout fisheries have been established in New South Wales water supply reservoirs and 'Guidelines for Recreational Uses' in reservoirs were supplied (Appendix 4).

Apart from potential effects on water quality, there may be concerns about effects of trout fisheries on public health. There are no diseases or parasites found in trout known to affect humans. Whirling disease, has been found in some brown trout in restricted locations in the South Island. It is a problem affecting juvenile trout in hatcheries and rarely affects wild stocks. Nevertheless, transfer of salmonids from the South Island to the North is closely controlled. Rainbow trout in L. Ototoa contain a parasite Ligula intestinalis (Penlington 1985). This can be a problem for freshwater fish, restricting growth and reproduction. It has probably been introduced by avian immigrants from Austalia, and at present is beleived to be restricted to L. Ototoa. As a result MAF Fisheries recommended an embargo on the transfer of fish from L. Ototoa to other waters. However, if water-fowl are a vector for this parasite, it could be more widespread in northern lakes, and in time will spread to other trout populations, including those in ARC reservoirs, if not present there already. The only other notable parasite of trout is a worm, (Eustrongyloides ignotus), which forms unsightly cysts in the muscle tissue of trout. This parasite does not affect humans. Its frequency of infestation in trout varies from year to year, at times being high enough for anglers to complain, and call for control of shags. Shags are likely to be the main vector, but other fish-eating birds cannot be ruled out. Because of this control of shags is now accepted as being inappropriate.

Hill (1976) expressed concern about the use of chemicals in ARC reservoirs to (a) control algae and (b) to eliminate coarse fish. High concentrations of copper, found in some algicides, can be lethal to trout (eg. the 95 percentile threshold of the LC50 for rainbow trout is $0.2mg.l^{-1}$). However, algicides have not been needed in ARC reservoirs to date, and are unlikely in the forseeable future (Ronberg 1989). Furthermore, copper-based algicides are undesirable from the point of view of public health, and alternatives are available (Ronberg 1989).

MAF Fisheries completely eliminated rudd in a small trout lake in the Auckland district using 4ppm rotenone (active ingredients are derris componds). At these concentrations roteneone is harmless to sheep, cattle and humans. However, as it is undesirable to use potentially toxic chemicals in water supply reservoirs, the use of this method in ARC reservoirs is improbable. At present effects of rudd on trout populations (cf. angling efficiency) are speculative and likely to vary from water to water. Calls to control rudd, or any other coarse fish, would need to be preceeded by a scientific study to determine the necessity for this, and the control options.

Remaining concerns about angling in reservoirs are related to the management of fisheries, and water treatment costs likely to be incurred by this. Management of fisheries involves the maintenance of fish stocks and their habitat, as well as the control of anglers.

The former could conceivably require activities such as:

(1) electric fishing surveys of tributary streams to assess stocks of juveniles.

(2) netting in the reservoirs to obtain data on adult trout populations.

(3) stocking reservoirs with trout from other waters or hatcheries to supplement existing stocks.

(4) introductions of forage organisms for trout such as smelt,

galaxiids, bullies, freshwater shrimps or crayfish.

(5) construction and monitoring of traps in streams during the spawning season to determine the size and number of spawning fish.

Problems that may arise with trout fisheries in reservoirs include:

(1) reduced catch rates due to;
   (a) recruitment failure (eg. spring floods),
   (b) decreased trout densites caused by high fishing pressure (too many anglers)

(2) decreased growth rates due to;
   (a) high densities of trout (not enough anglers),
   (b) a reduction in food supply,
   (c) competition with other species.

(3) a decline in condition factor due to;
   (a) early maturation/high proportions of spent fish
   (b) seasonally poor food supply
   (c) high parasite loadings

(4) illegal introductions of coarse fish which may compomise angling.

Such fisheries-related activities and problems may be rare in most trout lakes, but they cannot be ruled out in the future. The main concern for the water supply authorities will be management activities which have the potential to affect the quality, or supply of water.

As the ARC controls access to the reservoirs there are several mechanisms by which it can exercise control over anglers. There are also certain legal obligations which are the sole responsibilty of the fishery management authorities.

Firstly, any proposed activity that may directly affect water quality or quantity (eg. construction of fish counting gates in streams) would also require a water right. Use of the reservoirs for recreational purposes is secondary to their prime function of water supply. Activities which could detrimentally affect this would not be approved by the ARC Water Board.

