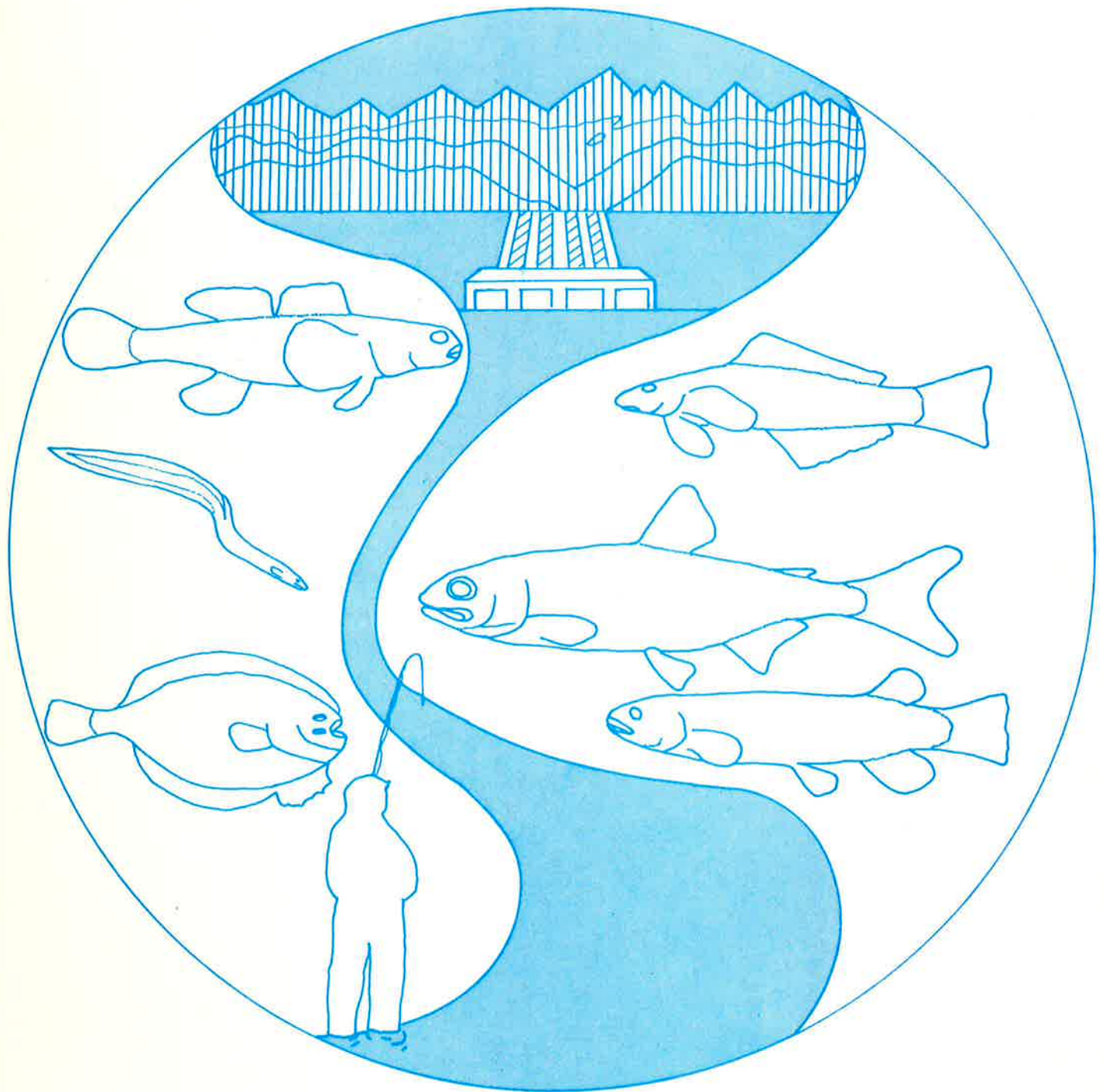


FISHERIES ASPECTS OF THE LOWER WAITAKI POWER SCHEME



Ministry of Agriculture and Fisheries
Fisheries Research Division

FISHERIES ENVIRONMENTAL REPORT NO.8

FISHERIES ASPECTS OF THE LOWER WAITAKI POWER SCHEME;

An Assessment of the Impact of Various
Development Options on the
Fish Stocks and Fisheries.



