MAF Fisheries Research

Background to fisheries studies of the lower Clutha River

Fisheries Environmental Report No. 76

Fisheries Research Division
N.Z. Ministry of Agriculture and Fisheries

Fisheries environmental report no. 76 (1986)
ISSN 0111-4794

Fisheries Environmental Report No. 76

Background to fisheries studies of the lower Clutha River

by

M.J. Harvey

D.J. Jellyman

Fisheries Research Division

N.Z. Ministry of Agriculture and Fisheries

Christchurch

November

1986

Fisheries environmental report no. 76 (1986)

FISHERIES ENVIRONMENTAL REPORTS

This report is one of a series of reports issued by Fisheries Research Division on important issues related to environmental matters. They are issued under the following criteria:

(1) They are informal and should not be cited without the author's permission.

(2) They are for limited circulation, so that persons and organisations normally receiving Fisheries Research Division publications should not expect to receive copies automatically.

(3) Copies will be issued initially to organisations to which the report is directly relevant.

(4) Copies will be issued to other appropriate organisations on request to Fisheries Research Division, Ministry of Agriculture and Fisheries, P.O. Box 8324, Riccarton, Christchurch.

(5) These reports will be issued where a substantial report is required with a time constraint, e.g., a submission for a tribunal hearing.

(6) They will also be issued as interim reports of on-going environmental studies for which year by year or intermittent reporting is advantageous. These interim reports will not preclude formal scientific publication.

ISBN 047703229X

CONTENTS

TABLES

FIGURES

Page

SUMMARY

The Clutha River has the largest catchment area (21 400 km^2) and the largest mean annual discharge (533 m^3/s) of any New Zealand river. It has a diversity of uses including recreation, irrigation, frost fighting, mining, and industrial and public supply, and it also supports important fisheries.

Use of the Clutha River is dominated by hydro-electric power development which started in the mid 1950s with the installation of Roxburgh dam and power station. Hydro development in the upper Clutha is proceeding with Clyde dam presently under construction and consideration being given to further development in the main river (Luggate and Queensberry) and in the Kawarau River. The potential of the lower Clutha is currently being investigated and, at the time of writing, three scheme options have been proposed.

Flows in the Clutha River have been modified by the Hawea control dam which was installed to provide additional storage for Roxburgh power station. Consequently average flows during the low-flow period of winter have increased and average flows in summer have decreased.

The installation of Roxburgh dam has caused large daily fluctuations in downstream flow and variations in water level. This has resulted in de-watering of the river margins and has supposedly led to bank instability. As no fish pass was installed, Roxburgh dam is a barrier for migratory fish, such as quinnat salmon and sea run brown trout and at least three species of native fish (lampreys, short-finned and long-finned eels).

The 75-km-long study area of the lower Clutha from Roxburgh to Tuapeka Mouth has been investigated to assess the hydrology and fish

stocks. The combined mean flows of the tributaries in this area contribute only 3% of the total mean flow of the Clutha River. Nevertheless, several of the tributaries provide valuable spawning and rearing waters for quinnat salmon and brown trout, for example, Benger Burn, Crossans Creek, and Carsons Stream.

The fisheries studies are part of a programme to identify the physical, biological, and social resources of the lower Clutha River and to assess the impacts of various power development options on these resources. This report provides background information to the series of fisheries studies which cover water based recreation, the existing fisheries values, and impacts caused by hydro-electric development. As part of the overall study programme the present report discusses the aquatic biology of the study area in the context of the whole catchment. Similarly the river flows over the 2 years of the study are compared with the flows from 1959-84. Compared with an average year, the study year flows were very atypical; with the exception of 3 months, all monthly flows were significantly greater than average.

1. INTRODUCTION

With its many lakes and rivers, New Zealand has a large potential for hydro-electric power generation. Consequently, there is a large dependence on hydro energy, which produces as much as 74% of the nation's electricity. In the North Island hydro-electricity generation is predominantly from the system of power stations on the Waikato River which have a potential production of 1045 MW. In the South Island the Waitaki system at present produces 1334 MW, but with further development could produce 2008 MW.

With the largest mean discharge of all New Zealand rivers, the Clutha River is an extensive hydro resource and is presently only partially developed. In total the Clutha system has a potential generating capacity of between 1512 MW and 1707 MW. As part of an ongoing investigation, the hydro potential of both the Kawarau and lower Clutha Rivers are currently being investigated. "If all these schemes were to be implemented, the Clutha River would be transformed from a river into a series of hydro lakes over something like four-fifths of its length." (Otago Catchment Board and Regional Water Board 1985a).

Apart from hydro-electric development the Clutha River has other important uses, including irrigation, angling, and recreation, as well as having valued scenic and aesthetic qualities. Although the multiple use concept is inherent in the 1967 Water and Soil Conservation Act, so far developments on the Clutha River have been "dominant purpose or special purpose" (hydro) (Otago Regional Water Board 1980). With further hydro development of the Clutha River there will be a substantial loss of scenic areas. One such area, the Cromwell Gorge is included in the "A" list of the draft National Inventory of Wild and Scenic Rivers (National Water and Soil Conservation Organisation (NWASCO) 1982), but it will be inundated by Lake Dunstan, the impoundment formed by the Clyde dam. Recently there has been considerable interest in the possiblity of retaining the Kawarau River as a "wild and scenic river" under the 1981 amendment to the Water and Soil Act, though, at the time of writing, no application to do this had been made.

Current management policy of the regional water board is for the upper Kawarau (Lake Wakatipu to the Nevis Rapids) to be retained in its present state and for no major developments downstream to proceed until all multiple purpose options have been investigated further (Otago Catchment and Regional Water Board 1985b).

A variety of human activities has led to substantial changes in the fisheries values of the Clutha River. The installation of Roxburgh dam has affected fish passage, and operation of the dam has led to highly variable downstream flows. Drainage of lowland wetlands has resulted in a major loss of habitat for a variety of native fish species. Another major change has been the introduction of salmonid species which now form part of a very important fishery especially in the upper Clutha River and lakes. Hydro development has already significantly altered the abundance and distribution of fish stocks in the Clutha catchment (Jellyman 1984), and further changes will accompany future development.

The Ministry of Agriculture and Fisheries (MAF) has overall responsibility for the management of freshwater fisheries under the Fisheries Act 1983, but management of recreational fisheries is delegated to acclimatisation societies and to wildlife conservancies of the Wildlife Service, Department of Internal Affairs (DIA). The Clutha catchment contains two districts administered in this way - those of the Otago Acclimatisation Society (OAS) and the Southern Lakes Wildlife Conservancy (SLWC).

As one of a variety of physical, social, biological, and engineering studies on the lower Clutha River, Fisheries Research Division (FRD) was requested by the Ministry of Works and Development (MWD) to carry out a fisheries study on the lower Clutha River. A team of three consultants (two scientists and one technician) was employed. Based at Roxburgh, they carried out a 2 year study of recreation, present fisheries values, and the implications of further hydro development. As part of the overall study programme, it was necessary to put general aspects of the study area and the hydrological conditions over the 2 years of the study into a broader perspective; these features form the basis of this report. Consequently, though this report "stands alone", its principal value is as a background to the recreational report (Whiting 1986), the fisheries study (Pack and Jellyman in prep), and the implications of hydro development (Jellyman in prep).

2. CLUTHA RIVER AND CATCHMENT

2.1 Physical Description and Hydrology

The Clutha River has the largest catchment (21 390 km^2) and mean annual discharge (533 m^3/s) of any river in New Zealand. The second longest river in the country (after the Waikato River), it flows for 322 km in a south-east direction to enter the sea at Balclutha (Fig.1). The catchment lies in an area bounded by latitudes 43°50'S and 46°20'S and longitudes 168°00'E and 169°50'E and covers 50% of Otago. It is generally rugged and steep with a small proportion of plains. The catchment area has three distinct regions (Murray 1975):

1. An alpine-subalpine region, west and north of the three source lakes.

2. A central area of block mountains of moderate altitude (maximum height 1200-2000 m) with arid valleys and gorges and limited areas of fertile terraces and fans.

3. A costal zone of rolling and flat country which includes the delta area east of Balclutha.

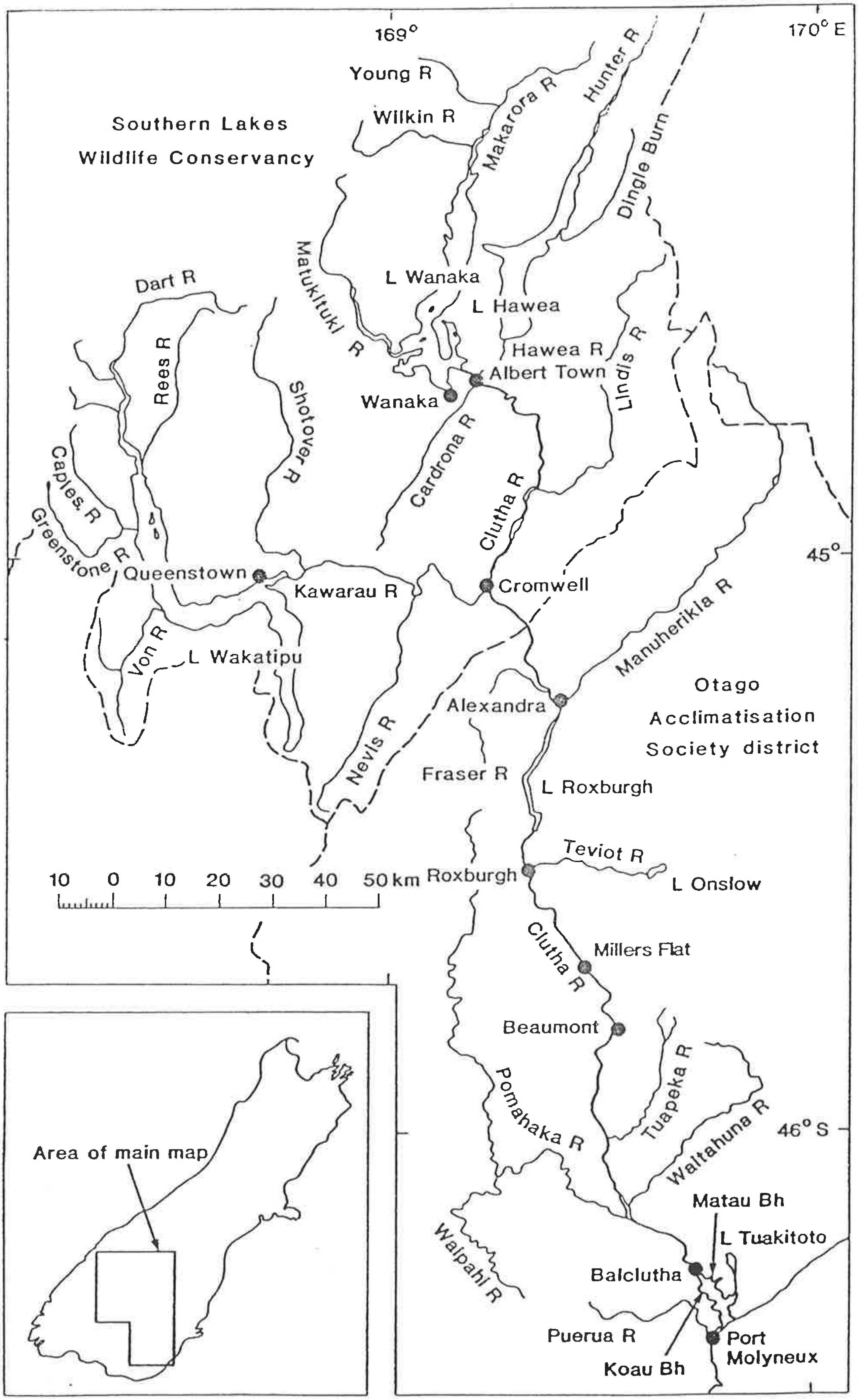

FIGURE 1. The Clutha River catchment.

The topography of the region is very diverse, with a mean elevation of 750 m (16.5% lies above 1500 m) (Otago Regional Water Board 1980). About 43% of the catchment area is higher than 100 m and this area provides most of the seasonal snowmelt during spring and early summer. The main period of inflow into the lakes coincides with snowmelt in November.

Overall the water quality of the Clutha River is high. The water at the outlet of the source lakes is in pristine condition (Biggs and McBride 1980). The tributaries also have a fairly high water quality and have no discernable effect on water quality in the river. Downstream from the confluence of the Clutha and Kawarau Rivers, the clarity is reduced by high levels of suspended solids originating largely from the Shotover River. There is very little organic pollution in the river, with the exception of effluent discharge from the Finegand Freezing Works at Balclutha. Chemically the river has fairly soft, dilute calcium bicarbonate waters with low levels of nitrogen and phosphorus (Davies-Colley 1985). Dissolved oxygen is near saturation levels. During low flows in the Hawea River, Biggs (1982) recorded oxygen supersaturation and maximum pH levels of 9.0 which, if they occurred over extended periods, could be detrimental to fish stocks.

2.1.1 Geology

The mountain system of the Clutha River Basin consists of steep-sided, block faulted mountains and intermittent depressions. The three source lakes are glacial in origin: the U-shaped valleys, lake basins, and cirques are evidence of glaciation.

Immense quantities of eroded gravels, silts, and detritus have been transported through the numerous basins of the catchment, and erosion processes are still going on at a reduced rate. In middle reaches of the Clutha there are rounded cobbles and pebbles of metamorphic quartz. In the lower Clutha valley, the quartz gravel is finer and a much greater proportion of materials along the river bed is sand and silt.

2.1.2 Lakes

The sources of the Clutha River are three large alpine lakes - Wakatipu, Wanaka, and Hawea. Wakatipu has an area of 293 km^2, Wanaka 192 km^2, and Hawea 119 km^2 with mean annual discharges of 156 m^3/s, 190 m^3/s, and 63 m^3/s respectively (Jowett and Thompson 1977). Collectively the three lakes dominate the hydrology of the catchment, and provide about 75% of the flow at Balclutha (Murray 1975).

2.1.3 River and Major Tributaries

The Clutha River is a fairly stable, single channel river (Fig. 2). At Roxburgh it has a mean annual discharge of 492 m^3/s, 10-20% of which comes from seasonal snowmelt. Between Roxburgh and Beaumont (50 kms) the Clutha River flows south to south-east with an average gradient of 1:1060 (0.9 m/km). The river is deep for most of this section with a deep ponding area below Roxburgh dam. Between Beaumont and Tuapeka Mouth, the river is wide and quiet flowing. From Beaumont to Balclutha, the gradient is slight, and the river widens and is quiet flowing over shingle and mud beaches below its confluence with the Pomahaka. The Clutha River discharges its water into Molyneux Bay by two mouths; the westerly Koau Branch (18 km long) runs almost directly into the sea and the easterly Matau Branch (29 km long) runs in a meandering course past Kaitangata. Alone, the Clutha River discharges 6% of all the water to leave the South Island into the sea (Murray 1975).

FIGURE 2. Clutha River near Beaumont.

On its course the Clutha River is joined by eight major tributaries and numerous smaller ones. The Makarora River feeds Lake Wanaka and the Clutha River drains it. At Albert Town, the Clutha River joins the Hawea River (63 m^3/s) and Cardrona River (6.4 m^3/s). The Lindis River (6.2 m^3/s) discharges into the Clutha River above Cromwell. The Kawarau River (174 m^3/s) from Lake Wakatipu, is joined by the Shotover River (38 m^3/s) 5 km below the lake outlet. It flows east through continuous gorges with long sections of white water and is joined by the Nevis River (10.1 m^3/s) before meeting the Clutha River at Cromwell. The Fraser River (2.4 m^3/s) runs into the Clutha River on the south bank at Alexandra and the Manuherikia River (15 m^3/s) does so on the north bank. The Manuherikia River becomes considerably reduced in summer because much of its water is used for irrigation. (The tributaries of the study area, from Alexandra to Tuapeka Mouth, are described in section 4.2.3). The Waitahuna River flows from the Lammerlaw Mountains and joins the Clutha River below Lawrence. The Pomahaka River (23.2 m^3/s at Burkes Ford) is the largest of the lower tributaries; it rises in the snowy ranges of the Umbrella Mountains and flows in a south-easterly direction to join the Clutha above Balclutha. Downstream of Roxburgh the tributaries contribute only a further 41 m^3/s, more than half of which comes from the Pomahaka River.

2.1.4 Flooding

The Clutha River is subject to flooding, especially in spring when warm north-west winds cause rapid snowmelt. If major storms coincide with snowmelt through upper catchment areas, devastating floods occur. The Clutha River's largest recorded flood was in 1878 with an estimated peak flow of 5700 m^3/s. It lasted for 3 weeks and caused the Matau and Koau branches (below Balclutha) to discharge through separate mouths whereas formerly they shared a single outlet (Poole 1983). A flood of 2000 m^3/s at Roxburgh has a return period of 15 years, and the probable maximum flood at this site is estimated at 7863 m^3/s (Jowett and Thompson 1977). Most floods of the Clutha River have similar characteristics: a moderately rapid rise, a prolonged peak, and a slow recession. The high country lakes have a buffering effect on the river flows.

2.1.5 Climate

The climate of the Clutha valley varies between the maritime coastal climate of eastern Otago and the semi-continental climate of central Otago. The continental climate (unique in New Zealand) is characterised by low precipitation, wide diurnal and annual temperature ranges, and clear skies. These produce sharp frosts in winters and cold nights and hot days with brilliant sunshine in summer. In the southern downlands, by the coast, there is a moderate, well-distributed rainfall and extreme temperatures are not recorded. Rainfall increases from central Otago to the coast and towards the lakes and main divide. Groundfrosts are experienced in central Otago in late winter and early spring and can be quite severe. On average, Roxburgh has 188 days of frost a year.

2.2 Aquatic Biology

2.2.1 Vegetation

Aquatic macrophyte growth in the river is confined to backwaters and ponds where flows are slowest. The high velocity of water in the main channel prevents the establishment of significant quantities of aquatic or semi-aquatic vegetation. There is a wide variety of native and adventive macrophytes present in the Luggate-Queensberry section of the upper Clutha River (Biggs 1981), though, even here, benthic algae provide most of the primary production. In the lower Clutha River, Biggs and Shand (1985) listed 8 aquatic and 37 semi-aquatic macrophyte species, but they noted that the aquatic macrophyte communities had no apparent unique components and were generally low in diversity.