Secondly, proposed legislation to restructure Acclimatisation Societies makes it mandatory for the new, regional Fish and Game Councils to prepare fisheries management plans for waters used as, or intended as fisheries. Such plans will be a formal statement of goals and objectives and will need to be approved by the Minister of Conservation. The aim of these planning requirements is to ensure that activities of the Fish and Game Councils do not endanger the environment. It is expected that they will list activities such as trout stocking regimes, and any proposed introductions of forage organisms. It is also likely that they will outline management activities involving major expenditure such as survey work, fish trapping exercises, or scientific studies. Management activities such as supplementary stockings, or introductions of forage organisms should be preceeded by careful study to determine the need and feasability of success. These studies should also examine implications for water supply and treatment. A condition of access to to ARC reservoirs could be that such plans are developed in consultation with the ARC and approved by the chief engineer, before they are submitted to the Minister. This would ensure effective communication takes place.

In the last instance the ARC controls access to the reservoirs and can prohibit angling if it proves to be incompatible with the prime function of water supply. However, cooperation and effective communication between fishery management authorities and the ARC should make this unnecessary.

Fishery management also concerns control over anglers, and whereas the ARC would control access, the Acclimatisation Society (Fish and Game Council in the future) is legally responsible for ensuring compliance with its regulations. Anglers must be licensed, and are usually restricted to using specified angling equipment. In addition the fishery management authority sets minimum sizes for kept fish, bag limits, fishing areas, and the times(season and hours) during which fishing is allowed. Rangers, both official and honorary, enforce these regulations. Control over access provides the ARC with the means to restrict fishing times, over and above any control exercised by the Acclimatisation Society. It also has the right to exclude angling if this proves to be incompatible with the supply of bulk water.

Most lakes used by trout anglers contain few, or no facilities. However, it may prove desirable, even necessary, to provide toilet and rubbish disposal facilities around water supply reservoirs, if angling is permitted and becomes popular. Bank erosion, and the danger to anglers of fishing from steep-sloping, muddy banks are valid concerns raised by Hill (1976). It may be necessary to construct signs, wooden walkways and, and/or casting platforms at popular fishing locations on reservoir banks. Launching ramps would be needed if boats are allowed access, and no-go areas may need to be marked by buoys. However, these problems may not arise and such facilities may not be needed. At present such problems are hypothetical, and should not be seen as *a priori* reasons for prohibiting angling. They, and the costs needed to overcome them, are matters for discussion between management authorities, and in the nature of fine-tuning exercises to make angling, a secondary use of the waters, compatible with the prime use, potable water supply.

8 RECOMMENDATIONS

1). That the Upper Mangatawhiri and Mangatangi Reservoirs both be evaluated as trout fisheries by the Auckland Regional Council.

2). That the ARC invite the Auckland Acclimatisation Society to develop, in consultation with ARC staff, a management plan for the use of the Upper Mangatawhiri Reservoir as a trout fishery for at least three seasons. This plan should describe:

(a) controls over the fishery (eg. the season, times of day, locations, methods, minimum size of fish, etc.)

(b) management actions to ensure compliance with the plan

(c) methods to evaluate the fishery (eg. provisions for licence checking, creel censuses, angler surveys, reports etc.).

Note 1. The Auckland Freshwater Anglers Club should be consulted as they could make a valuable contribution in providing assistance with (b) and (c) above.

Note 2. Impending legislation may make such plans mandatory, and subject to Department of Conservation approval. The legislation may also require additional information, not mentioned here, to be included in such plans.)

3). That when both parties, the Auckland Regional Council and Auckland Acclimatisation Society, are satisfied with the management plan, a formal agreement be drawn up to open the reservoir on a trial basis. This agreement should stipulate:

(a) any conditions of access,

(b) mutually agreed upon criteria under which use of the reservoir as a fishery should cease within the 3 year trial period,

(c) the means of maintaining regular communication between water supply and fisheries managers so any interim problems can be addressed.

4). That if a successful fishery becomes established in the Upper Mangatawhiri Resrvoir during the 3 year trial period, the ARC invite the Auckland Acclimatisation Society to prepare management plans for the continued use of the Upper Mangatawhiri Reservoir, as well as for the opening of the Mangatangi Reservoir as a trout fishery.

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LITERATURE CITED

Ashton, F. 1989. Effects of reservoir water quality on freshwater fish. Unpublished Report. Auckland Regional Authority. 5p.

Biggs, B.J., Gifford, J.S., Smith, D.G. 1983. Bological methods for water quality surveys. Water and Soil Miscellaneous Publication No. 54. New Zealand Ministry of Works and Development, Wellington. 85p.