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1. SUMMARY

This report is a preliminary attempt to assess the impact of various power development schemes upon the fish stocks and fisheries of the lower Waitaki River. The aim is to firstly assist N.Z.E. and M.W.D. power planners in evolving a scheme which will have an acceptable impact on the fisheries resource and secondly to outline what fisheries and allied investigations should be undertaken.

The lower Waitaki River and its tributary streams contain one of the most diverse fish faunas in New Zealand. Twenty of the thirty-three native freshwater species and five of the seven introduced salmonids are present. Detailed biological studies on the most important species are in progress and this report summarises data collected to date on their life histories, distribution, abundance, reproduction, food, age and growth rates.

The salmon and trout sports fishery is of national importance and there are also smaller fisheries for eels, whitebait, flounders, mullet and kahawai. The report briefly describes the fisheries and includes information on historical trends in fishing effort, catches and the size of fish caught. In the future the river could support a major salmon ranching industry and this potential must be recognised.

Relatively little is known about the physical, hydrological and chemical features of the river. This report summarises some of the information. Briefly, the mean flow of the present river is approximately 350 cumecs at the mouth and about 330 cumecs at the Waitaki Dam. The lower tributaries are relatively unimportant in terms of flow, except at times of flood. The river is 65 km long from the Dam to the Pacific Ocean and flows in a normally wide, braided shingle bed. A prominent feature of the water is its high load of suspended glacial silt.

This report also examines the impact of three possible alternative power development schemes which we have derived and modified from the various options described by the M.W.D. (1974, 1978, 1979). Our first and most favoured option (Option A, Fig. 4) is the construction of a power canal and separate floodway down the south bank of the Waitaki River from near Kurow to the State Highway 1 bridge. Running adjacent to it, on the north bank from a control structure below the Hakataramea River to the sea, would be a substantial residual river. We describe the features and basic design of the residual river and the flow regime required. Methods by which salmon and trout recruitment can be maintained are also discussed.

The second option (Option B) is similar to the first but the floodway and residual river are combined. The frequency and duration of floods passing down the combined channel are described together with the physical effects in flood plains of various widths. The impact of floods on invertebrate faunas and fish stocks are discussed and it is concluded that a residual river subject to repeated floods would be a very inhospitable environment. This option is not recommended.

The third option here (Option C, Fig. 5) is to enlarge the power canal into series of small hydroelectric reservoirs which would accommodate floods and the flows of tributary streams. There would be no residual river, only drains for groundwater. In this scheme fish would move between the reservoirs via fishways and fishing would be conducted in the reservoirs. The impact of a series of dams on the fish stocks, the possible fishery in the reservoirs and various design considerations are discussed. At present it appears that the valuable salmon and trout fisheries and the fish stocks of the lower Waitaki may be seriously damaged under this option. It is also likely that any

fisheries modifications to the design would greatly increase the capital construction costs. F.R.D. is generally opposed to, and does not recommend, this type of development because it would destroy the natural river ecosystem, fish stocks and river based fisheries.

The research planned to investigate the effects of development of the lower Waitaki River on its fish stocks and fisheries is also described.

2. RECOMMENDATIONS

- (a) If the river is to be developed, adequate compensation must be made to the present river system's users by the provision of a residual river or by other means.
- (b) Applications for water rights for any major development in the lower Waitaki system should be suspended until sufficient experiments and tests have been conducted to convincingly demonstrate the likely effects on the fisheries resource.
- (c) Detailed information must be collected on the present river users, wildlife and fisheries.
- (d) The research programme should be expanded to include the construction of experimental channels and the study of existing stable river systems.
- (e) If the river is developed the valuable lower reaches of the present river (downstream from the state highway bridge) should be left basically unmodified.
- (f) Extreme care should be taken with the design and testing of fisheries facilities to avoid less than successful structures such as the Waitaki Dam Fish Pass.
- (g) If the river is developed, any water abstraction should be made should come from the power canal and possibly harmful abstraction from the tributaries avoided.
- (h) If the residual river is developed, provision should be made for regular reviews and possible increases in the water allocation to the residual river, in case of unpredictable developmental changes.
- (i) If construction goes ahead, day to day construction procedures be designed so that attention is paid to the fish stocks. An independent fisheries inspector with a considerable veto power should be appointed.
- (j) If a development will unnecessarily and significantly damage the fish stocks and fisheries we recommend that it should not proceed.