The introduction of two major exotic aquatic species *Elodea canadensis* and *Lagarosiphon major*, has caused substantial changes in macrophyte communities since their establishment was first recorded in the late 1960s (Hill 1970). Major changes in the nature of vegetation in Lake Roxburgh have occurred since its formation in 1956. In 1964, the flora was dominated by the native species *Potamogeton*, *Myriophyllum*, and *Tillaea sinclairii* (Winter 1964). *Elodea* became established by 1970 (Hill 1970) and by 1973 it dominated the littoral zone in the depth range of 0.3-8.0 m. *Lagarosiphon* had also colonised the lake and was vigorously developing by 1974 (Coffey 1974). In an attempt to control it the lake level was dropped and exposed areas sprayed with diquat, but by 1979 it had re-established itself. By 1981, it was co-dominant with *Elodea* and, as the number of infestations of *Lagarosiphon* has increased, it now outcompetes *Elodea*. Although *Elodea* and *Lagarosiphon* are found in the lower Clutha River, they have not yet become established (Biggs 1984).

In the tributaries of the upper Clutha River filamentous green algae could become a seasonal problem for both fish populations and anglers; they cause accentuated fluctuations in dissolved oxygen and pH levels and hazardous conditions underfoot (Department of Internal Affairs 1981).

Daily regulation of Roxburgh power station causes periodic dewatering of shallow reaches below Roxburgh. However, the dense pockets of macrophytes which develop in the backwaters and silty-banks show a remarkable resilience to this daily dewatering (Biggs and Shand 1985).

2.2.2 Benthos

A diverse range of invertebrates has been recorded from the upper Clutha catchment with a considerable range in the tributaries and the riffle areas, and fewer in the backwaters (Biggs and Matthus 1981). Biggs and Malthus (1982) investigated the macroinvertebrates associated with three native and adventive aquatic macrophytes in Lakes Wanaka and

Roxburgh and in several backwaters of the upper Clutha River. They identified 26 invertebrate taxa and the communities were all dominated by the molluscs *Potamopyrgus antipodarum* and *Physa* spp. with the dipteran Chironomidae being subdominant. Over all, the mean abundance of macroinvertebrates was $1585/m^2$. In backwater areas there were fewer organisms; the snail *Potamopyrgus antipodarum* was dominant and the snail *Physa* sp. and the bivalve *Pisidium* sp. were abundant. The riffle areas had a mean density of invertebrates of $2200/m^2$. Tributaries were an important component to the system, and had a mean density of organisms of $4200/m^2$ (Biggs and Malthus 1981).

In the lower Clutha River study area Biggs and Shand (1985) identified 74 types of aquatic invertebrates. Overall standing crop of invertebrates was described as moderate to low with the highest number of organisms being found in backwaters and silty-banks. *Potamopyrgus antipodarum* dominated the fauna in all main river habitats. Tributaries had surprisingly low densities and standing crops of invertebrates.

2.3 Fish - Introduced Species

In the Clutha River system 6 species of fish have been successfully introduced and 12 native species have been recorded. Summaries of distribution and life history are given in this section, but more extensive information is contained in Jellyman 1984.

2.3.1 Brown Trout (*Salmo trutta*)

Brown trout were first imported into New Zealand from Tasmania in 1867, and the Otago Acclimatisation Society made their own importation in 1868 (Ayson 1958). They were first liberated into the Clutha River system at Lake Wanaka in 1876 and spread rapidly to become fully established by 1885. By 1892 the Clutha River and its tributaries comprised three-quarters of the best trout fishing waters in New Zealand (Spackman 1892). By 1904 brown trout were reported to be in every tributary of the Clutha River system (Hamilton 1904). Hutchinson (1974) reported that between 1945 and 1974 347 000 brown trout fry were released into various parts of the Clutha, Kawarau, Lindis, Cardrona, and Hawea Rivers though no releases have been made in recent years. Brown trout are the most commonly encountered fish in the Clutha catchment, and occur throughout the main river, tributaries, streams, and lakes; it is probable that they are absent only from water where natural obstacles have prevented upstream passage.

2.3.2 Rainbow Trout (*Salmo gairdnerii*)

Rainbow trout were first liberated into the Clutha River in 1895 when 1500 fish were released into the Waipahi River (Thomson 1922). In the early 1900s the Pembroke Hatchery was established at Lake Wanaka to stock this and the other lakes. During 1935 alone, 1.25 million rainbow fry were liberated into Lake Wanaka (Hutchinson 1980). Since 1945 there have been numerous liberations of rainbow trout by the Department of Internal Affairs, from stock obtained from the North Island (R. Hutchinson, Department of Internal Affairs, pers. comm.). As with brown trout, rainbow trout initially grew rapidly and attained a large size, but they are not as widespread as brown trout. They are mostly confined to the source lakes and their tributaries, though some are found in Lake Roxburgh, the river below the dam, and in some smaller lakes and reservoirs (Jellyman 1984).

2.3.3 Brook Char (*Salvelinus fontinalis*)

Brook char, also known as brook trout, were introduced from eastern United States in 1887 and were introduced into Otago about 1915 (Thomson 1922). They do not seem to be able to co-exist with other salmonids and are usually found further upstream than brown trout (Lane 1964). Populations are known from the upper Nevis and tributaries, and the upper Manuherikia and Matukituki tributaries (Jellyman 1984). Over recent years, liberations have been made into Lake Dispute and Dingle Lagoon with the latter expected to develop into a significant fishery (R. Hutchinson, Department of Internal Affairs, pers. comm.).

2.3.4 Quinnat Salmon (*Oncorhynchus tshawytscha*)

Quinnat salmon were introduced from North America in the mid 1870s, but it seems unlikely that any of these initial liberations were successful (McDowall 1978). In the 1920s quinnat salmon were raised in the Pembroke Hatchery, Wanaka, and were liberated into Lakes Wanaka, Wakatipu, and Hawea. All lakes established voluntary landlocked stocks, and anadromous stocks developed in Lakes Wanaka and Hawea. It is now considered unlikely that anadromous stocks ever developed in Lake Wakatipu, probably because adult salmon could not negotiate a natural water chute in the Kawarau River immediately upstream from its confluence with the Roaring Meg. Also, the poor water quality of the Kawarau, especially during the active mining period in the Shotover catchment, may have deterred fish from entering the Kawarau River (R. Hutchinson, Department of Internal Affairs, pers. comm.). Today the natural spawning of landlocked stocks in headwater tributaries of the lakes (for example, Dart and Rees in Lake Wakatipu) is supplemented by some stocking of hatchery reared fish. In Lake Wakatipu liberations of 15-month-old fingerlings average 6-8000 a year.

The installation and commissioning of Roxburgh dam in 1956 (without a fish pass) prevented the upstream migration of adult salmon beyond this point. The existing run in the Clutha River below the dam comprises the following: wild fish spawning below the dam, ex-hatchery salmon from the ICI/Wattie Hatchery at Kaitangata, and some of the landlocked population from the lakes that have passed down the spillways of the dam and have been to sea (Flain 1980). Over recent years increasing catches of anadromous quinnat salmon have been made, apparently as a result of hatchery liberations by ICI/Wattie.

2.3.5 Splake (Hybrid of *Salvelinus fontinalis* x *S. namaycush*)

Splake are a hybrid produced by fertilising mackinaw (lake char) eggs with brook char sperm. They have been produced by the Department of Internal Affairs hatchery at Wanaka and were liberated into Lake Dispute in 1982. Splake grow faster than either parent and are a fertile hybrid.

2.3.6 Perch (*Perca fluviatilus*)

The European perch was successfully introduced into the South Island from consignments which arrived in 1868, 1870, and 1877 from Victoria and Tasmania, Australia (Thomson 1922). By 1891 the Otago Acclimatisation Society annual report recorded that perch were becoming very numerous in Otago. Today they are more numerous in the lakes of the upper Clutha River than in the rivers of the Clutha system. Perch prefer still or gently flowing waters and, though they do occur in the main river, their numbers are not large and they are unlikely to reach a significant population size.

2.3.7 Unsuccessful Introductions

There have been two species introduced into the Clutha River which did not become established. The Atlantic salmon (*Salmo salar*) was introduced into New Zealand from Scotland and England in 1868. Although an estimated 147 900 fry were liberated into the Clutha system between 1868 and 1900 (Thomson 1922), neither anadromous nor landlocked stocks became established.

The lake whitefish (*Coregonus clupeaformis*) from North American was introduced in the late 1880s. A liberation was made into Lake Wakatipu and some of the other lakes but this and later liberations were unsuccessful. Nowhere in New Zealand were these liberations successful and the Government finally abandoned the project (Jellyman 1984).

2.4. Fish - Native Species

2.4.1 Lamprey (*Geotria australis*)

Only two adult lampreys were recorded in the Clutha catchment, but juveniles (ammocoetes) have been found in a muddy backwaters near Millers Flat and Tuapeka Mouth.

2.4.2 Short-finned Eel (*Anguilla australis*)

The short-finned eel is fairly common in the lower reaches of the main river, but it does not penetrate far inland and is uncommon in the vicinity of Roxburgh.

2.4.3 Long-finned Eel (*Anguilla dieffenbachii*)

This species is widespread throughout the Clutha system. It occurs in the source lakes, and in the main river and its tributaries. The estimated annual catch from the three source lakes is 40 t (Department of Internal Affairs 1981). A smaller fishery exists in Lake Roxburgh and the lower river with an annual catch of about 20 t.

2.4.4 Common Smelt (*Retropinna retropinna*)

Common smelt are seasonally abundant in the river below Balclutha and also occur in Lakes Tuakitoto, Wanaka, and Hawea. Smelt in Lakes Wanaka and Hawea are entirely lake dwelling and Hutchinson (1974) suggested they are self introduced because there is no record of them having been liberated in these lakes.

2.4.5 Giant Kokopu (*Galaxias argenteus*)

In the Clutha system giant kokopu have been recorded from Lake Kaitangata (now drained), Lake Tuakitoto, and the lower Pomahaka River. McDowall (1965) recorded that kokopu species made up 2% of the whitebait in the Clutha River samples, but giant kokopu are now regarded as rare.

2.4.6 Common River Galaxias (*Galaxias vulgaris*)

In the Clutha catchment the common river galaxias is principally an upstream species being recorded from major tributary rivers below the source lakes. It is the most common and widespread galaxiid in Otago (McDowall 1978).

2.4.7 Koaro (*Galaxias brevipinnis*)

The koaro has a very widespread distribution in the Clutha catchment. It is fairly common in the lakes and tributaries, but less common downstream of Roxburgh. The lake dwelling populations carry out their complete life history in freshwater, whereas populations downstream of Roxburgh are amphidromous. Koaro made up 8.5% of a Clutha River sample of whitebait (McDowall 1965).

2.4.8 Inanga (*Galaxias maculatus*)

In the Clutha catchment inanga have been recorded only from Port Molyneux and Lake Tuakitoto, but they undoubtedly exist in large numbers in tidal areas below Balclutha. McDowall (1965) indicated that *G. maculatus* juveniles make up to 89.5% of Clutha River whitebait samples.

2.4.9 Torrentfish (*Cheimarrichthys fosteri*)

Torrentfish have been recorded from Blackleugh Burn, Carsons Stream, and Tima Burn. They are seldom seen because their habitat is in tumbling broken waters of streams and rivers. They occur only below Roxburgh dam because they require access to the sea for part of their life history.

2.4.10 Common Bully (*Gobiomorphus cotidianus*)

Both seagoing and lake populations of the common bully are present in the Clutha system. The seagoing populations occur below Roxburgh dam and the lake populations in the lakes above the dam.

2.4.11 Upland Bully (*Gobiomorphus breviceps*)

The upland bully is widespread in the Clutha catchment. It has been recorded from downstream tributaries of the Pomahaka River, and also in Low Burn, Benger Burn, Elbow Creek (Lake Roxburgh), the lower Manuherikia River, the lower Lindis and Shotover Rivers, and tributaries of the upper Clutha River. This species does not require access to the sea.

2.4.12 Black Flounder (*Rhombosolea retiaria*)

The black flounder is a freshwater species which is common in inshore marine areas and river estuaries. In the Clutha River it is known from the lower Pomahaka (Turner 1983) and Tuapeka River and is no doubt common below Balclutha.

2.5 Uses of Water

2.5.1 Fish and Wildlife

The Clutha catchment supports substantial fish stocks. The native species are generally small (with the exception of eels), cryptically coloured and hence seldom seen, and most require access to the sea. They are mostly associated with slow to moderate flows, and abundant cover, which are largely confined to shallow margins of the main river and tributaries. In addition to their intrinsic value, several species are commercially and/or recreationally important, for example, inanga, eels, and flounders. All the introduced species are regarded as having significant recreational value, especially the brown and rainbow trout which form the basis of important fisheries in the upper catchment. Both landlocked and anadromous quinnat salmon are extensively fished for in the upper lakes and lower river respectively. In addition the anadromous salmon stocks have considerable commercial potential.

A total of 37 wetland-dependent bird species has been recorded from the Clutha river mainstem catchment (Otago Catchment Board and Regional Water Board 1985a). Although most of these species are highly mobile, there are several more secretive and less mobile species which are threatened by continuing land drainage.

It is likely that there are two gecko and three skink species present in the river banks and terraces of the upper Clutha River (Ministry of Works and Development 1982a).

2.5.2 Recreation

Angling is probably the most popular water based recreational activity on the Clutha River.

The recreational fishery of the Clutha River comprises both lake and river stocks of quinnat salmon, brown trout, and rainbow trout. The upper Clutha River from Wanaka to Cromwell is regarded as a nationally important trout fishery (Teirney, Unwin, Rowe, McDowall, and Graynoth 1982). Fishing is seasonally popular below Roxburgh dam where sea run brown trout are caught during December to January followed by quinnat salmon from late February to April. The area below Balclutha is also well utilised (Whiting 1986).

Other aspects of recreation in the Clutha River include boating and yachting on the lakes, jet boating, canoeing, rafting (in the Kawarau River which has continuous gorges with long sections of white water), waterskiing, skin diving, swimming, sunbathing and picnicking, camping, gold panning, beach activities, and bird watching. The upper Clutha valley provides hunting, mountaineering, tramping, bird watching, and shooting. Pinders Pond, a flooded dredge pond, midway between Roxburgh and Millers Flat, is extensively used for swimming, sunbathing, boating, picnicking, camping, and children's angling in the summer. A detailed account of recreation from Roxburgh to Tuapeka Mouth is contained in Whiting (1986).

2.5.3 Hydro

The major non-consumptive use of water in the Clutha River is for hydro-electric power generation. The main river below the lakes satisfies the requirements for hydro-electric development with high mean flows, seasonal and long term storage, and large potential head differences. Hydro development is considered in greater detail in section 4.

2.5.4 Irrigation

As Central Otago has low rainfall and high evapo-transporation rates intensive farming is possible only with irrigation. The irrigation season is from September to May with the time of peak demand varying considerably according to local climate and soil type.

Of the 15.4 m^3/s of water abstracted from the river for public water supply, irrigation, and frost fighting, 94% is used for irrigation (based on data from Otago Regional Water Board 1980). By May 1976 there were about 680 water rights (including mining privileges) for private irrigation and 84 Crown rights for government schemes (Otago Regional Water Board 1980). There are existing irrigation schemes in the following areas: Arrow River, Cromwell, Hawea River, Tarras, Ardgow, Pisa Flats, Earnscleugh, Roxburgh, Ida valley, Ida Burn, and Omakau (Cossens 1982).

Many irrigation schemes were adapted from earlier gold mining race systems. As mining claims, chiefly in Coal Creek area, were worked out the water rights were taken over by fruit growers who used races several miles in length to bring much needed water to ever increasing areas of orchards (Webster 1948). In the region around Cromwell, about 8000 ha are at present irrigated. Irrigation is used principally for pasture and hay meadows, and secondarily for cropping and orcharding, though all orchards are irrigated (O'Connor 1975).

"The overall picture of the existing irrigation in Central Otago is one where all the stream flow is fully utilised in dry times, except for the Molyneux (Clutha) and Nevis Rivers." (Lindup and Watt 1954). Several tributary rivers are seriously affected by abstraction of water for irrigation. For example, the Fraser River's entire flow is diverted for irrigation usage each year when a wall is bulldozed across the river several miles upstream of its confluence with the Clutha (Harker 1978). Future irrigation requirements in the upper Clutha are planned to be met from the Luggate and Queensberry impoundments and some augmentation of the low summer flows of the Lindis River may also be possible from these sources (Ministry of Works and Development 1982a).

At present 27 282 ha of the Clutha catchment are partially or fully irrigated, but a further 35 000 ha could be incorporated in proposed government schemes, including Earnscleugh (1750 ha) and Manuherikia (19 700 ha). Water abstractions will increase accordingly from the present requirement of 14.5 m^3/s to 27.4 m^3/s in an average year and 36.5 m^3/s in a dry year (Otago Regional Water Board 1980).

2.5.5 Frost Fighting

Central Otago produces 90% of New Zealand's apricots and 50% of its nectarines and cherries, as well as peaches, apples, pears, and plums. Protection of the blossom and young fruit from frosts during spring by use of sprinkler supplied water is a widespread practice. Frost fighting occurs from September to November, with a peak requirement usually in October, when both stone and pip fruit need protection. There may be an instant demand for up to 5 m^3/s of water and most of this is supplied from irrigation races (Otago Regional Water Board 1980).

2.5.6 Industry

Industry in the main Clutha valley is limited, and hence industrial water requirements are small. Apart from farming, tourism, and general servicing there are the following: game meat processing at Luggate and Cromwell, a large fruit processing factory at Roxburgh (Roxdale Cannery), the New Zealand Apple and Pear Board cool stores at Alexandra and Etterick, and a milk treatment station at Alexandra. The largest industrial water user in the catchment is the Waitaki-NZR Finegand Freezing Works near Balclutha, which draws most of its water from the Clutha River indirectly by way of groundwater. Most effluent from the works is only partially treated and is discharged directly into the main river (Otago Regional Water Board 1980).

2.5.7 Urban Supply

Requirements for public water supplies are fairly small in comparison with those for irrigation. The total water requirement for domestic consumption, stock water, and industry amounts to only 0.65 m^3/s (Otago Regional Water Board 1980). Water requirements of the urban communities in the catchment reflect the different climatic conditions which prevail over the catchment. Townships in Central Otago use, on average, six times as much water per head of population as do townships near the coast ((Otago Regional Water Board 1980). Although the Clutha River water is of sufficient quality for drinking, most urban areas draw supplies from groundwater.

2.5.8 Mining

For 50 years after the discovery of gold in 1861, considerable gold mining (sluicing, hard rock mining, and dredging) took place in the catchment, especially in the upper river from the lakes to Tuapeka, the Shotover River, and also the Upper Pomahaka. The last dredge ceased operation in 1962 (Ministry of Works and Development 1975) and today mining is of little importance, using only small quantities of water. However, mining operations resulted in an estimated 300 million cubic yards (229 million cubic metres) of aggregate being moved, and immense amounts of this material have been deposited in the river bed (Furkert, Hunter, and Hay 1920).