Bayly, I.A.E. and Williams, W.P. 1973. Inland Waters and their Ecology. Longman, Australia.

Fish, G.R. 1968. An examination of the trout population of five lakes near Rotorua. New Zealand Journal of Marine and Freshwater Research 2: 333-362.

Graynoth, E. 1976. Perchance you to pole a perch? Freshwater Catch No.1: 21-22.

Green, J.D. 1976. Plankton of Lake Ototoa, a sand-dune lake in northern New Zealand. New Zealand Journal of Marine and Freshwater Research 10: 43-59.

Hill, I.T. 1976. Report on recreational use of Auckland's water supply catchments. Unpublished report (2nd edition). Auckland Regional Authority, Auckland. 112p.

Hobbs, D.F. 1936. Report of preliminary survey of Auckland Acclimatisation district. Appendix to the Annual report of the Auckland Acclimatisation Society, 1936. Auckland.

Jolly, V.J. 1968. The comparative limnology of some NZ lakes. Part I. Physical and chemical characteristics. New Zealand Journal of Marine and Freshwater Research 2: 214-259.

Jones, D.R. 1971. The effect of hypoxia and anaemia on the swimming performance of rainbow trout (Salmo gairdnerii). Journal of Experimental Biology 55: 541-551.

Jones, J.R. & Hoyer, M.V. 1982. Sportfish harvest predicted by summer chlorophyll-a concentrations in midwestern lakes and reservoirs. Transactions of the American Fisheries Society 111: 176-180.

Magadza, C.H.D. 1973. Comparative limnology of six hydro-electric dams in the Waikato River, New Zealand (1970-1972). PhD Thesis. University of Auckland.

McColl, R.H.S. 1972. Chemistry and trophic status of seven New Zealand lakes. New Zealand Journal of Marine and Freshwater Research 6: 399-447.

New Zealand Forestry Council. 1981. Forested water supply catchments: discussion on public access. Bulletin No.9. New Zealand Forestry Council, Wellington. 66p.

New Zealand Department of Health 1980. Grading of Public Water Supplies in New Zealand. New Zealand Department of Health Report Series No. 27. 54p.

Penlington, P.B. 1985. The rainbow trout fishery in Lake Ototoa. New Zealand Fisheries Environmental Report No.54. New Zealand Ministry of Agriculture and Fisheries, Christchurch. 40p.

Penlington, P.B. 1983. Lake-shore spawning of rainbow trout at Lake Rotoma, New Zealand. New Zealand Journal of Marine and Freshwater Research 17: 349-355.

Pridmore, R.D., Vant, R.A., Rutherford, J.C. 1984. Chlorophyl nutrient relationships in NI lakes. Hydrobiologia 121: 181-189.

Richardson, J., Teirney, L.D., Unwin, M.J. 1985. The relative value of Auckland rivers to New Zealand salmonid anglers. New Zealand Fisheries Environmental Report No. 59. Ministry of Agriculture and Fisheries, Christchurch. 81p.

Ronberg, L.A. 1989. Fishing in catchments. Unpublished report. Auckland Regional Authority, Auckland. 4p.

Rowe, D.K. 1984a. Factors affecting the foods and feeding patterns of lake dwelling rainbow trout (Salmo gairdnerii) in the North Island of New Zealand. New Zealand Journal of Marine and Freshwater Research 18: 129-141.

Rowe, D.K. 1984b. Some effects of eutrophication and the removal of aquatic plants by grass carp (Ctenopharyngodon idella) on rainbow trout (Salmo gairdnerii) in Lake Parkinson, New Zealand. New Zealand Journal of Marine and Freshwater Research 18: 115-127.

Rowe, D.K. and Scott, D. 1989. Effects of climate warming on trout fisheries in northern New Zealand. Freshwater Catch No. 41.

Schipper, C.M. 1980. In search of perch. Freshwater Catch No. 7: 10.

Teirney, L.D., Unwin, M.J., Rowe, D.K., McDowall, R.M., Graynoth, E. 1982. Submission on the draft inventory of wild and scenic rivers of national importance. New Zealand Fisheries Environmental Report No. 28: Ministry of Agriculture and Fisheries, Christchurch. 122p.

Thompson, F.V. 1976a. Trout Survey Report, Upper Mangatawhiri Reservoir. Unpublished report. Auckland Acclimatisation Society, Auckland. 5p.

Thompson, F.V. 1976b. Trout Survey Report, Cossey's Reservoir. Unpublished report. Auckland Acclimatisation Society, Auckland. 3p.