3. INTRODUCTION

The advent of power development on the lower Waitaki River now seems highly probable. A firm decision on the most appropriate development option to be proceeded with is expected by early 1981; some initial design work will probably follow. Although at present it appears that the resultant power will not be needed before the late 1990's, an increase in demands upon the national grid could bring this date forward.

The build up of interest in the river in recent years has seen an expansion in the studies undertaken on the possible power development of the lower Waitaki. The M.W.D. have already produced several publications namely; "Preliminary Feasibility Report", 1974, "Interim Report on Power Investigation", 1978, "Lower Waitaki Discussion Paper Options for Hydroelectric Development", 1979, and are also involved with ongoing field feasibility studies.

The Waitaki Catchment Commission and Regional Water Board produced the "Lower Waitaki Preliminary Resource Study" in 1978 and is at present updating this, while the Lands and Survey Department is undertaking a riparian land use study of the Lower Waitaki to explore the future of the immediate river bed lands, questions of tenancy, use, etc. The Botany Division of the D.S.I.R. has had a brief look at the river vegetation and Waitaki Valley Acclimatisation Society (W.V.A.S.), who manage the sports fisheries in the lower Waitaki, have also issued several reports describing the fisheries of the lower river and the possible effects of the power development scheme (e.g. W.V.A.S. 1976, 1978). Dr D. Scott and his team from Otago University and Dr P. Henriques (N.Z.E.) are also working on the Waitaki. They are using replicate channels and ponds built on the south bank near Duntroon in mid 1980 to study the effects of flow fluctuations on juvenile salmonids and other features of interest. The Fisheries Research Division of Ministry of Agriculture and Fisheries are undertaking applied research into fish stocks and fisheries of the entire region.

Unfortunately power planning investigations in the past have not been on a sufficiently long time basis to allow proper investigation of the fisheries aspects and in several cases inadequate studies of the fisheries concerned has meant that they have been damaged. As the lower Waitaki supports such an important salmon and trout fishery it is essential that means to protect the fishery be developed and adequately tested well before a decision is made to progress with any development scheme.

This need to study the effects of development and methods to protect the fish stocks and fisheries has however been realised for some time. The first discussions of such topics between the fisheries staff of the then Marine Department and staff of the N.Z.E.D. were held in the later half of the 1960's. In 1975 the Ministry of Agriculture and Fisheries established a laboratory at Oamaru and appointed two staff to commence the first detailed studies on the fish stocks and fisheries of the entire Waitaki system, and in 1979 the draft copy of this report was produced. The interest shown by N.Z.E. to assist F.R.D. with the finance of investigations was carried through to fruition in early 1980 with the approval of the funding of an expanded programme of research into the fish stocks, fisheries and effects of the proposed development of the lower Waitaki River. Subsequently, in July 1980, four consultant scientists were appointed to work on the lower Waitaki in conjunction with F.R.D. staff.

It is planned to expand this research programme to include additional personnel in order to undertake detailed studies with the aim of presenting a report on the impact of Lower Waitaki River Power Development by the middle 1980's.

However, the fisheries staff realise it may be impossible to obtain a complete picture in such a short time period. For example, the four year life cycle of salmon means that the study of various options investigations should ideally be started 8 to 12 years in advance of any power planning decisions. For this reason studies past the mid 1980's will prove very useful.