Although about 65 000 t of coal are mined annually within the catchment (Otago Catchment and Regional Water Board 1985a), consumptive use of water for mining is small. Substantial lignite deposits exist at Lake Tuakitoto (Benhar field) and the upper Manuherikia (Hawkdun field) (Hooper, McKenzie and Natusch 1983). Should either deposit be mined, water requirements should be fairly minor. However, if a liquiefaction plant was incorporated, substantial amounts of water would be required for cleaning and cooling (Watson 1981).

3. HYDRO DEVELOPMENT

The hydro-electric potential of the Clutha River has long been recognised. Early investigations started at the beginning of this century though "A report presented to Parliament in 1904 on the hydro electric potential of the whole of New Zealand, dismissed any ideas of economic schemes on the Clutha River, a sentiment possibly influenced by the many gold mining operations on the river at the time." (New Zealand Electricity 1978). However, with the increasing demand for electricity, renewed investigations on the Clutha and Kawarau Rivers started in 1944. Development, which commenced in the mid 1950s with Roxburgh Power Station, is continuing.

3.1 Lake Control Structures

The need for providing additional hydro storage within the catchment arose from the small size of Lake Roxburgh which is designed to cope only with daily fluctuations in demand (Jones 1981). Of the three source lakes, only Lake Hawea (the smallest) is fully controlled to provide additional storage for Roxburgh power station.

Commissioned in 1958, the Hawea weir raised the lake level by 20 m with an operating range of 21.6 m (Jones 1979). However in response to complaints by Hawea residents about the unsightly nature of the exposed lakeshore and attendant dust storms, the recommended range has recently been reduced to 10 m (Otago Catchment and Regional Water Board 1985a).

Lake Wakatipu was partially controlled at the Frankton outlet, for goldmining, but it was never controlled for hydro-electric purposes because Queenstown was already subject to flooding within the natural flood range of the lake. Ten control gates were installed at Frankton by the Kawarau Gold Mining Company to reduce flows in the Kawarau River and so enable gold mining. They were closed for the first time in August 1926; the government departments concerned determined that the gates could only be closed for a maximum of ten days or a rise in the level of the lake of 6 ft, which ever occurred earlier. However, the mining scheme failed because the combined flows of the Shotover and Arrow Rivers were greater than anticipated, contributing about 5% of the Kawarau's normal flow, with the result that the company became insolvent (Jones 1981). Ownership of the gates passed to Electricity Division, New Zealand Ministry of Energy (NZE), in 1956 as part of the Roxburgh hydro-electric scheme to give limited control (not now exercised) over the outflow of Lake Wakatipu. Today the Kawarau gates at Frankton remain permanently open.

Lake Wanaka is not controlled because it is covered by the Lake Wanaka Preservation Act 1973, which was enacted in response to environmental protection pressure. The act controls any manipulation of lake levels. Consequently any control for hydro-electric power is not possible. It is recognised that the lake has much hydro-electric potential which could be exploited by using the natural fall between Lakes Wanaka and Hawea. The restriction on making even minor variations to Lake Wanaka's levels or natural outflows represents a significant underutilisation of the total energy resource of the catchment (Otago Regional Water Board 1980).

3.2 Roxburgh

3.2.1 Physical Description

Roxburgh hydro-electric power scheme is a "run of the river system". It has a dam and associated generating station which releases water back to the river immediately downstream (Fig. 3).

The dam is of concrete with a height of 76 m and a length of 366 m (New Zealand Electricity 1978). Construction of the dam was started in 1949 and the river was diverted in 1954. The powerhouse has eight penstocks which carry the lake water through a drop of 45.7 m to the turbines (New Zealand Electricity 1978). Eight 40 MW machines were installed to give a total generating capacity of 320 MW, with the first power being produced in 1956 (Jones 1979). There are three spillways which are designed to cope with a maximum flood flow of 4250 m^3/s. The sluice gates which were intended for flushing out accumulated sediment cannot now be opened because of large quantities of sediment which have built up behind the dam.

Lake Roxburgh is unlike most other storage lakes in the country in that it is long and narrow with extremely steep banks. The lake is 32.2 km long with a mean width of 0.4 km and extends back from the dam through the Roxburgh Gorge. At normal operating levels it has an area of 5.9 km^2 (Jowett 1984). Although the lake has an operating range of 1.85 m, the average daily range from 1975 to 1983 was 0.76 m (Jowett 1984) (Table 1). Maximum daily fluctuations occur during winter. The mean residence time of the water in Lake Roxburgh (calculated with an estimated 1985 volume of 65.6 x $10^6 m^3$ and mean discharge of 492 m^3/s) is 1.54 days.

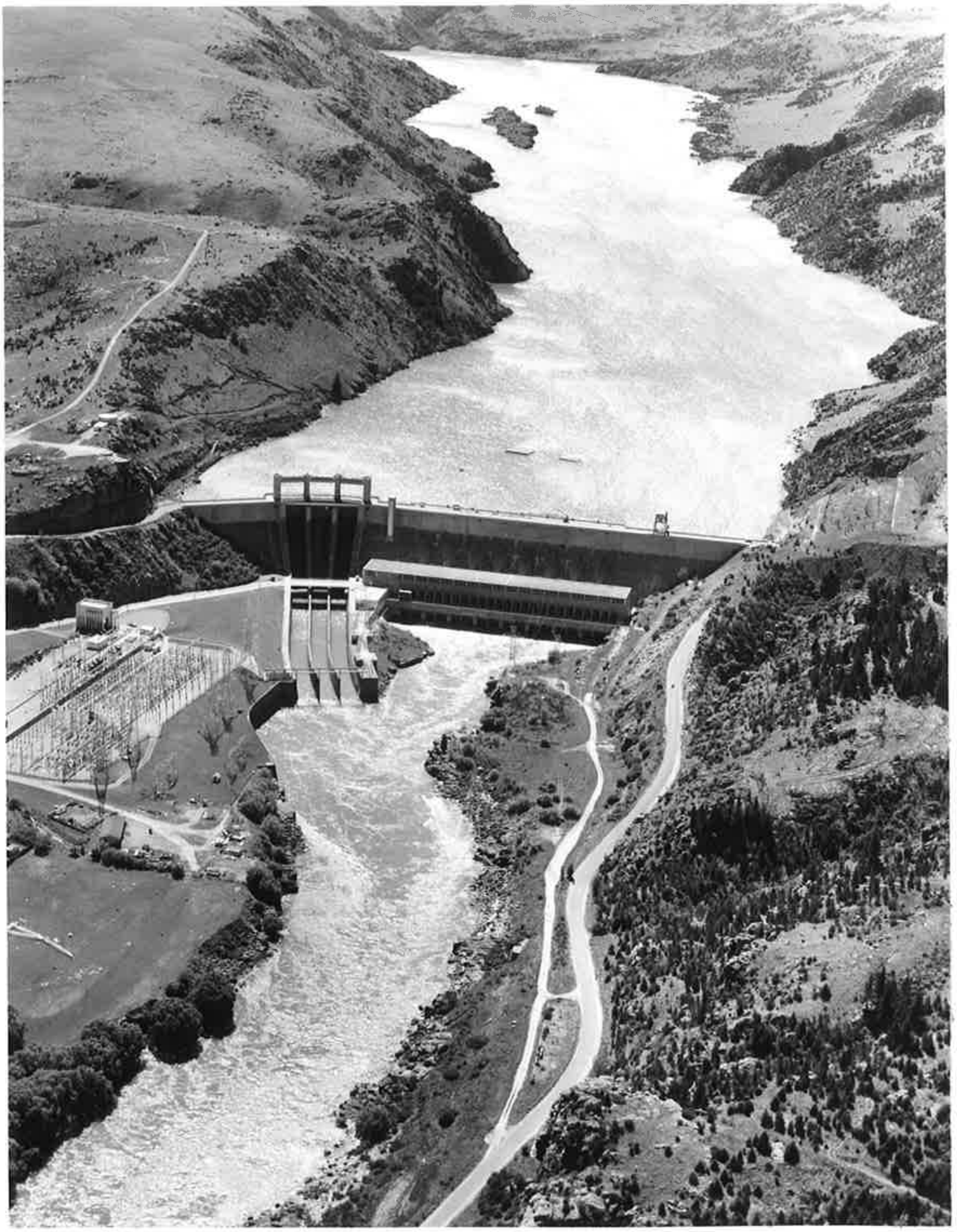

FIGURE 3. Roxburgh hydro (dam and powerhouse), Lake Roxburgh and Clutha River.

TABLE 1. Daily lake level variation in Lake Roxburgh (from Jowett 1984)

	1975-83												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Level variation (m)	0.69	0.61	0.80	0.75	0.84	0.97	0.90	0.83	0.83	0.66	0.54	0.64	0.76

3.2.2 Operating Regime of Roxburgh Power Station

Roxburgh is a peak load station capable of full generation capacity (320 MW) at 832 m^3/s; river flows greater than this require spilling. Discharge through Roxburgh follows a daily pattern similar to that of the daily electricity demand (Gillies and Torrance 1979) with maximum output during the day and minimum at night. As Lake Hawea is used for storage of high summer flows and augmentation of low winter flows, this results in almost constant monthly flows at Roxburgh (Jowett 1984).

Peak load power generation results in rapid increases in discharge from the power station. The daily discharge can rise from a very low base flow to a peak flow of up to 800 m^3/s in as little time as 1.5 hours (Otago Regional Water Board 1980). The duration of the peak discharge is about 13 hours (during the day) with peak demand at about 11 a.m. and 9 p.m. This is followed by a recession period of about 3 hours with a low discharge during off-peak power demand. Discharge is low between midnight and 7 a.m.

The magnitude of daily changes in discharge also varies seasonally. Mean variations in lake level (Table 1) indicate that, on average, June can be expected to show the greatest variations in mean discharge, and November the least. From the study period the mean hourly discharge for the months of June (1983 and 1984) and November (1983 and 1984) are shown in Figure 4. The monthly plots indicate that extreme daily variations occur in the June (for example, an increase of 504 m^3/s in 6 hours) whereas variations in November are markedly less (for example, 241 m^3/s increase in 8 hours). The high and fairly constant average discharges during November 1983 show the impact of seasonally high flows; spilling occurred on every day of this month (see Table 2). Over the 2-year study period the mean hourly discharges ranged from 97 m^3/s (July 1984) to 2178 m^3/s (December 1984).

The generation wave is modified as it travels downstream 110 km from Roxburgh to Balclutha. The rise and recession periods of the wave at Balclutha are about three times as long as they are at Roxburgh and the range in flows is correspondingly less. The effect of high discharges is to impose stresses on the channel boundaries each day, particularly at full load, of a magnitude similar to those imposed much less frequently during natural flood events. This results in in-channel erosion, especially in erosion prone boundaries (Otago Regional Water Board 1980).

When the lake is filled to capacity excess water is passed over the spillways especially during times of high inflow (Fig. 5). Table 2 shows average rate of discharge over the spillways per month, from April 1983 to February 1985. The 6 months between April and September 1984 were free from spillways discharges. During December 1984 and January 1985 the rate of discharge was high, owing to high rainfall in the mountains and flooding in the three source lakes (in January 1985 spilling occurred every day of the month).

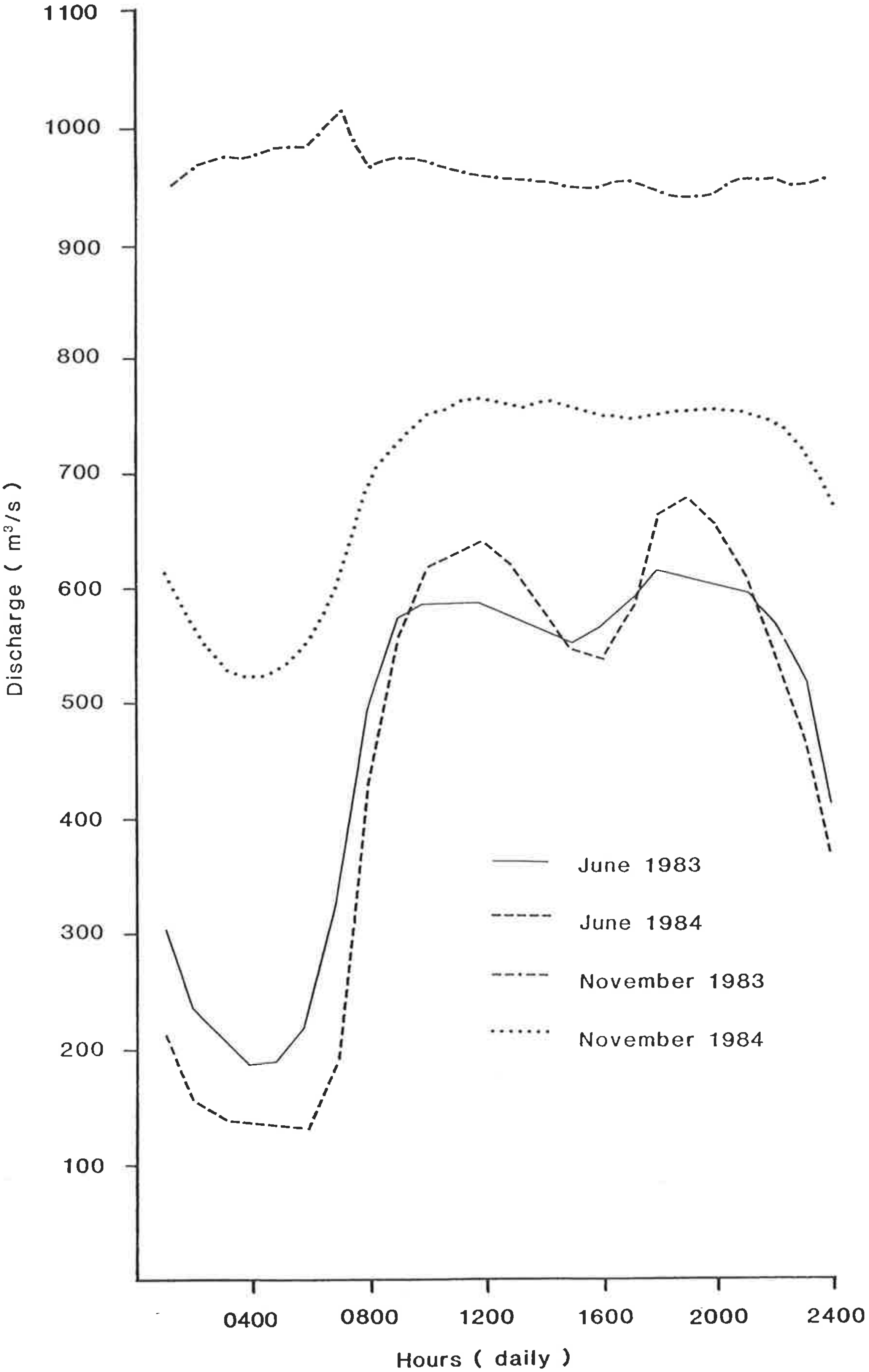

FIGURE 4. Mean hourly discharge, Roxburgh power station, June and November 1983 and 1984.

TABLE 2. Rate of spillway discharge per month at Roxburgh power station, April 1983 - February 1985

Month and year	Number of days when spilling occurred	Average rate of spillway discharge per day of spilling (m^3/s)
1983 Apr	8	280.0
May	14	408.7
Jun	2	25.0
Jul	0	-
Aug	0	-
Sep	4	144.8
Oct	28	529.0
Nov	30	620.0
Dec	13	272.9
1984 Jan	18	324.0
Feb	20	355.4
Mar	6	575.6
Apr	0	-
May	0	-
Jun	0	-
Jul	0	-
Aug	0	-
Sep	0	-
Oct	15	487.0
Nov	1	53.7
Dec	24	917.3
1985 Jan	31	854.7
Feb	8	514.2

Data provided by Roxburgh Power Station (NZE)

FIGURE 5. Spillway discharges, Roxburgh hydro.

3.2.3 Impact on Fisheries

Construction of a dam in any waterway provides a barrier to fish which have a migratory phase in their life cycle. If there is storage for generation then power production is accompanied by fluctuating flows in the river and fluctuating levels in the lake.

Roxburgh dam was constructed without a fish pass. This decision was made by fisheries managers from the Wildlife Division of the Department of Internal Affairs, and the (then) Marine Department, apparently to protect "upper lake fisheries" from contamination by eels or salmon (Little 1975). Consequently, the dam has substantially altered fish populations in the Clutha River by denying upstream access to the introduced sea run brown trout and anadromous quinnat salmon and to the native koaro, common bullies, torrentfish, and possibly smelt (Jellyman 1984). However young eels (elvers) have been observed by operators at

Roxburgh power station wriggling up the damp margins of the spillways (John Ford pers. comm.). Eels that are less than 28 years old (the time since the dam was installed) have been caught in Lakes Wakatipu and Roxburgh, which indicates that they have traversed the dam (Pack and Jellyman in prep). The dam will have affected downstream migration of fish by delays and by direct mortality or injury when fish pass through the turbines or down the spillways.

Daily variations in discharge from Roxburgh result in quite regular exposure and flooding of downstream littoral reaches of the main river. Despite this, Biggs and Shand (1985) noted that the major macrophyte communities (in backwaters and silty-banks) and periphyton communities (in braids and on bedrock) were remarkably resiliant to this daily dewatering. Presumably the potential for dessication of the macrophyte communities is lessened by the operating regime because lowest flows are typically of short duration and occur at night whereas highest flows occur during the day. The invertebrate communities were dominated by snails and bivalve molluscs; both groups have a high resistance to dessication. The degree to which the flow fluctuations have modified the invertebrate communities has not been studied though Biggs and Shand (1985) found some evidence of high flows reducing invertebrate abundance in backwaters.

Daily dewatering also enforces movements of fish from the preferred backwater habitats. Thus these areas, which have the highest densities of food organisms, become periodically unavailable to fish. Also, fluctuating flows are assumed to affect the success of spawning by salmonids in mainstem areas. For example, quinnat salmon have been observed spawning in a braid of the river between Seagull Island and the Roxburgh Golf Course (Pack and Jellyman in prep), but later in the same day the reach was found to be dry. Although eggs would probably survive this dewatering, it is very unlikely that newly hatched fry would.

Slumping of river banks, migration of the Koau Branch mouth, and blockages of both mouths with consequent risk of flooding, have all been attributed to variations in flow from Roxburgh (Otago Regional Water Board 1980).

Lake drawdown adversely affects littoral areas. A study of Lake Roxburgh (Winter 1964) indicated that 15-70% of the littoral area was exposed daily which resulted in considerable reductions in invertebrate fauna.

3.3 Upper Clutha

Under the adopted development scheme for hydro-electricity generation in the upper Clutha (Scheme F), five power stations were proposed - two stations on the upper Clutha River (Luggate and Queensberry), two on the Kawarau River (Kawarau and Gibbston) and one on the Clutha River (Clyde). Engineering investigations since 1977 have highlighted difficulties with the Kawarau sites and have led to five possible development schemes (Ministry of Works and Development 1984b) which could produce 590-1070 GWh of electricity.