Thompson, F.V. 1976c. Trout Survey Report, Wairoa Reservoir. Unpublished report. Auckland Acclimatisation Society, Auckland. 2p.

Thompson, F.V. 1976d. Trout Survey Report, Lower Nihotupu Reservoir. Unpublished report. Auckland Acclimatisation Society, Auckland. 3p.

Thompson, F.V. 1976e. Trout Survey Report, Lower Huia Reservoir. Unpublished report. Auckland Acclimatisation Society, Auckland. 3p.

Vant, W.N. 1987. Eutrophication: an overview. pp 151-166. In Vant, W.N. (ed), Lake Managers Handbook. A guide to understanding investigations into lake ecosystems, to assess management options. Water and Soil Miscellaneous Publication No. 103. New Zealand Ministry of Works and Development, Hamilton. 230p.

APPENDIX 1

Address all communications to
The Director-General of Health.
Telegraphic Address:
Health, Wellington.

Reply reference
124/20/3

DEPARTMENT OF HEALTH
HEAD OFFICE

MACARTHY TRUST BUILDING, LAMBTON QUAY, WELLINGTON,
NEW ZEALAND

P.O. BOX 5013
TELEX NZ 3571
TELEPHONE:
727 627

RECEIVED
28 SEP 1983
Min. of Agriculture
and Fisheries
ROTORUA

26 September 1983

Ministry of Agriculture
and Fisheries
PO Box 251
ROTORUA

Attention: Mr David Rowe

RECREATIONAL USE OF WATER SUPPLY RESERVOIRS AND CATCHMENTS

Your letter dated 2 August 1983 refers.

The current Department of Health policy on this matter is unchanged since the recommended policy was circulated in 1980. It is noted from the file that you have a copy of this recommended policy. It has been decided to leave this 'policy' as a recommendation to water supply authorities, who must take responsibility for the quality of water supplies under their control.

If freshwater angling was permitted on ARA reservoirs in the Hunuas, then it is true there would be no change to their existing 'A' grading. The likely score for supply source would probably be 17 as you say, depending on whether entry was restricted to 'controlled' anglers and whether provision was made for toilets. Even the worst score of 22 would still give them an 'A' grade due to the high degree of treatment.

However the following general principles apply and are forcefully supported by the World Health Organisation:

1 a high quality source of water should not be downgraded simply on the basis that high quality treatment will upgrade it again;

2 water quality can have a very marked effect on public health, and thus it is desirable to have as large a safety factor as possible, in terms of multiple barriers against the risk of infectious disease.

The Department of Health acknowledges that there may be circumstances where recreational use of catchments is appropriate. The recommended policy states that this would be appropriate if there are no other areas of land or water reasonably convenient and available to the public. However this is not the case in relation to the Hunua water supply catchment area. The ARA is in fact proposing a peripheral walkway around the catchment area, which appears to be a sensible compromise. The public will have partial access but will be kept well away from water courses and impoundment areas.

Should you have any further queries on this matter, it is suggested that you route them through the head office of Ministry of Agriculture and Fisheries in accordance with normal interdepartmental protocol.

J R O'Grady

J R O'Grady
for Director
Division of Public Health

APPENDIX 2

Salmon and Freshwater Fisheries Laboratory
Ministry of Agriculture, Fisheries and Food
Whitehall Place, London, SW1A 2HH

Telex 889351 Direct Line 01-217 6107 or
Switchboard 01-217 3000

Dr David Rowe
Ministry of Agriculture and
Fisheries
P O Box 951
Rotorua
New Zealand

Our reference FGB15571

4 June 1981

Dear Dr Rowe,

Thank you for your letter of the 20th of May asking about our experience with the possible adverse effects from the use of water storage reservoirs for recreational and, particularly, fishing.

There is no doubt that in this country trout fisheries in water storage reservoirs are seen as an unmitigated benefit. I believe that at some reservoirs, but a very few, there is a requirement for anglers to carry out some sterilising procedures using a hypochlorite solution but in the main, water recreation at reservoirs is well accepted here. Some water authorities even allow Scuba diving.

So completely is the acceptance that when new reservoirs are planned the recreational aspects, including fisheries which are usually put and take rainbow trout fisheries, are placed on the benefit side of the equation against such things as the loss of agricultural land, etc. Since receiving your letter I have spoken to several water authority personnel and none had ever heard of fisheries causing deleterious effects on water quality or indeed a need for additional treatment facilities. In fact, more than one person said that their water engineers regarded the trout fishery as providing an early warning system in case of trouble.

I hope these remarks are of some interest but should you require more information please do not hesitate to contact me again.