Three demonstration channels with flows which can be closely controlled will be used in the research programme. These channels will offer an opportunity to study the effects of various flows on the ecology of waters, such as the proposed residual river, and are the first of their type in the world. Approval for funding from N.Z.E. came in December 1980 and some preliminary design work has already been completed. The channels will be sited opposite Duntroon on the northern side of the river.

From the plans already published by M.W.D. (1978, 1979) it appears that hydro development of the Waitaki may come in one of three basic themes: a one channel chain of hydro reservoirs and dams, a two channel system of a power canal and a residual river subject to the excess flows, (especially at times of flood), or a three channel system with a power canal, floodway and residual river.

Fisheries Research Division, who act as advisor to the W.V.A.S. consultants to other government departments and work in close association with the consultants funded by N.Z.E., has several aims and objectives with respect to the development of the Lower Waitaki. One of our prime responsibilities is to ensure that the stocks of the various species of fish present are maintained as close as possible to their present levels of abundance. Others are to ensure that the current recreational fishery is not damaged and that the river's considerable potential for supporting increased recreational, as well as commercial, fisheries is not unnecessarily reduced.

The draft of this report was initially prepared by F.R.D. staff in response to requests by N.Z.E. for information as to the effects of power development on the fisheries of the lower Waitaki River and also in response to the latest discussion paper prepared by the M.W.D. (1979).

The aim of the report was to assist power planners in evolving a scheme which will have an acceptable impact on the fisheries resource and also to outline what fisheries and allied investigations should be undertaken. The report has been updated, following the same aims and structure as before. We outline the present fisheries, and fish stocks, the basic physical characteristic of the lower Waitaki River, and then discuss the possible implications of development along the lines of each of the three themes (one, two or three channels). We have pointed out some of the methods of maintaining the fishery and fish stocks, the recreational attributes of the present river and some of the disadvantages of the various schemes. We have also outlined a suggested programme of investigation.

4. THE LOWER WAITAKI RIVER

4.1 GENERAL FEATURES

The Lower Waitaki River has a catchment of approximately 240,000 ha, which generally lies east of the Waitaki Dam and is bounded by the Kakanui, St. Marys and Kirkliston Ranges and the Hunters Hills. The catchment upstream of the dam covers an additional 946,380 ha and has been considerably modified by hydroelectric development, including the construction of three river impoundments (Lakes Benmore, Aviemore and Waitaki) immediately upstream of the Lower Waitaki River.

The river is large (mean flow of approximately 350 cumecs) and is of a relatively steep slope, falling approximately 209 m eastwards from the base of the Waitaki Dam to the South Pacific Ocean, a distance of some 65 km. The river runs in a wide braided channel and the surrounding relief is predominantly terrace lands, fans and downlands. (See photographs on pp. 13, 36, Waitaki Catchment Commission and Regional Water Board (W.C.C.R.W.B.), 1978).

A summary of the relief, topography land use, geology and other general features may be found in "The Lower Waitaki Preliminary Resource Study", (W.C.C.R.W.B., 1978).

4.2 HYDROLOGY

The waters of the Lower Waitaki come from two sources, a number of relatively minor tributary streams and rivers in the lower catchment and from the Upper Waitaki catchment.

The Tributaries

The tributary streams generally contain small amounts of clear water and contribute in total only 17 cumecs to the mean flow of the lower river (M.W.D., 1979). The largest tributary is the Hakataramea River, with a mean annual flow of approximately 5.2 cumecs (M.W.D. data). Many of the other tributaries have estimated mean flows of less than 1 cumec (see Table 1) or have intermittent flows. The tributaries become more important contributors to the river in times of flood, e.g. the Hakataramea River has been estimated to have a 100 yr flood of 490 cumecs and the Maerewhenua River reached 700 cumecs in June 1980 (Table 1). Such flood waters carry high bed loads and suspended sediments and occur at times of heavy precipitation (winter, early spring). M.W.D. (1979) implied that floods from the tributaries may total 1500 cumecs, but that these may not coincide with high flows from the Upper Waitaki (see also p.42). Low flows in the tributaries occur over the summer period when precipitation is low, although such natural flow regimes may be altered by water abstraction.