3.3.1 Clyde and Lake Dunstan

Construction of the Clyde dam started in August 1977 at a site about 1.5 km upstream of the Clyde Bridge. The site was chosen towards the downstream end of the Cromwell Gorge so that as much of the head available above Lake Roxburgh could be utilised and the dam would be founded on rock. The impoundment created by Clyde dam will be Lake Dunstan.

The new dam is a concrete gravity type and will be 64 m high. The crest of the dam will stretch for 0.5 km from one side of the Cromwell Gorge to the other. Clyde dam will consist of a diversion channel on the true right side, a penstock section in the middle, and a spillway section on the left side which will have radial crest gates for controlling the lake level in flood conditions above the maximum operating level. The powerhouse, which will be the full width of the existing river, will initially have four generators installed with a generating capacity of 400 MW at 850 m^3/s (Jowett 1984). Provision is being made in the design to allow two more generators to be installed, thus extending the generating capacity to 600 MW (Ministry of Works and Development 1982b). The average energy production per year is estimated to be 1800 GWh. The dam is due to be commissioned in July 1987.

Lake Dunstan will have a surface area of 26.4 km^2 and a mean depth of 16.3 m. The lake will stretch 18.5 km through the gorge to Cromwell where it will divide and extend another 17 km up the Clutha River and 11 km up the Kawarau River. In the Cromwell Gorge the lake will inundate 374 ha of farm and orchard land, 915 ha above Cromwell and 116 ha in the Kawarau Arm (Ministry of Works and Development 1977). A new town centre is being built on the north-western edge of Cromwell to replace the existing commercial and civic amenities that will be flooded.

The lake will have an operating range of 1 m (Jowett 1984) with a maximum change in lake level on any single day of 0.5 m. Typical daily flows from Clyde will be from 140 to 850 m^3/s which, at average inflows, will cause the lake to fluctuate over 0.43 m. The estimated mean flow through the lake at Clyde is 472 m^3/s (Jowett 1984) giving a mean residence time of the water of 10.5 days.

With filling of Lake Dunstan, the sediment which presently settles in Lake Roxburgh will settle in Lake Dunstan, and the passage of sediment will be reduced to that passed through the new headpond. This sediment, being the finer fraction, should pass through Roxburgh with little settlement. The net effect of this is liable to be only a small decrease in turbidity of water at Roxburgh (Davies-Colley 1985). The storage capacity of Lake Dunstan will enable a regime to be developed for Roxburgh that should result in an improvement to conditions downstream of Roxburgh, by reducing the range of flows passed if this is considered to be effective and desirable. Certainly existing conditions at the river mouth will be made no worse. However, reduction in the variability of discharge from Roxburgh will mean a greater range in lake level fluctuations.

3.3.2 Potential Dams (Upper Clutha and Kawarau Rivers)

As the upper Clutha River has a mean flow of about 260 m^3/s and a potential head of 83 m from Lake Wanaka to the head of the future Lake Dunstan, a potentially large hydro-electric resource is available (Ministry of Works and Development 1982a). Four options were proposed for the Luggate/Queensberry development which involved one or two dams incorporating power canals. All the options included a dam at Luggate, but with either a power canal to a powerhouse at the head of Lake Queensberry or a powerhouse just below Luggate dam. Planned output for Luggate varies from 90 to 120 MW. The chosen option, option 4, has a dam at Luggate and a short headrace to a powerhouse, and a dam at

Queensberry with a power canal to the Queensberry powerhouse, giving an overall generating capacity of 210 MW.

3.3.2.1 Luggate

Hearings for the Luggate water rights took place in April 1985 and water rights have been issued. The current commissioning date is April 1992 (Wong 1985).

Luggate dam and associated structures are to be located in a narrow channel incised by the Clutha River, 3 km downstream from the present Luggate Bridge. The dam would be a 35-m-high earth-fill structure, with a short headrace to a powerhouse 400 m downstream on the right bank of the river. Lake Luggate would be about 13 km in length with an area of 3.9 km^2. River terraces would confine the lake to a width seldom exceeding 100 m except for a wider arm of the lake near Luggate township (Ministry of Works and Development 1984c). The three turbines will have a total output of 90 MW at a discharge of 450 m^3/s, and a generating potential of 435 GWh a year.

In the operation of Luggate, changes in output will depend on the system demand and availability of water and generating plant to meet that demand. An operating range of 2 m will allow for flexibilities in operating the whole system in times of low flows. A spillway structure together with a diversion culvert will be built into the base of the dam. When Lake Luggate reaches the design flood level, the spillway will be capable of passing a probable maximum flood of 2600 m^3/s.

3.3.2.2 Queensberry

The required approval date for Queensberry power station is April 1987, with a commissioning date in April 1994. The site of the Queensberry dam is undecided at present and will depend upon further geological investigations at the proposed Maori Point dam site and an alternative site 6 km upstream (Ministry of Works and Development 1984c). The dam would be a 36-m-high earth-fill structure, with a power canal 8.5 km long traversing river terraces to the powerhouse. Lake Queensberry would have an area of 4.4 km^2 with water backing up to the Luggate dam, but being confined within the existing river valley. The lake would have an operating range of 2 m. The powerhouse, situated upstream of Gravelly Gully, would have power turbines generating a total of 180 MW at 450 m^3/s with a generating potential of 860 GWh a year. The residual river (from the dam to the powerhouse) would be 15 km with a recommended base flow of 30 m^3/s (Commission for the Environment 1982). Queensberry power station will discharge into the future Lake Dunstan via a canal, with daily variations in flow modified by Luggate power station.

3.3.2.3 Kawarau

As part of the overall upper Clutha River's development there is a possibility of a power scheme on the Kawarau River. In 1982, an assessment of development schemes was completed and five possible schemes were proposed; these varied between one and three dams and powerhouses with some schemes involving canals and tunnels to the powerhouses. Output from the schemes ranged from 590 GWh (two dams and associated powerhouses) to 1080 GWh with one dam at Gibbston and a long canal and tunnel system to a powerhouse 23 km downstream (Ministry of

Works and Development 1984b). The required approval date for the Kawarau scheme is April 1991 and the expected commissioning date is in April 1997 (Ministry of Works and Development 1984c). However, it is possible that the scheme may not go ahead, because the Kawarau River could be preserved as a wild and scenic river. On 6 February 1985 it was reported in the *Otago Daily Times* that Government had made a decision to preserve the Kawarau River against any hydro-electric development. "The Minister's statement said the Kawarau River will be protected for its entire length above the confluence with Lake Dunstan which will be created when Clyde Dam is completed." At the time of writing there has been no application for a water conservation notice, which would be the first step in the procedures to retain the Kawarau in its present state.

3.3.3 Impact on Fisheries

There is a mixed population of salmonids in the Clutha River above Clyde (rainbow trout, brown trout, and quinnat salmon). Apart from some recruitment from upstream lakes, Lake Dunstan and any further upstream reservoirs will have to be self sufficient in production of juvenile fish or the shortfall supplemented by hatchery stocks. Downstream moving quinnat salmon are considered to contribute to anadromous stocks of quinnat salmon in the lower river and higher mortalities of fish will occur with their passage through further turbines or over spillways. The greatest impact on fisheries values of Clyde dam will be the change from a river to a lake environment, but a new productive lake fishery should develop given the extensive littoral zones, high water quality, and fairly small drawdown.

Hutchinson (1977) suggested that more efficient management can be achieved by treating the new lake as a discrete fishery and by supplementary artificial stocking as necessary. The Department of Internal Affairs concluded that a fish hatchery would be required to maintain adequate fish stocks in Lake Dunstan and upstream reservoirs because existing spawning facilities were limited (Adams 1977). The department intends to manage the hydro lake fisheries in favour of the more readily caught species of salmonid - rainbow trout and quinnat salmon. Provision of a suitable hatchery by NZE was included as a condition in the Clyde dam water rights (National Water and Soil Conservation Organisation 1979).

The existing Wanaka hatchery has insufficient capacity to satisfy the Clutha Valley Development requirements so a new hatchery is proposed to provide for the projected needs of the Southern Lakes Wildlife Conservancy as well. In particular the hatchery is required to stock Lake Dunstan as a requirement of the Clutha Development (Clyde Dam) Empowering Act 1982 (Ministry of Works and Development 1984c). Several possible sites have been considered (Ministry of Works and Development 1982a) and a site at Wye Creek (Lake Wakatipu) is currently being evaluated by government.

There are substantial spawning possibilities in the Lindis River. If the low summer flows of the Lindis could be augmented from upstream dams (Ministry of Works and Development 1982a) and the intakes could be screened, the Lindis has the potential to provide most, if not all, the spawning requirements of Lake Dunstan. For such reasons, it has been suggested that the need for a hatchery be reviewed (Otago Catchment Board and Regional Water Board 1985b).

3.4 Lower Clutha (Potential Options)

A report on the potential of the hydro-electric development of the whole Clutha River was published in 1971 ("The Henderson Report") after which the government decided to confine investigations to the development of the river above Roxburgh. However, in 1980 the government authorised renewed investigations of the lower Clutha area, provided that proposals ensured a minimum of flooding of agricultural and horticultural land and that work on sites known to involve considerable impacts on farmland should cease. The hydro-electric potential of the lower Clutha River was then estimated at 550 MW or 2500 GWh a year (Jones 1981). Engineering investigations by the Ministry of Works and Development commenced in early 1981.

Four separate schemes have been proposed for the area between Roxburgh and Tuapeka Mouth, to utilise the available head of 64 m. All schemes involve a series of two to four dams with the tailwaters of an upstream dam discharging into the lake, formed by the dam immediately downstream. The first dam, a low dam at Dumbarton Rock, is common to all schemes. Below this there are choices of two low dams (at Beaumont and Tuapeka), three low dams (at Beaumont, Birch Island, and Tuapeka), or a single high dam at Tuapeka or Birch Island. Characteristics and data for each scheme are shown on Table 3 and the proposed dam sites are shown on Fig. 6.

TABLE 3. Proposed hydro-electric schemes for lower Clutha River

Scheme	Dam site location	Maximum lake level (m) (a.s.l.)	Tailwater level (m) (a.s.l.)*	Net head for generation (m)	Mean flow for generation (m^3/sec)	Lake area (km^2)	Operating storage (x $10^6 m^3$)	Operating range (m)	Installed capacity MW	Total capacity MW
A	Dumbarton Rock	85.0	69.0	14.0	496	2.0	4.0	2	110	455
	Beaumont	69.0	42.0	24.5	504	10.6	21.2	2	200	
	Tuapeka (low)	42.0	22.0	18.5	508	9.2	18.4	2	145	
B	Dumbarton Rock	85.0	69.0	14.0	496	2.0	4.0	2	110	475
	Tuapeka (high)	69.0	22.0	45.5	508	32.0	64.0	2	365	
C	Dumbarton Rock	85.5	69.0	14.0	496	2.0	4.0	2	110	410
	Birch Island	69.0	32.0	36.5	507	23.5	47.0	2	300	
D	Dumbarton Rock	85.5	69.0	14.0	496	2.0	4.0	2	110	440
	Beaumont	69.0	42.0	24.5	504	10.6	21.2	2	200	
	Birch Island	42.0	30.0	9.5	507	3.2	6.4	2	80	
	Tuapeka	30.0	22.0	6.5	508	3.0	6.0	2	50	

* Data from Ministry of Works and Development 1984a and Jowett 1984.

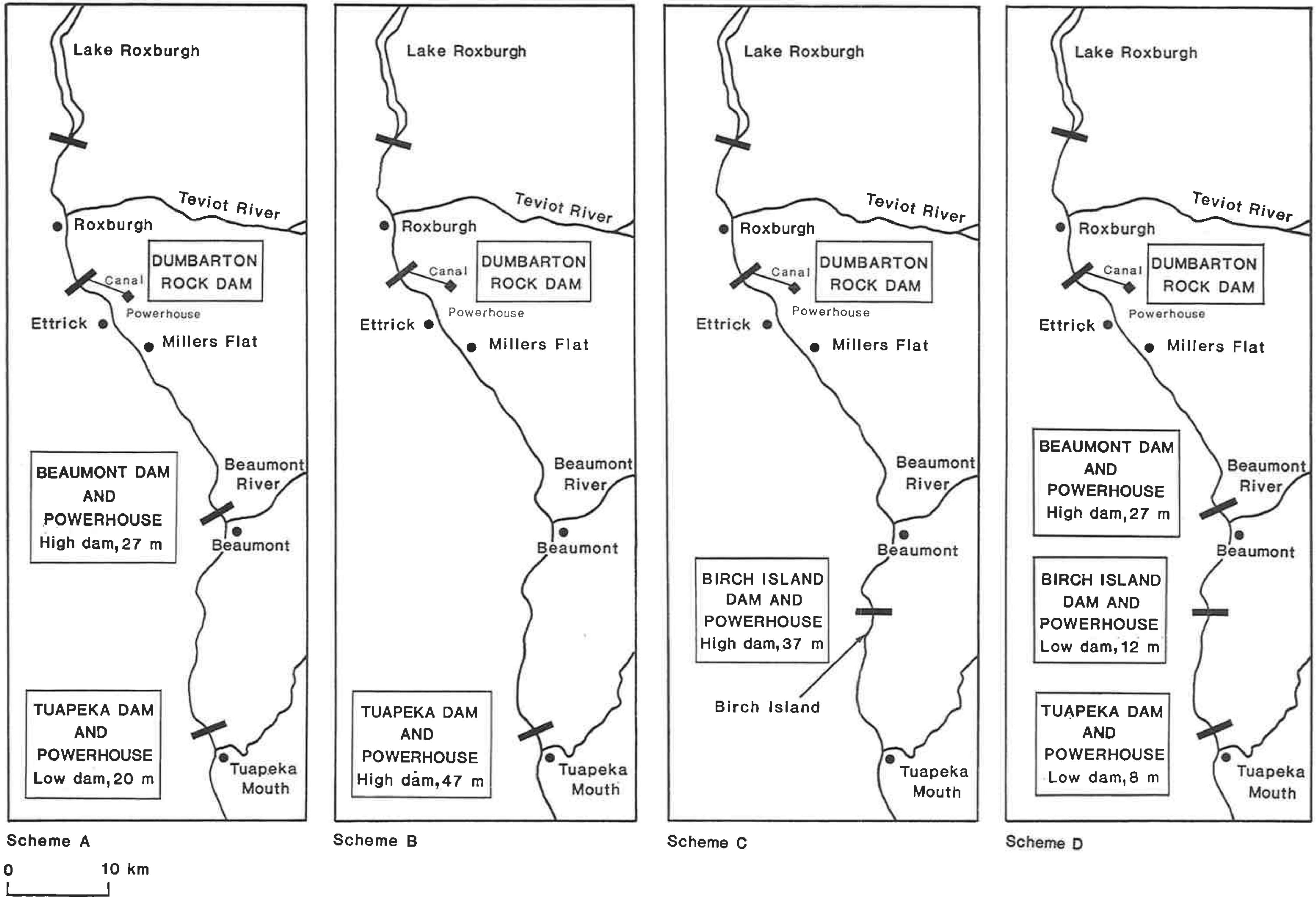

FIGURE 6. Proposed schemes for lower Clutha hydro-electric development.

3.4.1 Scheme A

At Dumbarton Rock, a low dam would be constructed with an 11-m-high concrete canal inlet from which a 4.5-km-long canal would lead to a powerhouse at Teviot. The canal would pass across Teviot Flats on the left bank of the Clutha River. The lake would be fairly small (2.0 km^2) and narrow, confined mainly within the existing river bed and extending upstream to Roxburgh powerhouse. There would be some inundation of present backwaters and Pinders Pond.

Scheme A has two further dams at Beaumont and Tuapeka Mouth. Beaumont dam would be concrete (27 m high) with a powerhouse directly below the dam and immediately downstream of the Beaumont Gorge. The lake that would form (10.6 km^2) would extend upstream mostly within the existing riverbed to the dam at Dumbarton Rock. However it would inundate about 600 ha, including the Island Block Flats and river flats downstream of Millers Flat.

The third dam, at Tuapeka Mouth, would be a low concrete one (20 m high) with an associated powerhouse. The lake formed would have an area of 9.2 km^2 and would be confined to the river bed upstream of the Clutha dams (6 km south of Beaumont), but about 500 ha of low flats downstream of the Clutha Downs would be inundated.

3.4.2 Scheme B

The second dam in this scheme is a single 47-m-high concrete dam at Tuapeka Mouth and has an associated powerhouse. It would form a lake with an area of 32 km^2 inundating about 200 ha including Beaumont and all the river flats up to and including Island Block. This scheme would generate the most power of the three (475 MW).

3.4.3 Scheme C

The second dam in this scheme is a single 37-m-high concrete dam at Birch Island, with an associated powerhouse. The site at Birch Island has yet to be identified, but it would be desirable to place the dam upstream of Birch Island in order to preserve the island which is of botanical interest. The lake formed by this dam would have an area of 23.5 km^2 and would inundate Beaumont Flats, Island Block Flats, and all low lying flats between Beaumont and Birch Island. In total about 1500 ha would be inundated.

3.4.4 Scheme D

Scheme D is an option which provides least inundation of marginal land. In common with Scheme A, Scheme D has dams at Dumbarton Rock and Beaumont; downstream of this the scheme has two small dams at Birch Island and Tuapeka respectively. In addition, Scheme D has the river flats at Island Block separated off by a polder.

The difference between schemes B and C is the site of the lowermost dam. Scheme B with the dam at Tuapeka Mouth, will cause the largest amount of land to be inundated (about 2100 ha). Both schemes (B and C) would inundate the township of Beaumont and the river flats up to Ettrick, and both would have significant environmental impacts. Scheme C would preserve Birch Island. Scheme D (with four dams) would inundate the least area of any scheme. However, it is liable to be the least attractive economically as it incorporates the construction of four separate powerhouses and dams. Scheme B is the most attractive from an engineering point of view because it has the largest generating capacity (475 MW), whereas Scheme C represents an underutilisation of the available energy between Roxburgh and Tuapeka (generating capacity of 410 MW) and would be justified only if it is considered important to preserve Birch Island. As the Dumbarton Rock powerhouse requires diversion of water into a power canal, a residual flow in the natural river channel would almost certainly be required.

3.4.5 Operating Regime

It is envisaged that the chain of powerhouses and reservoirs on the main stem Clutha River will be operated as a system similar to the chain of stations on the Waikato River. This would mean that the stations would operate together and follow the demand for electricity generation, except that the lowermost powerhouse could be operated to minimise variations in downstream river flows. The Waikato chain is operated so that large flow fluctuations of the upstream stations are successfully regulated using the storage downstream. A similar operation in the Clutha River has been proposed (Jowett 1984) with the lower Clutha River powerhouses being operated in conjunction with Clyde and Roxburgh. Reduced fluctuations in discharge than those that presently occur from Roxburgh, are desirable because the present Roxburgh regime is thought to detrimentally affect the downstream fishery values, as well as possibly affecting channel erosion, mouth instability, and drainage patterns near the mouth. To achieve a flow regime similar to that of inflows to Roxburgh, the level of the most downstream lake would fluctuate more than levels in upstream lakes. Jowett (1984) calculated that complete re-regulation could be achieved within the 2 m operating regime currently proposed.