Yours sincerely

B Stott
Principal Scientific Officer

APPENDIX 3

INSTITUTE OF FRESHWATER RESEARCH
S-170 11 DROTTNINGHOLM
SWEDEN

LN/KB

June 4, 1981

Mr David Rowe
Fisheries Research Laboratory
Ministry of Agriculture and Fisheries
Box 951
ROTORUA
Nya Zealand

Dear Mr Rowe,

Thank you for your interesting letter concerning the effect of recreational fisheries on water quality. It is a small world indeed. In 1974 I worked for the Environment Protection Board in Sweden. The Ministry of Foreign Affairs obviously had received a request from the New Zealand Government seeking advice on how to halt the eutrophication of Lake Rotorua, and I wrote a short report on the subject but never heard a word on what happened to it. I should not say I am happy that you still have a problem but I have been deeply interested in New Zealand freshwater fisheries for at least two decades, both its native fauna of galaxids and retropinnids but also in the "success" of the introduced exotics - particularly those of European origin like the brown trout, the Atlantic salmon and the perch.

Most of my personal information derives from contacts with Radway Allen and Donald Scott (of Otago University). After this small detour I'll try to focus on your questions.

Our Institute has devoted a large share of the total research performed over the decades to the problems of fish species interactions and also to interaction between fishes and lower trophic levels. Interactive segregation and size-dependent predation are two key terms which must always be considered when trying to analyse the potential effects of how fish introductions and various fishing methods may influence the water quality of a lake or reservoir. There are some general principles that must be agreed on first: the water reservoirs you are willing to open for recreational fisheries have temperatures and oxygen levels suitable for salmonid fish. There are no native species of fish which need special protection. If oxygen levels are too low and/or temperatures too high for salmonids there is an interest in perch as a sport fish. Fish introductions and fisheries activities should be directed toward attaining unchanged or improwed water quality.

With these principles accepted there should be no hazards involved in opening up reservoirs for recreational fisheries. In this country we have a long experience of manipulating the biological production of lakes, and Sweden has many features in common with New Zealand on the freshwater side, e.g. the few species involved and the climate (our winters being colder though). A first step toward achieving these goals must be to stop introductions of rudd or any other cyprinid fish because they are capable of accelerating the growth of phytoplankton thus affecting the entire biological production and the water transparency. Also, these species compete extremely successfully with trout and perch to the degree that your statement that "anglers find that they can-not get lures beyond rudd to the trout and consequently now catch many rudd and no trout" in fact may indicate that trout are more or less wiped out of the reservoirs. Both brown trout and perch, in our experience, are best managed in "monocultures", i.e. allopatrically - perch though even better in combination with northern pike (Esox lucius L.) a species you may not have in New Zealand. On the other hand both species (brown trout and perch) are heavily dependent on the littoral zone which is often depleted of life in our impounded lakes where the annual amplitude of water level regulation may exceed 30 meters. Rod and line fisheries never seem to adversely affect the water quality in such non-cyprinid waters, and even extensive net fisheries may be operated on the reservoirs.

This information is however very general and scanty and if you are interested in more precise recommendations I would be willing to set up a joint project between our laboratories at no cost - unless you have financial means of providing return fares for more personal on-location advice.

My first reaction to your questions is thus: a) fisheries have very little effect on water quality, b) no additional treatment facilities will be needed, provided you follow "our" recommendations.

Yours sincerely,

Lennart Nyman
Director
Institute of Freshwater Research
S-170 11 DROTTNINGHOLM
Sweden

New South Wales Government

New South Wales State Fisheries

Fisheries House,
211 Kent Street,
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Your reference:

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Dr. D. Rowe,
Fisheries Research Laboratory,
Ministry of Agriculture &
Fisheries,
P.O. Box 951,
ROTORUA.
NEW ZEALAND

22nd May, 1981

Dear Dr. Rowe,

Thank you for your recent letter concerning recreational fishing in water supply impoundments.

Several years ago various New South Wales agencies drew up a set of guidelines which was issued by the Health Commission of New South Wales. I enclose a copy of these guidelines for your information. As a fisheries manager the guidelines still seem conservative, but they are a start.

The Federal Government, through the Department of Capital Territory has allowed recreational fishing in Canberra's water supply, Googong Dam. If you have not as yet contacted Dr. Brian Pratt of that Department I suggest you do so for further information.

Please do not hesitate to contact me again if you think I can be of further assistance.

Enc.

Yours sincerely,

Donald D. Francois,
Director of Fisheries.