Upper Waitaki Waters

Generally most of the lower Waitaki River flow has come from the Upper Waitaki, the long term mean flow past at the Waitaki Dam being 330 cumecs (M.W.D., 1979), that is, some nineteen times the total mean contribution from the lower catchment. However, the actual flows passing the dam fluctuate with N.Z.E. policy and electricity demands. Some indication of seasonal and daily fluctuations in water use for power generation are given in Fig. 24 W.C.C.R.W.B., 1978. As would be expected, flows are highest at times of peak electricity demand, e.g. winter, around 0800 hrs and 1800 hrs. Changes in flow that do occur are normally limited to 30 cumecs per hour, but this rate can be doubled (M.W.D. 1978). The turbines at Waitaki Dam can pass a maximum of 596 cumecs and a minimum of 130 cumecs (if 20 MW are to be generated,

TABLE 1 - RIVER FLOWS

Inflow of significant tributaries below Waitaki Dam
 Data taken from Lower Waitaki Interim Report April 1978
 Table 1 Section 4.1.5

Further information supplied by
 Ministry of Works and Development,
 Duntroon

Catchment	Size km ²	Estimated Mean ₃ flow m /s	Estimated 100 ₃ yr flood m /s	Flood Flow July ₃ 1978 m /s	Flood Flow 5 June ₃ 1980 m /s
*Little Awakino	20	0.02	30	-	-
*Awakino River	64	0.8	70	-	-
Kurow River	48	0.5	55	-	35.9
Malcolm's Creek	38	0.3	45	-	15.3
Otiake River	59	0.7	65	-	31.9
Waitoura/Doctors Creek	18	0.02	25	0.56	6.9
Otekaieke River	101	1.6	110	-	77.9
Waikaura Creek	21	0.02	30	2.26	15.3
Maerewhenua River	298	4.4	285	-	700.3
Awamoko Stream	125	2.2	120	7.4	88.2
Waikoura Creek	50	0.5	55	-	-
Hakataramea River	900	5.2	490	-	260
Racecourse Drain	26	0.03	35	-	-
Penticotico Stream	-	1.15	-	11.3	49.2
Waihuna Elephant Hill St	78	1.05	80	8.0	12.6
Ikawai Stormwater Channel	-	-	-	15.6	50.4
Grassy Hill Culvert	-	-	-	0.70	9.4
Waikakahi	-	-	-	-	10.9

* enter the lower Waitaki above the proposed diversion weir

M.W.D., 1978) but low flows from the Upper Waitaki do not generally drop below 170 cumecs (M.W.D., 1974).

At times of flood, excess water may be released over spillways. However when the national grid can not absorb the power being generated the turbines may not operate at full load and therefore extra water will be passed to the spillway flow (see M.W.D., 1978 for historical records of flows and discussion of Present Operating Arrangements).

Natural fluctuations in flow from the Upper Waitaki also occur. The highest seasonal flows occur in early November to February as the result of spring rainfall and the melting of snow and glacial ice. Lowest flows are in the autumn to winter when precipitation in the headwaters takes the form of ice and snow. Hydro development has reduced the magnitude of these flow fluctuations and introduced a degree of flood control. Floods are likely to be less severe and less frequent than in the past. M.W.D. (1979) estimated that floods from the Upper Waitaki may have peak flows of less than 2800 cumecs.

Water Characteristics

Upper Waitaki waters are generally clouded by glacial rock flour, Lake Waitaki recording a low mean annual secchi disk reading of 2.2 m (L. Whitehouse, pers. comm.). There are, however, seasonal variations in transparency with the water clearest in late summer and winter and least transparent in spring (around September).

Some chemical features of the waters in Lakes Benmore, Aviemore and Waitaki for the period November 1970 to March 1973 have been recorded and summarised by L. Whitehouse (pers. comm.). The waters are well oxygenated, close to neutral pH and are moderately rich in silica. The dominant anion is bicarbonate and it is likely that the waters have a low calcium content like other New Zealand waters, but that the sodium content is comparatively high. Most probably the Lower Waitaki River, at least initially, resembles the chemical and glacial silt load of the upstream impoundments.