Operationally Dumbarton Rock would follow the same pattern as Roxburgh and would use the small amount of storage available to absorb small differences between the outflow of the two. Below Dumbarton Rock the amount of storage available for re-regulation varies from 33.6 x $10^6 m^3$ for Scheme D to 64 x $10^6 m^3$ for Scheme B (high dam at Tuapeka). A likely operating strategy is that Clyde, Roxburgh, and Dumbarton Rock, would operate in tandem following the South Island load pattern with a similar twice daily peak generation. Load patterns could be re-regulated by the downstream reservoirs in any of the four schemes. The difference between them is the reservoir level fluctuation caused by re-regulation. Pickford (1985) has modelled the effect of three operating strategies (total re-regulation, operation like Roxburgh, and a compromise between these two) on downstream discharges.

In Scheme A, re-regulation could be achieved by a fairly small low dam (Tuapeka) generating at a fairly low constant rate resulting in large lake level fluctuations. Scheme B, the Tuapeka high dam, would have the least fluctuation of lake level, but much water would be used for flow re-regulation and electricity generation would be committed to constant load. Scheme C, with a high dam at Birch Island, is an intermediate option with intermediate lake level fluctuations and generating capabilities. In Scheme D, re-regulation would require manipulation of levels of both Tuapeka and Birch Island reservoirs.

4. LOWER CLUTHA STUDY AREA

4.1 Land Use

Within the study area most intensive agricultural activities, major settlements, and most individual farms are concentrated along the flat land immediately adjacent to the Clutha River.

Agriculture in the lower Clutha valley varies from extensive pastoral farming in the higher country to intensive (horticultural) farming of the lower lying river flats. The high country pasture and steep sided valleys are used for extensive sheep grazing. Horticulture (orchards and market gardening) is concentrated in the Coal Creek, Dumbarton, Ettrick, Millers Flat, and Beaumont regions alongside the Clutha River, with most orchards being situated on the west side. Because of the warm semi-continental climate of Central Otago this is one of Otago's largest orcharding districts and a major apricot growing area in New Zealand. A large variety of fruit is grown including peaches, nectarines, cherries, berry fruit, apples, and pears. Rainfall is sufficient to prevent severe drought, but irrigation is required for these crops.

Between Beaumont and Tuapeka Mouth, the Clutha River flows past the Beaumont and Rankleburn State Forests. Beaumont State Forest covers an area of 6914 ha and was planted between 1928 and 1932; Rankleburn State Forest covers 11 234 ha and was planted between 1957 and 1959. Both forests contain a mixture of indigenous and exotic species and are planted on the steep erosion-prone, east facing slopes of the Blue Mountain Range (Sheppard, Rout and Kearsley 1983).

Settlements are close to the Clutha River, with Roxburgh being the largest and also the major service centre in the study area. Roxburgh (township, hydro township, and Roxburgh east) had a population of 758 in 1981 (data in Ministry of Works and Development 1984a). Millers Flat is the second largest township with a population of 230, then Tuapeka, with a population of 128 and Beaumont with a population of 110. There are small settlements at Ettrick, Tuapeka Mouth, Raes Junction, and Dumbarton.

The only industries in the area are Harliwich's coal plant at Coal Creek and industries related to horticulture. The Central Otago Fruit Company cannery is situated midway between Roxburgh hydro township and Roxburgh (on State Highway 8). Darlings Fruit Juices factory is located at Ettrick and the New Zealand Apple and Pear Marketing Board have a depot there.

In the 75 km study area, four road bridges cross the Clutha River at the following places - Roxburgh hydro, Roxburgh, Millers Flat and Beaumont. There is an operating swing bridge at Rigney and an infrequent punt at Tuapeka.

4.2 Physical Descriptions and Hydrology

4.2.1 Lake Roxburgh

About 80% of the inflow into Lake Roxburgh is contributed by the three source lakes (Jowett and Hicks 1981). The head of Lake Roxburgh is at the Clutha-Manuherikia confluence. The Manuherikia River has a mean annual flow of 15 m^3/s (Murray 1975) which is only 3% of the total flow at Roxburgh. Tributaries entering the lake are very small and have no discernable effect on the flow at Roxburgh (that is, the flow at the Clutha-Manuherikia confuence is virtually the same as that at Roxburgh).

Since formation in 1956 Lake Roxburgh has acted as a trap for sediment being brought down by the Clutha River. An average of 2.89 million tonnes of sediment is transported annually into the lake of which 1.85 million tonnes (63%) is deposited (Thompson 1976). Jowett and Hicks (1981) calculated an average annual rate of deposition of 1.46 x $10^6 m^3$/year between 1961 and 1979, but 2.77 x $10^6 m^3$ of sediment was deposited between 1978 and 1979 because of the 1978 October flood.

Suspended sediment entering Lake Roxburgh has been sampled by Jowett and Hicks (1981). It was found that at the Manuherikia-Clutha confluence, 3% of the suspended sediment came from the Manuherikia River, with the remainder from the Clutha River. Of the sediment derived from the Clutha River, 1% came from the catchment between Alexandra and the Kawarau-Clutha confluence, 88% from the Kawarau River and 8% from the Clutha River above the Kawarau-Clutha confluence.

As a result of siltation and deposition of sediment in Lake Roxburgh, the lake volume has been decreasing (Table 4). Although it was originally estimated that the lake would take 150 years to silt up (Winter 1964), there has been a reduction in volume of 44% in only 29 years.

TABLE 4. Lake Roxburgh volumes from siltation surveys

Date	Lake volume $10^6 m^3$	Decrease ($10^6 m^3$) (change in volume)	Average annual rate of deposition $10^6 m^3$/year
Jun 1956	117.18		
		15.94	3.19
Jul 1961	101.24		
		13.98	1.55
Jul 1970	87.26		
		4.83	1.21
Jul 1974	82.43		
		4.02	1.00
Jul 1978	78.41		
		2.77	4.71
Feb 1979	75.64		

Data from Thompson 1976, Jowett and Hicks 1981, Ministry of Works and Development (pers. comm.).

Much of the sediment enters the lake as silt which settles out when the turbulence is not vigorous enough to maintain it in suspension. At the upstream end of Lake Roxburgh, where the water is fairly turbulent and the velocity greatest, the deposited material is coarse sand and larger grained material, whereas downstream towards the dam where the lake is deeper and less turbulent the deposited material is fine silt. Thompson (1976) found that Lake Roxburgh is trapping incoming sediment with grain size larger than 0.01 mm and that finer grained sediment passes right through the lake. At the head of the lake an extensive delta formation has resulted from the considerable loads of silt carried by the river. Transition from a river to a lake environment is evident at Gorge Creek tributary where the lake becomes more open and the water velocity decreases (Shand and Biggs 1985).

Monthly water temperature profiles (temperatures recorded at depth intervals of 1 m) were recorded at the northern end of the rocks between Flag Beach and McKenzies Bay during the study period (Table 5). A seasonal range from 7.6°C to 16.8°C was recorded. These temperatures show a slightly higher maximum temperature than those recorded at Roxburgh dam (Fig. 7) probably because the dam temperatures are recorded at 0900 h whereas the time when the profiles were taken was generally later than this and some surface warming in the lake is evident from data in Winter (1964). There was very little variation with depth (maximum decrease in temperature with depth recorded was 0.4°C) and no evidence of a thermocline. Throughout the lake the water is well mixed, and because of the short residence time (1.54 days) the water does not have long enough to develop any temperature stratification. These results are similar to those of Winter (1964) except she recorded a slight vertical temperature gradient on one very hot calm day, when the temperature of 21.5°C at the surface decreased to 17.5°C at a depth of 30 m, though there was no evidence of a thermocline.

TABLE 5. Temperature profiles of Lake Roxburgh at Flag Beach, December 1983 - October 1984

Date	Air temperature °C	Surface	Water temperature °C 1m	5m	10m
1983					
8 Dec	24.0	15.3	15.1	14.9	14.8
1984					
10 Jan	15.7	16.8	16.8	16.6	16.4
6 Mar	16.1	16.1	16.2	16.2	16.2
3 Apr	18.8	15.1	15.0	14.8	14.7
1 May	9.5	12.0	12.1	12.1	12.1
29 May	8.2	9.5	9.6	9.5	9.5
25 Jun	14.9	7.7	7.6	7.6	7.5
24 Jul	10.0	7.6	7.3	7.3	7.3
21 Aug	12.4	9.4	9.2	9.1	9.0
18 Sep	15.0	9.7	9.6	9.6	9.6
26 Oct	23.3	12.0	11.8	11.7	11.6

Water quality of Lake Roxburgh is high (Davies-Colley 1985) and very similar to that in the lower Clutha River (section 4.2.2). Lake Roxburgh is oligotrophic with low nitrogen and phosphorus concentrations. The only quality likely to impair some uses of the water is the high turbidity and large amount of suspended sediment, much of which settles out in Lake Roxburgh.

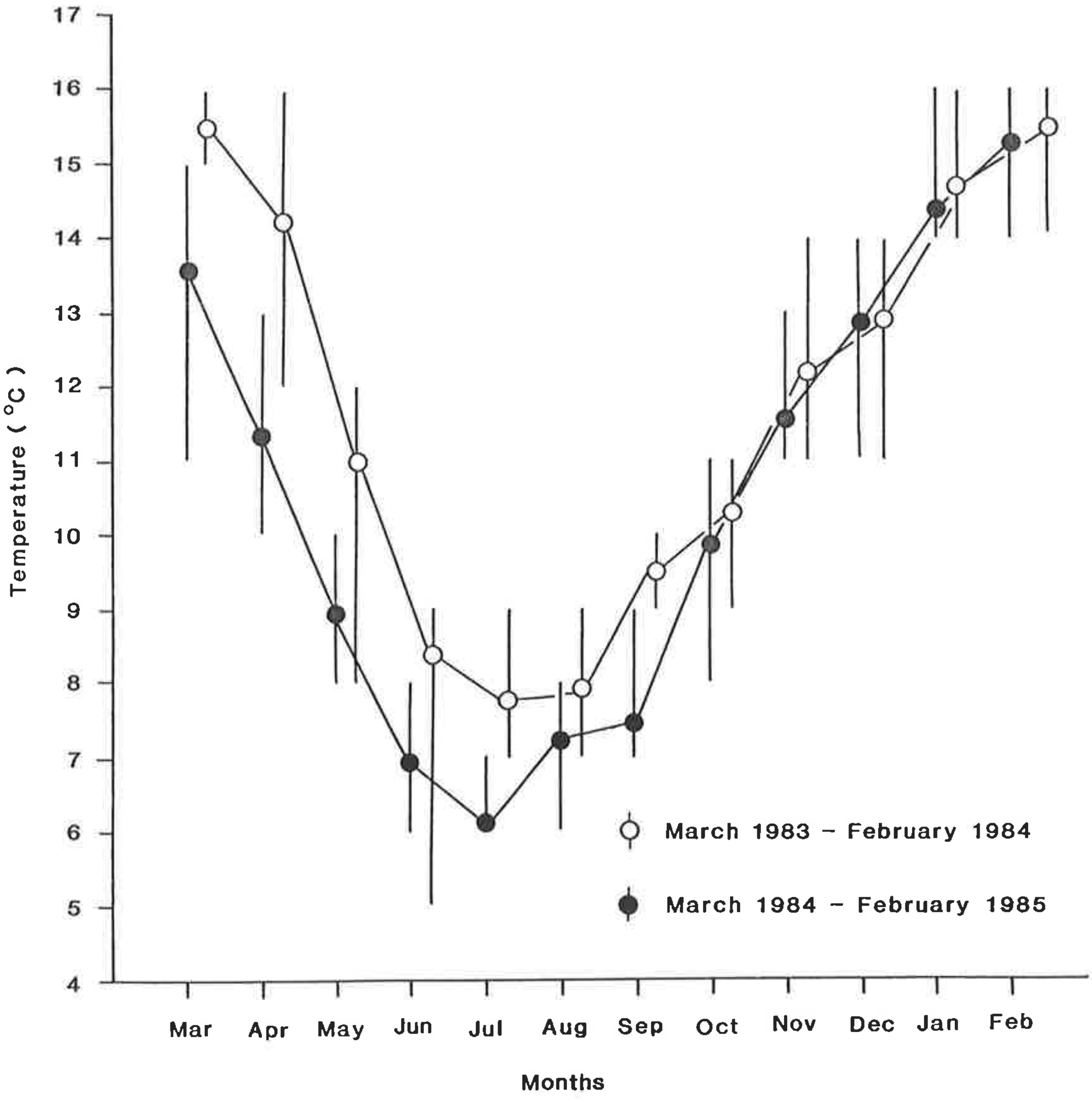

FIGURE 7. Mean monthly temperatures (and ranges) for the two study years at Roxburgh dam.

Secchi disk transparencies were measured at monthly intervals in Lake Roxburgh by Davies-Colley (1985) (from November 1982 until January 1984) and by FRD (from December 1983 to October 1984). The mean value over this period was 1.31 m (minimum 0.3 m, maximum 2.78 m, n = 23). However, it should be noted that the minimum value (0.3 m) was recorded in September 1983 after floods had caused distinct discolouration. A single reading of 5.0 m was recorded in April 1970 (Green 1975) which is considerably higher than any others recorded. Such readings would suggest a shallow euphotic zone for significant plant growth, which would be largely within the average daily range of water level (0.76 m). However, the scattering effect of light by the suspended sediment means that the euphotic zone is about 10 m (Davies-Colley 1985) which corresponds to the greatest depth of macrophyte beds (Shand and Biggs 1985).

4.2.2 Clutha River Mainstem

Although the Clutha River is a single channel river there are a few major braids and some minor ones which appear only at times of low flow. For example in the vicinity of Roxburgh golfcourse there are two braids which are both dewatered daily by fluctuating flows, whereas larger side channels such as at Birch Island and one behind Mayds Island are always flowing. Shingle and gravel banks are exposed throughout the study reach during times of low flow.

Immediately below Roxburgh dam there is a deep ponding area after which the river moves over outcrops of bedrock which create eddies and small waves. The river flows through a gorge area (Beaumont Gorge) from Rigney to Beaumont. Midway between Canadian Stream and Raes Creek to the confluence of the Clutha and Beaumont Rivers there is an area of white water which is masked at high flows. At Tuapeka the river bed widens and there are fewer rapids, riffles, and eddies than further upstream. For most of the Clutha River's length in the study area the river banks are lined with willows, except around Rigney and Beaumont. At Beaumont on the right hand side of the river there is the Beaumont State Forest and on the left hand side, from above Birch Island to just above the confluence of the Clutha and Blackcleugh Burn, native beeches line the river.

The Clutha River provides several different habitat types in this area which have been defined by Biggs and Shand (1985) as (with percentage of total area in brackets) main channel (76.0%), backwaters (0.9%), braids and riffles (2.1%), shoulders (6.3%), silty willow-lined banks (7.0%), bedrock (7.3%), and tributaries (0.4%).

4.2.2.1 Hydrology

The flow of the Clutha River shows a seasonal pattern of lower flows during the winter and higher flows during late spring and early summer. However, the flow regime has been substantially altered with the installation of the Lake Hawea control structure. Mean monthly flows at Roxburgh for 26 years before Hawea was controlled (pre-Hawea) and 26 years afterwards (post-Hawea) can be seen on Fig. 8. Although mean annual flows, pre-Hawea and post-Hawea are very similar (486 m^3/s and 499 m^3/s respectively), the monthly distribution of flows has altered. Pre-Hawea summer flows from December to April are higher than those post-Hawea, but pre-Hawea winter flows from May to October are lower. This is to be expected as Lake Hawea is used to store high spring-summer flows and augment low winter flows.

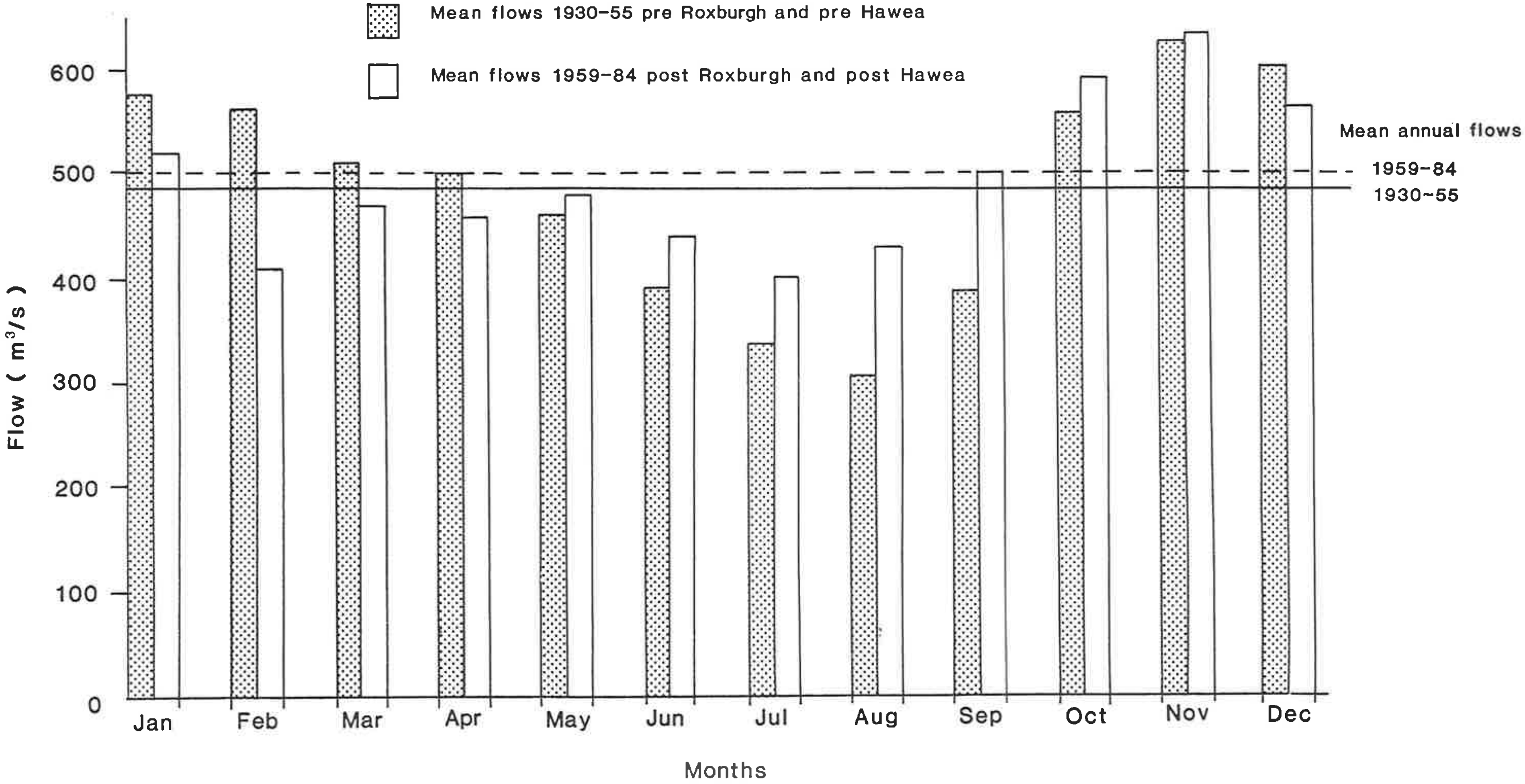

FIGURE 8. Mean monthly flows of the Clutha River, pre-Hawea and post-Hawea.