Water temperatures at the Waitaki Dam ranged from a mean of 5.2°C in August to a mean of 16.8°C in February (N.Z.E. records at Waitaki Power Station) but this temperature regime will be modified in the various braids of the river.

Evidence suggests that the conductivity of the river water is likely to range from 5-7 millisiemens/m. (Stout, 1978; L. Whitehouse, pers. comm.) and measurements made show that dissolved oxygen levels are close to saturation and faecal coliform bacterial counts are low (Waitaki Valley Acclimatisation Society (W.V.A.S.), 1976). As with temperature, oxygen levels, and possibly other physical or chemical factors, may vary not only daily and seasonally, but also between sites, for example, between quiet pools and riffles, main channels and sites close to tributary outlets within the present river.

4.3 GEOMORPHOLOGY

Floodplain

The area which is subject to periodic flooding and erosion by the Lower Waitaki River covers approximately 12,000 ha (M.W.D., 1979). This area, apart from a short stretch immediately below the Waitaki Power Station, where there is little shingle near the water level and high rocky banks, can be divided into two characteristically different sections. From the Waitaki Power Station to Black Point (100 m above S.L.) a distance of 36 km, the river flows in a gravel riverbed of

approximately 0.8 km width. The river is most braided in the middle of this reach and is generally bounded by river terraces. The surrounding hillsides are steep and generally made of schist or greywacke. The gradient at Kurow is 4 m/km but the average gradient over the entire distance is 3.0 m/km. From Black Point to the South Pacific (29 km) the river widens to run in a river bed of between 0.8-1.6 km width. Again the river is bounded by gravel river terraces; the channels are very braided and interspersed with numerous islands. The boundary hills are gentle and lie well back from the river. The average gradient (3.5 m/km) is slightly greater than that of the upstream section but this is partly because in the immediate coastal region the river gradient increases as it becomes entrenched below the general level of the surrounding gravel fan.

Vegetation

An annotated list of the plants and an outline of the general vegetation patterns found in the Lower Waitaki River bed are presented in two unpublished reports by Williams (1976 a, b). Williams (1976 a, b) found in his brief study, made in late 1975, that gorse and broom occupy vast areas of stable riverbed and lower terraces upstream of the main highway bridge. Tree lupins occupy similar sites downstream. Gorse and broom seedlings are on almost all the young surfaces in the central river bed.

Where breaks in the above mentioned shrubs allow, and according to grazing pressure and water availability, various assemblages of ground plants may be present. These include sweet vernal, broome grass, stone crop, vulpa hair grass and scabweed. Where gorse and broom have been cleared by burning, the ground layer includes other plants (sheeps sorrel, catsear, possibly rushes and sedges in damp places, broom and gorse seedlings, to name a few).

Willow trees and shrubs grow extensively along the banks and are scattered over the riverbed. Where there is enough light, similar assemblages of ground species as mentioned above are found beneath the willows.

The herbaceous vegetation again varies with habitat type. The lower most dry terraces or stabilised islands have vegetation similar to that already described. In young and dry sites, depending upon the presence of stock or rabbits, there may be ox eye daisy, sheeps sorrel, firewood, *Raoulia tenuicaulis* and sweet clover as examples. In damper sites one may find cress, monkey musk, cudweeds and rushes, plus many other species; the community composition depending on the nature of the habitat.

Training Works

Following the reduction of rabbits in the early 1950's the Lower Waitaki Riverbed became choked with crack willows, broom, gorse and tree lupins. This resulted in a tendency for flood flows to break away from the main axes of the river and erode the surrounding landscape.

The W.C.C.R.W.B. initially and successfully cleared a 500 m fairway in the main river bed between 1954 and 1969 and followed this with spraying programmes in 1974/75, 1975/76. Clearways across the entire river width were cut at 500 m intervals to act as sites for gauging stations. These cuttings caused some breakaway flows into adjacent properties and are now reverting to broom, willow, gorse, etc.