In Fig. 9, the mean monthly flows at Roxburgh for the 2 study years have been compared to an "average" year (mean monthly flows 1959-84). The figure shows that flows during 1983 and 1984 were very atypical. Over the 2 years, all flows except for 3 months (April, May, and September 1984) were higher than those of the average year. Notably the January 1983 flow was almost twice the average for that month and the spring flows in both years were substantially greater than average. The mean annual flows of 704 m^3/s and 611 m^3/s respectively for 1983 and 1984 were considerably greater than the average annual flow of 499 m^3/s. Similarly, the annual range in flows of 601 m^3/s and 646 m^3/s respectively for 1983 and 1984 was more than two and a half times the average range.

The minimum mean monthly flow recorded at Roxburgh was 140 m^3/s in July 1930. However, since Lake Hawea has been controlled, the minimum mean monthly flow has been 219 m^3/s for July 1978. From the flow duration curve for post-Roxburgh flows, flows less than 200 m^3/s occur for less than 15% of the time and flows less than 120 m^3/s occur for less than 4% of the time. As low flows create problems for pump-water supplies from the river there is an agreement that the minimum flow from Roxburgh powerhouse will be 100 m^3/s from May to August and 150 m^3/s from September to April (Otago Catchment Board and Regional Water Board 1985b).

The variable discharges from Roxburgh powerhouse result in varying river flows and levels downstream. The range in mean daily tailwater levels at Roxburgh (recorded once per hour) for the period March 1983 to February 1985 is 3.45 m. Under a typical weekday load regime, tailwater levels vary from 84.8 m (60 MW output) to 87.2 m (220 MW) and maximum

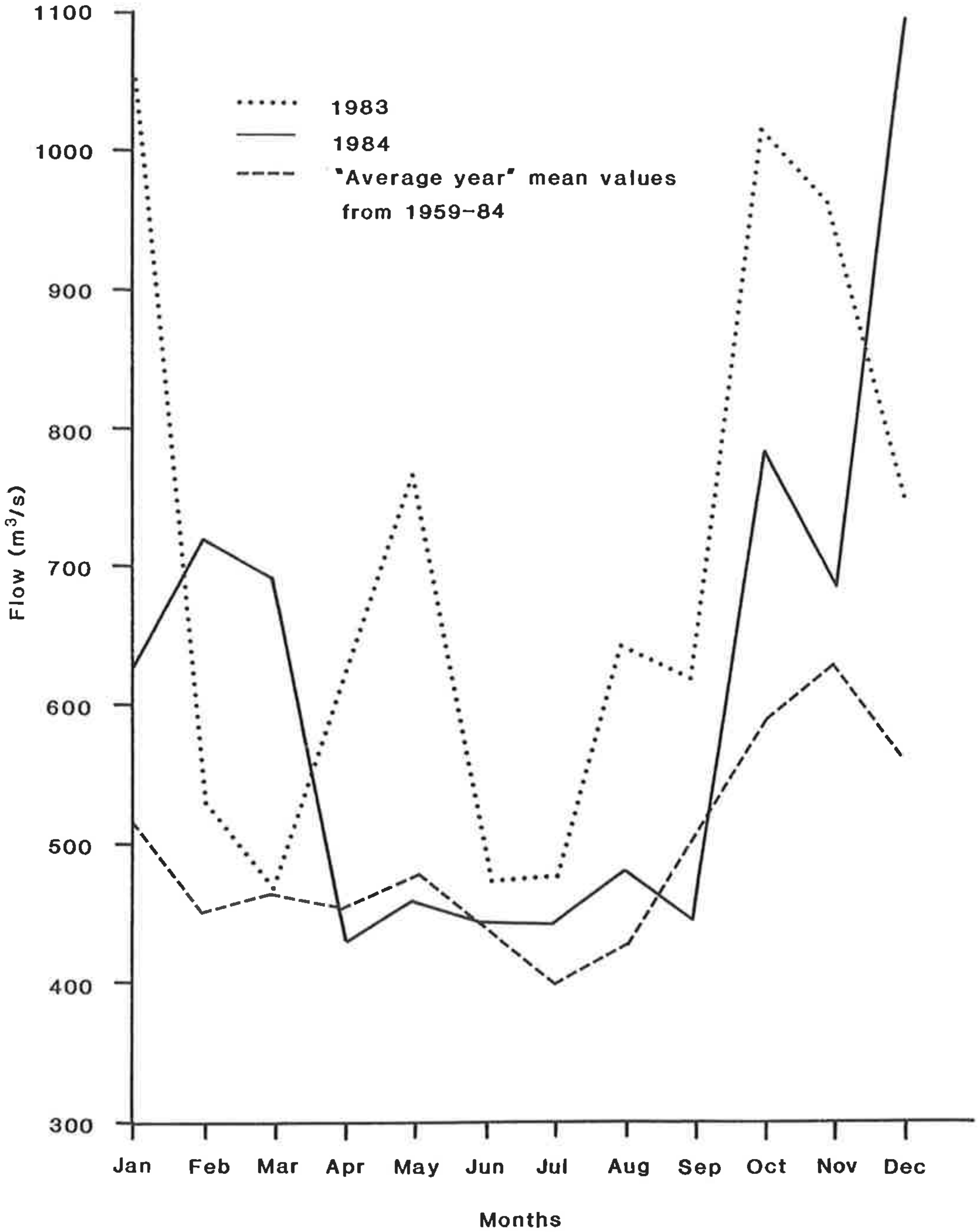

FIGURE 9. Mean monthly flows of the Clutha River for the two study years and the "average year".

output (320 MW) gives a level of 88.6 m (Roxburgh powerhouse personnel, pers. comm.). Thus from minimum to maximum load the corresponding increase in water level immediately downstream is 3.8 m. Spillway discharges cause further increases in water level, but because values for the total discharge (powerhouse plus spillway) and water level do not correlate well, it is difficult to predict river levels when spilling is taking place.

Water level data were also obtained from a continuous recorder operated by Ministry of Works and Development at Millers Flat from April 1983 to January 1984. Over this period the maximum range in water level was 2.72 m. A linear regression of mean daily levels, y (in mm) against mean daily discharge at Roxburgh, x (in m^3/s) for the months of May and October 1984 gave the equation $y = 2.142\ x + 851.494$ with a correlation coefficient of 0.99. Assuming a typical daily range in discharge of 130 - 720 m^3/s (calculated from Fig. 9.1, Otago Regional Water Board 1980), these flows correspond to a range of 1.26 m in river level at Millers Flat, a reduction of about 2.5 m height in the 21 km from Roxburgh dam.

4.2.2.2 Water Temperatures

Water temperatures are recorded daily at Roxburgh dam at 0900 h. Mean monthly temperatures for the period March 1983 to February 1985 are shown in Fig. 7. Over the 2 years there was a seasonal range of 11°C from a minimum 5°C to a maximum of 16°C. Although summer temperatures were similar, the 1983 autumn and winter temperatures were about 2° cooler than those for 1984.

4.2.2.3 Water Quality

The overall water quality of the lower Clutha River is described as high. Davies-Colley (1985) surveyed the water quality of the lower Clutha River and found it to have the following characteristics: dissolved oxygen levels are very close to saturation, pH is usually in the range of 7-9, the nutrient status is close to a pristine state, and the fairly high turbidity is the only quality likely to impair some water uses.

4.2.3 Tributaries

The tributaries in the study area are shown in Fig. 10. Physical surveys of selected reaches of the 12 tributaries indicated were carried out by FRD as part of a project to find out the trout and salmon spawning potential of these waterways (Jellyman in prep). In addition the Alexandra and Dunedin branches of MWD carried out 2-monthly flow gaugings (plus temperature, oxygen, and pH measurements) at the eight tributaries indicated in Table 6. Three tributaries of varying sizes and characters were selected for monthly fisheries surveys, namely, Benger Burn, Tima Burn, and Talla Burn. Estimates of flow were made for the Benger Burn only; these estimates were made by multiplying the cross-sectional area times the surface velocity by a factor of 0.77 (appropriate correction factor supplied by Ministry of Works and Development, Alexandra).

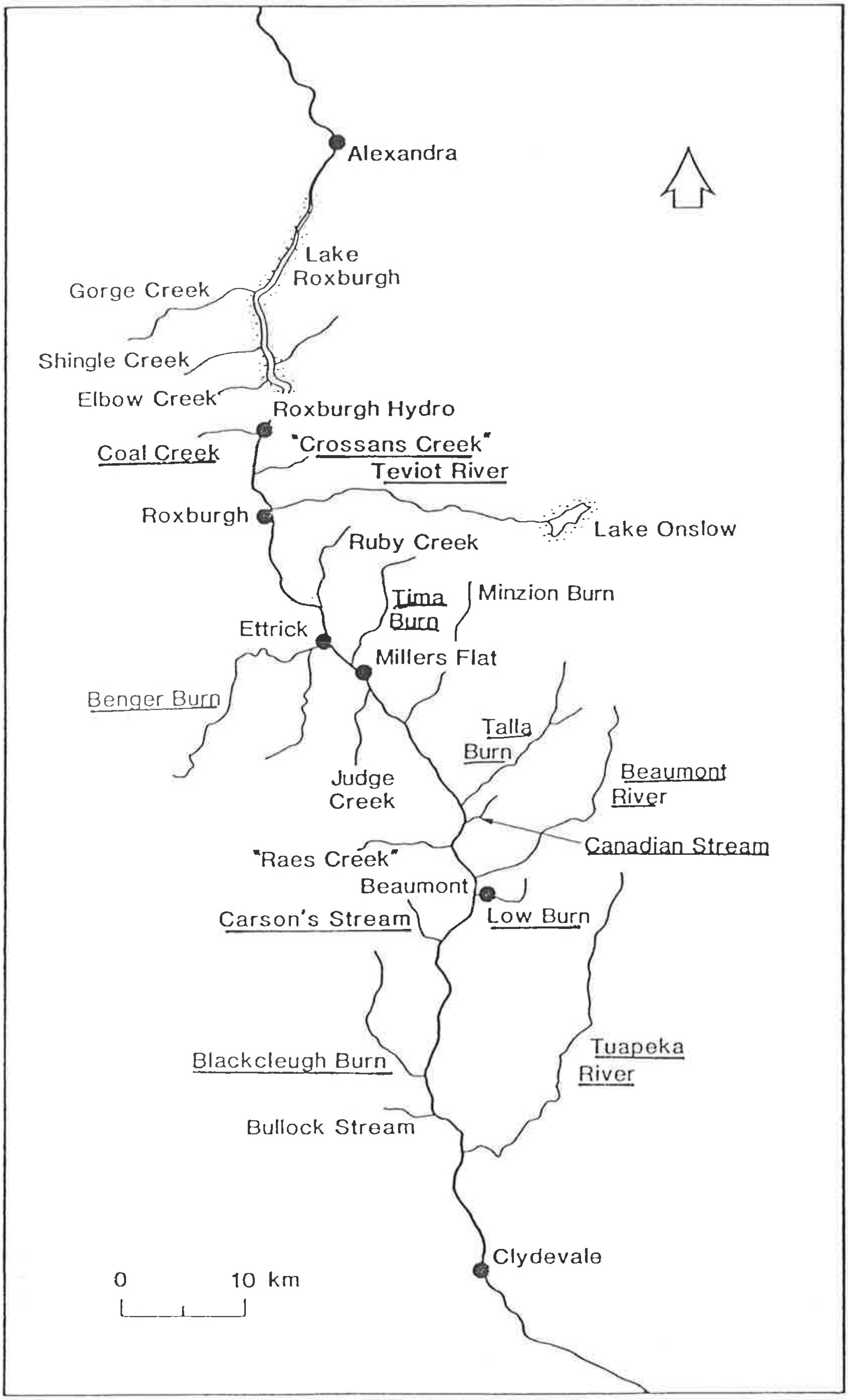

FIGURE 10. The study area with tributaries surveyed by FRD underlined.

TABLE 6. Main tributaries within the study area - catchment area, stream gradient and length, and flow (mean and range)

Tributary	Catchment area (km^2)	Average gradient	Length (km) main channel	Flow (m^3/sec) range mean (no. of obs.)
Coal Creek	21.21	0.095	6.7	0.19 - 0.72 0.5 (4)
Crossans Creek	5.11	0.044	1.4	0.6 - 0.22 0.14 (2)
Teviot River*	313.00	1.48	44.0	1.51 - 11.51 6.23 (17)
Benger Burn*	74.00	0.032	19.7	0.0174 - 11.732 1.0592 (20)
Tima Burn*	43.00	0.052	9.9	0.095 - 0.93 0.424 (7)
Talla Burn*	116.00	0.055	10.0	0.9905 - 6.0 2.69 (9)
Canadian Stream	7.45	0.099	4.3	0.14 - 0.17 0.155 (2)
Beaumont* River	68.0	0.044	18.9	1.07 - 1.93 1.32 (7)
Low Burn	21.46	0.055	10.6	0.14 - 0.25 0.195 (2)
Carsons* Stream	17.00	0.082	6.3	0.102 - 1.289 0.363 (9)
Blackcleugh* Burn	446.00	0.052	14.0	0.304 - 2.33 0.825 (9)
Tuapeka* River	254.00	0.017	40.2	0.58 - 4.956 1.855 (9)

Flow data obtained from MWD Alexandra and Dunedin, and present study.

* Tributaries gauged regularly by MWD, Alexandra and Dunedin.

Catchment areas and lengths of tributaries are summarised in Table 6. Three catchments (Teviot River, Blackcleugh Burn, and Tuapeka River) account for three-quarters of the total catchment area. However, the collective catchment areas and flows of all tributaries are small in relation to the Clutha River as a whole, that is, the total catchment area of all tributaries is only 6.5% of the complete Clutha River catchment and the combined mean flow from the tributaries (15.8 m^3/s) contributes only 3% of the total Clutha River mean flow.

On the whole, water quality of the tributaries in the study area is reasonably high. Davies-Colley (1984) suggested that the tributaries are dilute, or very dilute soft waters which are quite distinct in character from the lower Clutha River itself. The most distinctive feature of the tributaries of the left bank is a yellow colouration caused by dissolved humic substances derived from boggy upland drainage. pH was recorded for the eight tributaries during the study period and in general was found to be neutral to slightly alkaline. For the Blackcleugh Burn, four pH readings were taken and one value of 8.6 was recorded whereas the others averaged 7.5. This was the most alkaline pH recorded. The lowest pH reading was 6.0 recorded from the Beaumont River, but the other readings for the Beaumont River averaged 7.5. Measurements of dissolved oxygen taken during summer were all found to be over 105% saturation except for the Tuapeka River which had a mean value of 95.3%.

4.2.3.1 Coal Creek

Coal Creek arises from hills east of the Umbrella Mountains and flows in a north-west direction and for most of its length. It is a tumbling stream (Fig. 11). It is joined by Washpool Creek about 1 km

FIGURE 11. Upper Coal Creek.

before it enters the Clutha River, below which, it passes through Harliwich's coal plant. Below the coal plant, benthic invertebrates were noted as being far fewer, almost certainly because of the coal-fines covering extensive areas of the substrate. The lower portion of the creek is quite overgrown with willows, briar, and gorse, but in the upper portion it is more open with lower vegetation (Fig. 12).

4.2.3.2 Crossans Creek

Crossans Creek, at 1.4 km long is the smallest of the tributaries surveyed in the study area. It is spring fed and flows through quite flat farmland, but the gradient is steeper near the creek's confluence with the Clutha River. Abundant macrophytes and bottom fauna make it a good nursery stream for trout.

FIGURE 12. Coal Creek below S.H.8 bridge.

4.2.3.3 Teviot River

The Teviot River flows south through barren hill country into a swampy basin between the Lammerlaw and Lammermoor Ranges; this basin has been dammed to form Lake Onslow. From the lake the river flows west to the Clutha River; in the lower 4 km the substrate is mainly boulders and the gradient is steep (Fig. 13). In this part of the river the flow is controlled by the powerhouse (Fig. 14).

There are several dams and powerhouses on the river which make up a hydro and irrigation complex with Lake Onslow as a reservoir (Fig. 15). The scheme was first constructed in 1924 with a capacity of 0.6 MW. The Teviot Bridge power station was added in 1972. On 30 October 1982, an extended scheme was commissioned. This consisted of a new concrete dam, 4 m higher than the old stone structure, which increased the lake area from 367 ha to 834 ha (Tonkin 1982). An additional powerhouse (Teviot "A") was added to the existing Teviot Bridge station and a new powerhouse (Teviot "B") was built upstream. The total generating capacity of the scheme is 11.9-12 MW.

Lake Onslow supports a brown trout fishery of considerable regional importance. To reach the Clutha River, trout moving downstream would have to negotiate the dam at the lake, smaller dams, and then from one to three powerhouses. Alternatively they would have to negotiate the residual river. Consequently it is unlikely that trout from Lake Onslow contribute significantly to the Clutha river stocks. A combination of the power scheme and steep rocky nature of the residual river has resulted in dramatically reduced spawning facilities in the river for Clutha River salmonids.

The area of the river above the powerhouse to the first dam is known to dry up at times, owing to the water abstraction for irrigation and the power scheme (Fig. 11).

The water quality is quite high with dissolved oxygen at saturation values and the pH is very slightly alkaline.

4.2.3.4 Benger Burn

The Benger Burn (Figs. 16 and 17) is a medium-sized and clear stream flowing from the Stronach Range to the south bank of the Clutha River at Ettrick. It has two branches - a main branch 20 km long (with a gorge section about 5 km from the mouth and just above the confluence with the south branch) and a south branch 7 km long. Both branches then flow through farmland. Filamentous algae are common throughout the stream, but macrophytes are confined to the mouth. The outlet is affected by Clutha River backwash, owing to the fluctuating river levels.

FIGURE 13. Teviot River (residual river above powerhouse).

FIGURE 14. Teviot River powerhouse.

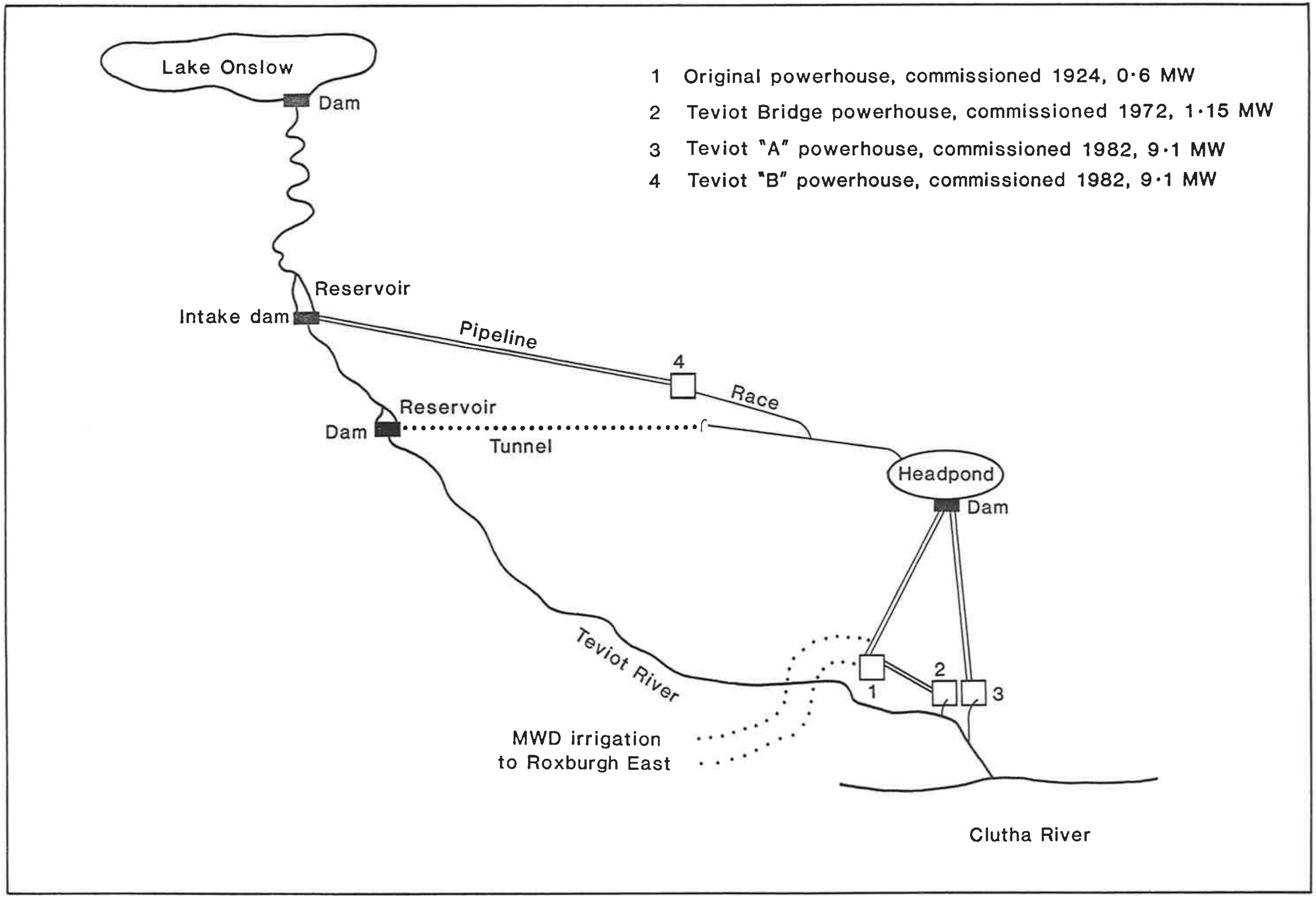

FIGURE 15. Schematic diagram of the Teviot River power scheme.

FIGURE 16. Benger Burn, middle reach.

FIGURE 17. Benger Burn, lower reach.

During the study period the Benger Burn was electric fished monthly at two study sites (each 100 m long), immediately upstream of the Moa Flat Road bridge and State Highway 8 bridge respectively. Flows were calculated and temperatures recorded. Over the 2 summers when temperatures were recorded (Fig. 18) the mean monthly temperature in the Benger Burn exceeded temperatures in the Tima Burn and Carsons Stream by several degrees. The maximum temperature recorded, 22.8°C, is considerably above the optimum temperature for trout.

The stream is ephemeral and from local information it has been known to dry up from the Normans Road Bridge to the outlet to the Clutha River. The Otago Acclimatisation Society had to carry out fish salvages in 1947, 1949, 1950, 1952 and in 1954 because of the stream drying out during the summer. It did not dry up during summer of 1983-84, but in 1985 it was dry from mid February until mid May.

The Benger Burn is a "flashy" stream, subject to frequent short-term floods especially during late summer to autumn. At present the Moa Flat Road Bridge is being replaced to cope with the "100 year flood". At the time of writing the river flood channel had been straightened above and below the existing bridge, willows had been pulled out for 100 m in either direction from the bridge, and new piles placed across the stream. The normal flow channel had been diverted and straightened. As a result of construction of the new bridge, about 800 m^3 of gravel is being removed from the flood channel. The removal of substrate, bulldozing, and debris entering the stream have caused a temporary loss of habitat for all aquatic fauna. Discussions have been held with the contractor in an attempt to ensure that instream works are kept to a minimum during the autumn-winter salmonid spawning season.

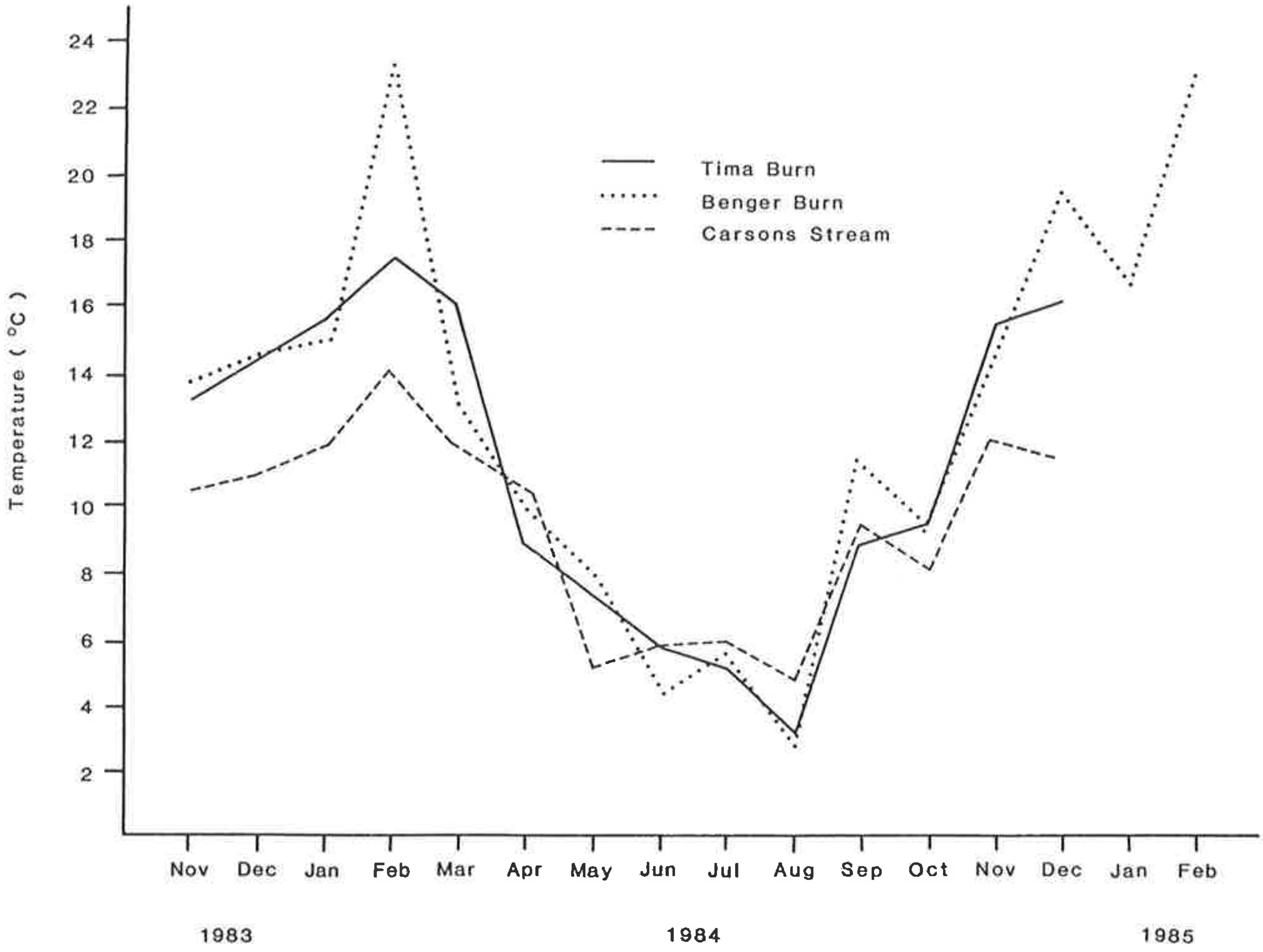

FIGURE 18. Mean monthly temperatures for the Tima Burn, Benger Burn, and Carsons Stream.

The Benger Burn is an important spawning tributary for salmon and brown trout (Pack and Jellyman in prep). However, the "flashiness" of the catchment may seriously reduce spawning success because flood waters deposit sediment, derived from upstream erosion-prone areas, over fish redds. Similarly, the rearing potential of the stream is limited by low summer flows; the small size and short duration of natural low flows are worsened by abstractions of up to 0.17 m^3/s and by stock-water dams on some tributaries.

The considerable rearing potential of this stream could be enhanced by augmenting low flows in summer by water derived from the proposed Dumbarton Rock dam (Jellyman in prep).

4.2.3.5 Tima Burn

The Tima burn (Figs. 19 and 20), a brown-coloured peaty stream, flows in a south-west direction from hills east of Lammerlaw Range and enters the Clutha River about 1 km north-west of Millers Flat. It has a smaller catchment area than the Benger Burn and the main channel is 9.9 km long. In the upper reaches, the stream flows through a small gorge area, after which the gradient decreases and the stream flows through scrub and grassland. The bedrock substrate of the upper reaches gives way to deep silty holes and shallow riffles in the lower reaches; macrophytes are present in patches.

In recent years the lower area of the stream has been cleared of willows and a new outlet to the Clutha River has been created.

FIGURE 19. Tima Burn, middle reach.

FIGURE 20. Tima Burn, lower reach.

The Tima Burn was electric fished and temperature and flow measurements were taken at monthly intervals during the study period, at two different sites - one immediately above the road bridge and one about half a kilometre below the road bridge. As with the Benger Burn and Carsons Stream, regular spawning surveys were done on this stream during 1984.

4.2.3.6 Talla Burn

The Talla Burn arises in the Lammerlaw Range and flows into the Clutha River between Millers Flat and Ettrick. The mean flow (2.69 m^3/s) is larger than the other tributaries with the exception of the Teviot River. In its upper region it is joined by a large tributary, the Fruid Burn, and here it flows through pastureland and scrub. In its lower reaches it flows through a gorge where there are deep pools and the substrate is mainly boulders. Consequently, there are very few aquatic weeds here and bottom fauna is also scarce (Fig. 21).

FIGURE 21. Talla Burn, lower reach.

The water of the Talla Burn is slightly peaty, but water quality is high. Temperatures recorded from summers of 1982-85 ranged from 10.8°C to 16°C (Ministry of Works and Development, Alexandra) and dissolved oxygen saturation for each summer had a mean of 107%.

4.2.3.7 Canadian Stream

Canadian Stream arises in hills west of the Lammerlaw Range, near the Beaumont River. It is a small stream with a length of 4.3 km and a catchment area of 7 km^2. The top part of the stream is in a gorge and is overgrown with native bracken and scrub. The lower part of the stream, near the outlet to the Clutha River, has more open sections and is surrounded by willows. Bottom fauna was found to be abundant in areas below the gorge.

4.2.3.8 Beaumont River

Beaumont River (Fig. 22) flows south from the Lammerlaw Range and into the Clutha River just north of Beaumont township. There are two main channels in the upper reaches (Beaumont and Little Beaumont) both of which pass through pastureland and scrub. About 2.5 km upstream of the outlet, the river passes through a gorge, which has large boulders and numerous small waterfalls. It is doubtful whether fish could travel upstream through the gorge. The bottom section of the river is steep sided, bordered by ferns and native trees, and it has a boulder substrate. Over its entire length the river falls 1100 m and 200 m of this occurs over the last 4 km (Royds, Sutherland and McLeay 1981).

FIGURE 22. Beaumont River above the gorge.

Despite the slightly peaty brown colour, water quality in the Beaumont River is high. Temperatures recorded from 1982 to 1985 ranged from 9°C to 16.8°C (Ministry of Works and Development, Alexandra). Dissolved oxygen had a mean value of 105% saturation.

4.2.3.9 Low Burn

Low Burn (Fig. 23) arises in the Lammerlaw Range, near Beaumont River. It flows south and then west to join the Clutha River after passing through Beaumont township. It has a small catchment area relative to its length (Table 6). Over all, the stream is narrow and not very steep. Its water colour is slightly brown.

FIGURE 23. Low Burn, middle reach.

4.2.3.10 Carsons Stream

Carsons Stream borders on the northern side of Beaumont Forest. The mainstem of the stream is about 6.3 km long. It is joined by numerous smaller tributaries in its upper reaches and by a smaller stream about 2 km from its mouth. The headwaters flow through steep bouldery reaches surrounded by native vegetation. As it flows through the scrub covered plains of the lower reaches the stream bed becomes wider and more open (Fig. 24).

During the study period Carsons Stream was electric fished monthly, and temperature was also recorded at this time; regular spawning surveys were also carried out. It was noted that the stream was extensively used by spawning salmon and trout and that large numbers of juvenile trout were present all year round. The spawning and rearing capacities of the stream were attributed to various factors. In the lower reaches there were fairly large areas of suitably sized and clean spawning gravels. During electric fishing the bottom fauna was noted to be both diverse and abundant. In addition, water temperatures were found to have the least variation of the three streams measured (Fig. 18) and water quality was consistently high.

FIGURE 24. Carsons Stream, lower reach.

4.2.3.11 Blackcleugh Burn

Blackcleugh Burn (Fig. 25) arises in the Blue Mountains and flows in a south-east direction through Beaumont Forest to the Clutha River. Although it has the largest catchment area of all the tributaries in the study area, the mean flow is exceeded by five other tributaries (Table 6). About 7 km from the mouth there is a very rugged gorge section, with steep rocky outcrops projecting into the stream. A waterfall is present below the gorge. In combination, the gorge and waterfall would be impassable to all fish with the possible exception of small eels and koaro, which both have the ability to climb exposed surfaces. Above the gorge, a high density of bottom fauna was noted, but in the lower section there is no aquatic weed and very little bottom fauna.

The water quality was found to be high, and the water was clear. Temperatures for the summer period 1982-85 ranged from 9.0°C to 12.8°C.

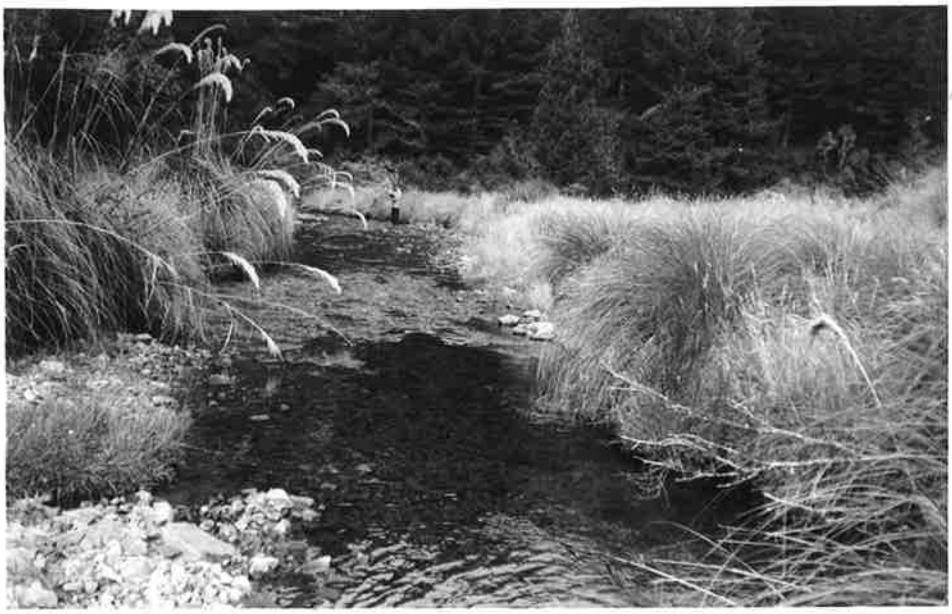

FIGURE 25. Blackleugh Burn, upper reach.

4.2.3.12 Tuapeka River

Tuapeka River arises in the south-western foothills of the Lammerlaw Range and flows in a southwest direction to the Clutha River, joining it at Tuapeka Mouth township. It is the second longest tributary (40.2 km) in the study area and has a fairly large catchment area (254 km^2). In its headwaters, it is joined by Youngs Valley Stream flowing through native grassland. The Tuapeka River then flows through a gorge section after which the gradient is slight and the river meanders through farmland and rolling hill country (Fig. 26). Willows line the banks of the river. In its lower reaches the substrate is mainly bedrock and there is very little aquatic flora and fauna.

The water of Tuapeka River is a slightly brown colour. Temperatures ranged from 5°C to 17°C during the study period and levels of dissolved oxygen were slightly less than saturation levels. An estimated mean annual flow (2.2 m^3/s) at the river's confluence with the Clutha (Eggar and Eggar 1981) was close to the flow of 1.9 m^2/s calculated during the study period.