Attempts since 1964 to train the river have proved inadequate, although the catchment commission believe that they have been able to keep pace with the damage inflicted by the river (W.C.C.R.W.B., 1977). The

training works carried out included scarifying and loosening up of gravel bars and islands to encourage river flow within the cleared fairway, cutting of temporary pilot channels and the protection of banks with willow trees, piled rail retards and shingle stopbanks. It was initially planned to block side channels with retards and stopbanks, however "permeable" banks were built across some channels but in instances they did not allow continual water penetration, thus streams important for fish spawning, food production and nursery water, have been destroyed.

The Ministry of Works Investigation Road built along the southern bank of the river, has also destroyed some side channels previously important to the fishery.

The present river control scheme (1977-82) is aiming to maintain the training works already constructed and continued clearance of willow, broom and gorse from a reduced fairway of 400 m width using aerial spraying of 'safe' herbicides. Other aims of the scheme and background information may be found in W.C.C.R.W.B. (1977, 1978).

Channels

As described above, the river is generally wide, braided and also continually changing (for example, continual washing out of the M.W.D. investigation road on the southern bank). There is very little data available on the geometry of the channels. W.C.C.R.W.B. (1977) found the average width of a channel (for those reaches of the river where the flow is in one channel) to be 120 m, the radius of curvature approximately 400 m and the length of meander 1200 m (taken from some unspecified aerial photographs). Measurements of the aerial photographs (surveys number 2847 and 5055, May 1975, February 1977 respectively) indicate that an average cross section contains about 12 channels with a total water width of about 280 m, individual channel widths ranging up to 150 m at low flows, with a mean width of approximately 24 m.

Information on channel depths is again lacking. (In the Rakaia River, a similar east coast, braided system, the ratio of maximum depth/channel width is approximately 1:40). In general the Waitaki is wide and shallow and channel depths do not usually exceed 3 or 4 metres, even during floods (see Option B page⁴⁶).

In places, water levels in the channels appear to lie almost flush with the shingle islands and banks (see Fig. 2) and on occasions water appears to be flowing at different levels in adjacent channels. However, banks are prevalent along many channels and islands, sometimes reaching over a metre in height.

The river is generally fast flowing with normally only a few calm backwaters and side channels. These calm areas may increase during and immediately after floods when banks are overtopped and tributary streams are backed up.

Channels are generally unstable, and their morphology likely to change with high flows. However, some channels, such as those on the north bank opposite Duntroon amongst the established willow trees, are fairly stable, their bottoms lying close to the bedrock.

In general the substrate is sorted by the river to a fairly uniform size, for example in many sites the range is 10-15 cm (see page⁶⁹).

Aquatic vegetation varies with the habitat. In standing water the most important plants are *Pomatogeton cheesemanii*, *Glyceria fluitans* and *Myriophyllum elatinoides*.

5. THE FISH STOCKS AND FISHERIES

5.1 INTRODUCTION

The lower Waitaki River and its tributary streams are populated by 20 of the 33 species of native fish and 5 of the 7 imported salmonid species and thus contains one of the most diverse fish faunas of any river system in New Zealand.

The excellent stocks of rainbow and brown trout and of quinnat salmon support a recreational fishery of national importance besides which the stocks of flounder, whitebait, mullet, eels and kahawai support smaller more local fisheries.

Published information on the fish stocks and fisheries is contained in Finlay (1931), Parrott (1971), Graynoth and Skrzynski (1973), Waitaki Valley Acclimatisation Society (1976 and 1978) and Dougherty (1979). There is also much information on file or in unpublished reports held by the Waitaki Valley Acclimatisation Society and F.R.D.

Detailed reports, based on recent studies, describing the fish stocks and fisheries are in the course of preparation by F.R.D. However, some studies have still to be completed and a firm publication date cannot be given. This, therefore, is a brief summary detailing some of the present results.

5.2 INTRODUCED FISH

Brown Trout (*Salmo trutta*)

Brown trout were first introduced into the Waitaki River system between 1870 and 1885 (Hobbs, 1948). They quickly became established and nowadays are found in large numbers throughout the lower river and in most areas of the larger tributary streams. The trout support an important fishery and in recent years this has stimulated research into the life history of brown trout in the lower river.