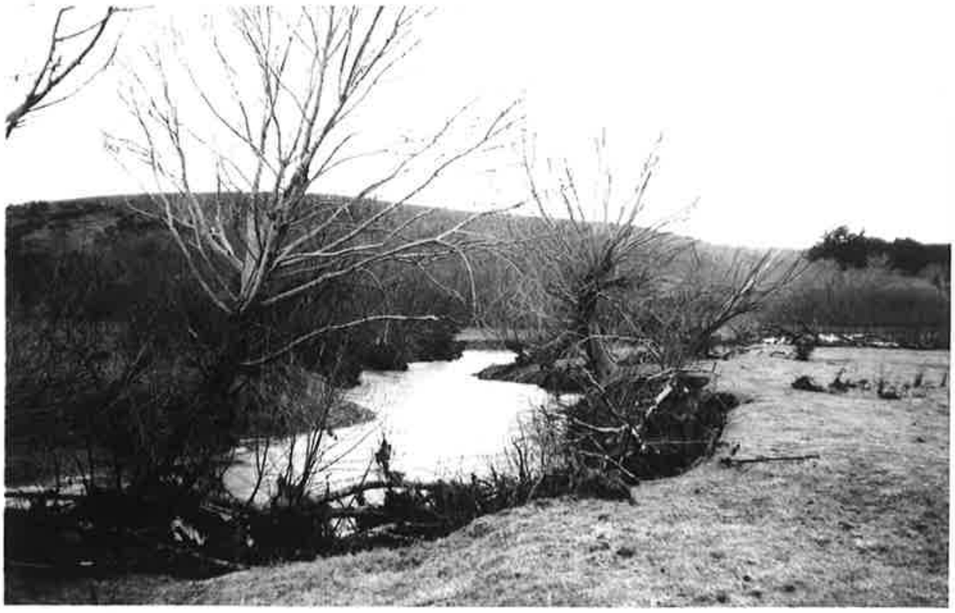

FIGURE 26. Tuapeka River, middle reach.

4.3 Study Programme

In late 1981 a wide ranging programme of studies was drawn up for the lower Clutha River including comprehensive environmental studies to identify the present environmental resources and to assess the impacts of various power development options (section 3.4) on these resources. The investigations included physical studies of engineering, geology, mineral resources, soil, and climate, and the biological studies included agriculture, aquatic resources (macrophytes and invertebrates), and a fisheries study. It is envisaged that a summary of these studies will be featured in a comprehensive report to be published in 1986.

Ministry of Works and Development contracted Fisheries Research Division to do the fisheries study and liaison between the two parties during 1982 led to the following objectives:-

1. To collate existing information on the pre-Roxburgh fishery and assess subsequent changes (Pack and Jellyman in prep).

2. To determine the distribution and relative abundance of fish species within the study area, and to study life histories of selected species (Pack and Jellyman in prep).

3. To evaluate the current recreational value of the study area with particular references to trout and salmon fishing (Whiting 1986).

4. To evaluate the impacts of any proposed dams on the fishery values of the study areas (including recommendations for appropriate mitigations), and the fisheries potential of proposed reservoirs. These are presented in Jellyman in prep. The present report provides background information to the other reports.

The fisheries study commenced in March 1983. Although not strictly within the study area, Lake Roxburgh was included to provide information on the fisheries value of a hydro lake. During 1983, with the assistance of ICI/Wattie and Otago Acclimatisation Society, visual spawning surveys of salmonids were carried out in the area. Fyke nets were set to capture spawning salmonids and eels. From September to November 1983 all the streams were electric-fished for a species surveys. In addition the three study streams were electric-fished at monthly intervals from October 1983 to April 1984. Fish in Lake Roxburgh and the mainstem Clutha River were sampled by netting at monthly intervals. A visual survey was carried out to estimate spawning potential of the main streams in the study area.

During 1984 spawning was monitored by visual surveys on the three study streams and a fish trap was placed in the Benger Burn. Food availability (invertebrates) was monitored by grab sampling in Lake Roxburgh, drift sampling in the lake, river, and study streams, and Surber sampling in the study streams only.

The recreational survey took place over 12 months from October 1983 to September 1984. A total of 74 bankside surveys was carried out to observe recreation, with the major emphasis on angling. An anglers' postal survey was undertaken to make an assessment of angler's catch and effort for the 1982/83 fishing season in the lower Clutha River. This consisted of a postal questionnaire which was sent out in September 1983 to 898 randomly selected anglers from the Otago Acclimatisation Society district. During the course of the recreational survey quantitative information on the fish and fishery was obtained from angler interviews. An angling diary scheme was set up to obtain additional information on the lower Clutha River fishery over the 1983/84 fishing season. Between

September 1983 and March 1984, 63 diaries were distributed to volunteer anglers who fished the lower Clutha River and tributaries. In addition, a local-angler attitude questionnaire was distributed to members of the Teviot Angling Club at their annual general meeting in September 1984.

Information from the fisheries and recreational studies will provide the basis for suggested mitigation and enhancement of the fishery to be covered in the final report (Jellyman in prep).

5. ACKNOWLEDGMENTS

We would like to thank the other lower Clutha River consultants, Eve Pack, Ros Whiting, and Rob Baldwin for their assistance with reviewing literature and data collection, and Ken Lake for jetboat transport and assistance with field work. We also wish to acknowledge John Ford and personnel at Roxburgh dam for providing information on dam operations; Peter Stevenson and hydrology team (Ministry of Works and Development, Alexandra) and Mike Butler and hydrology team (Ministry of Works and Development, Dunedin) for providing hydrological data for the tributaries and Clutha River; and Dick Hutchinson (Wildlife Service, Department of Internal Affairs, Queenstown) for information on the upper Clutha River fishery. We would also like to express our thanks to Carol Whaitiri for typing the manuscript.

6. LITERATURE CITED

Adams, G.P. 1976. Appendix II. The lakes/recreation technical group. 12 p. *In*: N.Z. Ministry of Works and Development 1978, Clutha Valley Development, Environmental Impact Report on Design and Construction Proposals, Appendices. (Unpaged.)

Ayson, C. 1958. Report by Chas Ayson. *Waitaki Valley Acclimatisation Society Annual report 1958*: 23-26.

Biggs, B.J. 1981. An assessment of the possible effects of the proposed Luggate and Queensberry hydro-electric impoundments on the aquatic vegetation of the Clutha River. Technical Paper 1. 29 p. and figures. *In*: New Zealand Electricity and Ministry of Works and Development, Clutha Valley Development, Environmental Impact Report, Luggate and Queensberry Hydro Power Stations, Technical papers. (Unpaged.)

Biggs, B.J. 1982. The effects of low flow regulation on river water quality and biology. A case study. pp. 28-42. *In*: McColl, R.H.S. (Ed.) River Low Flows: Conflicts of Water Use. *Water and Soil Miscellaneous Publication No.47*.

Biggs, B.J. 1984. Aquatic macrophytes and factors affecting development in the Roxburgh hydro-electric impoundment. N.Z. Ministry of Works and Development, Water and Soil Science Centre, Christchurch, for the National Water and Soil Conservation Authority. Internal Report No. WS879. 18 p.

Biggs, B.J., and Malthus, T.J. 1981. An assessment of the possible effects of the proposed Luggate and Queensberry hydro-electric impoundments on the benthic invertebrates in the upper Clutha River. Technical Paper 4. 18 p. *In*: New Zealand Electricity and Ministry of Works and Development, Clutha Valley Development, Environmental Impact Report, Luggate and Queensberry Power Stations, Technical Papers. (Unpaged.)

Biggs, B.J., and Malthus, T.J. 1982. Macroinvertebrates associated with various macrophytes in the backwaters and lakes of the upper Clutha valley, New Zealand. *N.Z. Journal of Marine and Freshwater Research 16*: 81-88.

Biggs, B.J., and McBride, G.B. 1980. An assessment of the possible effects of proposed Luggate and Queensberry hydro-electric impoundments on the water quality of the upper Clutha River. Technical Paper 2. 11 p. *In*: New Zealand Electricity and Ministry of Works and Development, Clutha Valley Development, Environmental Impact Report, Luggate and Queensberry Hydro Power Stations, Technical papers. (Unpaged.)

Biggs, B.J., and Shand, B.I. 1985. Biological communities and the potential effects of power developments in the lower Clutha River, Otago. N.Z. Ministry of Works and Development, Christchurch. Unpublished Report No. WS987. 66 p. and appendices.

Coffey, B.T. 1974. Report on submerged weed control in the Clutha valley with particular reference to existing and proposed hydroelectric lakes on the Clutha River. Electricity Division, N.Z. Ministry of Energy. Unpublished report. 25 p. and figures and tables.

Commission for the Environment. 1982. Clutha Valley Development: Proposed Luggate and Queensberry Hydro Power Stations. 77 p. and appendices.

Cossens, C.G. 1982. Ground water resources and salinity analyses in Otago irrigation schemes. Mosgiel Southern South Island Region of N.Z. Ministry of Agriculture and Fisheries. Unpublished report.

Davies-Colley, R.J. 1985. Water quality of the lower Clutha River. An assessment of the potential water quality impact of proposed hydro-electric development. N.Z. Ministry of Works and Development, Water Quality Centre, Hamilton. *Publication No. 6.* 27 p. and figures and tables.

Department of Internal Affairs. 1981. Upper Clutha Development - Luggate/Queensberry power projects. Fishery Impacts. Technical Paper 5. 17 p. and figures. *In*: New Zealand Electricity and Ministry of Works and Development, Clutha Valley Development, Environmental Impact Report, Luggate and Queensberry Hydro Power Stations, Technical Papers. (Unpaged.)

Department of Statistics. 1984. New Zealand Official Yearbook. Government Printer, Wellington. 1054 p.

Egarr, G.D., and Egarr, J.H. 1981. New Zealand recreational river survey. Part III. South Island Rivers. *Water and Soil Miscellaneous Publication No. 15.* 160 p.

Flain, M. 1980. Those dammed Clutha salmon. *Freshwater Catch No. 7*: 7.

Furkert, F.W., Hunter, A.J., and Hay, F.C. 1920. Report of Rivers Commission on Clutha River. Presented to both Houses of the General Assembly, Wellington. 18 p.

Gillies, A.J., and Torrance, A.M. 1979. The effect of peak load hydro-power generation waves on the regime of alluvial rivers.

International Association for Hydraulic Research - Hydraulic problems in hydro-power. Otago Catchment and Regional Water Board, Dunedin. Unpublished report. 8 p.

Glova, G.J., and Davis, S.F. 1981. Submission on the proposed Luggate/Queensberry hydro-electric development. *N.Z. Ministry of Agriculture and Fisheries, Fisheries Environmental Report No.9.* 19 p.

Green, J.D. 1975. Light penetration. pp. 84-89. *In*: Jolly, V.H., and Brown, J.M.A. (Eds.). "New Zealand Lakes." Auckland University Press. 388 p.

Hamilton, G.D. 1904. "Trout Fishing and Sport in Maoriland." Government Printing Office, Wellington. 428 p.

Harker, P.J. 1978. Clutha Valley Development. Clyde power project. *Otago Acclimatisation Society Annual Report 1978*: 55-57.

Hill, C.F. 1970. Report on visit to South Island lakes. Electricity Division, N.Z. Ministry of Energy. Unpublished report. 9 p.

Hooper, R.J., McKenzie, C.J., and Natusch, D.F.S. 1983. Lignite as a source of liquid transport fuels in New Zealand. *Liquid Fuels Trust Board Report No. LF2028.* (Unpaged.)

Hutchinson, R.T. 1974. A complete survey of the Clutha, Kawarua, Lindis, Cardrona and Hawea Rivers covering the major drainages from Lake Roxburgh upstream to the outfalls of Lakes Wakatipu, Wanaka and Hawea. N.Z. Department of Internal Affairs, Queenstown. Unpublished Investigation Report, Southern Lakes Fisheries Project. 34 p. and appendices.

Hutchinson, R.T. 1977. Impact on fisheries by proposed DG3 dam. N.Z. Department of Internal Affairs, Queenstown. Unpublished report. 5 p.

Hutchinson, R.T. 1980. The freshwater fishery. pp. 45-50. *In*: Robertson, B.T., and Blair, I.D. (Eds.). The Resources of Lake Wanaka. *Lincoln Papers in Resource Management No. 5*. 66 p.

Jellyman, D.J. 1984. Distribution and biology of freshwater fish in the Clutha river. *N.Z. Ministry of Agriculture and Fisheries, Fisheries Environmental Report No. 46*. 69 p.

Jellyman, D.J. In prep. Impacts of possible hydro development on fishery values of the lower Clutha River. *N.Z. Ministry of Agriculture and Fisheries, Fisheries Environmental Report*.

Jones, D.H. 1979. Hydro-electric power development and recreational use of water in Otago. Electricity Division, N.Z. Ministry of Energy. 30 p.

Jones, D.H. 1981. Hydro-electric power development and environmental conservation in Southland, Otago and Mackenzie County. Electricity Division, N.Z. Ministry of Energy. 101 p.

Jowett, I.G. 1984. Operation of the lower Clutha power scheme in conjunction with Roxburgh and Clyde power stations. N.Z. Ministry of Works and Development, Power Directorate, Wellington. Unpublished report. (Unpaged.)

Jowett, I.G., and Hicks, D.M. 1981. Surface, suspended and bedload sediment - Clutha River system. *Journal of Hydrology (N.Z.) 20*: 121-130.

Jowett, I.G., and Thompson, S.M. 1977. Appendix 2. Clutha power development. Flows and design floods. 114 p. *In*: N.Z. Ministry of Works and Development 1978, Clutha Valley Development, Environmental Impact Report on Design and Construction Proposals, Appendices. (Unpaged.)

Lane, E.D. 1964. Brown trout (*Salmo trutta*) in the Hinds River. *Proceedings of the N.Z. Ecological Society 11*: 10-16.

Lindup, F.W., and Watt, J.D. 1954. Report on irrigation in Central Otago. N.Z. Ministry of Works and Development, Wellington. Unpublished report. 37 p. and appendices and maps.

Little, R.W. 1975. Clutha Valley Development: fisheries interests. Appendix 4. 2 p. *In*: Upper Clutha Valley Development. Environmental Impact Report. N.Z. Ministry of Works and Development. 119 p. and appendices.

McDowall, R.M. 1965. The composition of the New Zealand whitebait catch 1964. *N.Z. Journal of Science 8(3)*: 285-300

McDowall, R.M. 1978. "New Zealand Freshwater Fishes: a Guide and Natural History." Heinemann Educational Books, Auckland. 230 p.

Ministry of Works and Development. 1975. Upper Clutha Valley Development. Environmental Impact Report. 119 p. and appendices.

Ministry of Works and Development. 1977. Clyde Power Project. Environmental Impact Report on Design and Construction Proposals. Clutha Valley Development. 170 p.

Ministry of Works and Development. 1982a. Clutha Valley Development. Environmental Impact Report. Luggate and Queensberry Hydro Power

Station. Report for Electricity Division, N.Z. Ministry of Energy. 232 p.

Ministry of Works and Development. 1982b. New riches from the Clutha. Electricity, Irrigation, Recreation. Brochure - revised December 1982. 19 p.

Ministry of Works and Development. 1984a. Lower Clutha Hydro-electric Investigations. Interim Report. *Investigation Report 84/2*. 50 p.

Ministry of Works and Development. 1984b. Kawarau Progress Bulletin. Hydro-electric Investigations. 23 p.

Ministry of Works and Development. 1984c. Clutha Valley Development. Environmental Statement on Luggate Hydro Power Station. Report for Electricity Division, N.Z. Ministry of Energy. 143 p.

Murray, D.L. 1975. Regional hydrology of the Clutha River. *Journal of Hydrology (N.Z.) 14(2)*: 83-98

National Water and Soil Conservation Organisation. 1979. Water rights for the Clyde Dam, Clutha hydro power development. *Water and Soil Miscellaneous Publication No.8*. 28 p.

National Water and Soil Conservation Organisation. 1982. A draft for a National Inventory of Wild and Scenic Rivers. Part I - Nationally Important Rivers. *Water and Soil Miscellaneous Publication No. 42*. 64 p.

New Zealand Electricity. 1978. Roxburgh Power Station. Government Printer, Wellington. 4 p.

O'Connor, K.F. 1975. Multiple resource use in the upper Clutha Valley. *Journal of Hydrology (N.Z.) 14(2)*: 130-145

Otago Catchment Board and Regional Water Board. 1985a. Water Resource Inventory for the Clutha, Kawarau, and Hawea Rivers - A Review. 112 p.

Otago Catchment Board and Regional Water Board 1985b. Draft management plan for the Clutha, Kawarau and Hawea Rivers. 97 p.

Otago Regional Water Board. 1980. Clutha catchment water allocation plan. Volume 1. A land and water resource inventory of the Clutha catchment. 172 p.

Pack, Y.M., and Jellyman, D.J. In prep. Fish stocks in the lower Clutha River. *N.Z. Ministry of Agriculture and Fisheries, Fisheries Environmental Report.*

Pickford, A.J. 1985. Lower Clutha investigations. Possible development schemes and operation strategies. N.Z. Ministry of Works and Development. Unpublished report. (Unpaged.)

Poole, A.L. 1983. Catchment control in New Zealand. *Water and Soil Miscellaneous Publication No. 48.* 185 p.

Royds, Sutherland and McLeay 1982. Small hydro-electric potential of the Otago Electric Power Board District. 43 p. and appendices.

Shand, B.I., and Biggs, B.J. 1985. A compilation of data from recent studies on macrophytes and macroinvertebrates in Lake Roxburgh, Otago. N.Z. Ministry of Works and Development, Christchurch. Unpublished report No. WS975. 27 p.

Sheppard and Rout, and Kearsley, G.W. 1983. Lower Clutha River hydro-electric investigations community study. Full study report. N.Z. Ministry of Works and Development for Electricity Division, Ministry of Energy, Wellington. Various pagings.

Spackman, W.H. 1892. "Trout in New Zealand: Where to Go and How to Catch Them." Government Printer, Wellington. 9 p.

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

Thompson, S.M. 1976. Clutha Power Development. Siltation of hydro-electric lakes. Appendix 3. 32 p. and figures. *In*: Ministry of Works and Development, Clutha Valley Development, Environmental Impact Report on Design Construction proposals. Appendices. Various paging.

Thomson, G.M. 1922. "The Naturalisation of Animals and Plants in New Zealand." University Press, Cambridge. 607 p.

Tonkin, C.C. 1982. Lake Onslow - a fishery in the making? *Otago Acclimatisation Society Annual Report 1982*: 18-20

Turner, B. (Ed.) 1983. "The Guide to Trout Fishing in Otago." Otago Acclimatisation Society, Dunedin. 102 p.

Watson, N. 1981. Southland and Central Otago lignite. *Otago Acclimatisation Society Annual Report 1981*: 21-24.

Webster, A.H.H. 1948. Teviot tapestry; a history of the Roxburgh-Millers Flat district. Otago Centennial Historical Publications, Dunedin. 179 p.

Whiting, R. 1986. Water-based recreation on the lower Clutha River. *N.Z. Ministry of Agriculture and Fisheries, Fisheries Environmental Report No.61.* 155 p.

Winter, J.W. 1964. A survey of Lake Roxburgh, a recent hydro-electric dam. *Proceedings of the N.Z. Ecological Society 11*: 16-23.

Wong, S. 1985. Evidence for the hearing on the water right applications Luggate Power Station. Evidence presented to the tribunal hearing the Luggate Power Station water right applications, April 1985. 19 p.