Spawning surveys, which have been conducted annually since 1975, have shown that brown trout spawn in May, June and July in gravel beds throughout the lower river system and in its main tributaries. However, certain localities are preferred, such as the stable side channels opposite Duntroon and in the Hakataramea, Awakino, and Maerewhenua Rivers, the Duntroon Stream and the Penticotico. The number of trout spawning each year in the entire system is difficult to estimate, but may range between 5-10,000. Recent studies (Table 2) of the hydraulic characteristics of these spawning grounds have determined that redds are normally dug in water about 31 cm deep (range 12-83 cm), flowing at about 0.55 m/sec (range 0.14-1.19 m/sec.).

Brown trout fry emerge from the redds from July to October and begin to feed upon the small larvae of midges, mayflies and caddisflies. They grow rapidly and may reach 100 mm in length by March. Thirteen localities have been regularly electric fished in recent years and it has been found that growth rates vary substantially between sites and between years, depending upon the local environment.

As the juvenile trout grow, they often move downstream and some fish probably enter the sea because large 'sea-run' brown trout are often caught by anglers at the river mouth. As the fish grow their diet changes to larger items such as snails, sandy cased caddis larvae and small fish such as bullies and smelt. They normally reach maturity at 3 years of age when they are about 40 cm in length.

Unlike salmon, trout spawn more than once, with brown trout continuing to grow to a maximum age and length of about 8 years and 85 cm

respectively. Adult trout are found throughout the lower river system wherever there is sufficient water depth and cover. The number present is not known; however, brown trout are more abundant than rainbow trout.

Angling surveys undertaken in 1957, 1962, 1965, 1967 and from 1973 onwards have shown that brown trout are caught throughout the lower river system during the angling season from October to April. In 1965 it was estimated that about 6,600 brown trout were killed in about 9,600 angling visits. Nowadays about 10,000 fish are caught. In 1965 most of the fish were caught using spinning techniques (45%) followed by artificial flies (27%), worms (15%) and smelt (12%) as bait. Most of the trout killed range in length from 35 to 50 cm and mean lengths range from 43 to 47 cm in different years. A few specimen trout exceeding 75 cm and 4.5 kg are caught each year. Compared with other rivers in the South Island the trout caught are rather larger than on average (Allen and Cunningham, 1957, p. 44). The average size has remained virtually unchanged since records began in 1957. Anglers catch rates are fairly good ranging from 0.20 to 0.44 fish per hour depending upon the anglers skill and there is again no evidence of any historical trends to suggest changes in trout abundance.

The stocks were managed in the past by the annual release of hatchery reared fish. This practice was found to be expensive and unnecessary and was discontinued in 1968. Managers nowadays try to protect the natural stocks against the adverse effects of water abstraction, river control schemes and power generation flow fluctuations.

Rainbow Trout (*Salmo gairdnerii*)

Rainbow trout were introduced in the Waitaki River in the early 1900's, some years later than brown trout. Like brown trout they rapidly became established and are now found throughout the lower Waitaki River and in the larger tributary streams.

They spawn in similar gravels to those used by brown trout at water depths averaging 31 cm (range 12-68 cm) in velocities averaging 0.51 m/sec (range 0.19-0.97 m/sec). Spawning takes place in stable side stream areas and in the main tributaries, the Hakataramea, Awakino and Maerewhenua Rivers. Compared with brown trout the main difference is that they are basically spring spawners, spawning from late July through to early October. The numbers spawning each year vary, but runs of 200 fish in the Maerewhenua and 1000+ in the Hakataramea are common, while total numbers spawning can be in excess of 2,000. Studies on the juvenile fish, their growth rates, diet and distribution have been undertaken recently; the results of which will be published later.

Rainbow trout in the Waitaki are numerous right down to the sea; adult fish being found in fast water and the larger pools of the main river. Although no direct evidence of sea migration has been found, rainbow trout are now appearing in the Kakanui, 34 km south of the Waitaki. There are no recorded liberations of this species in the Kakanui system and they may have migrated from the Waitaki, which is the nearest river containing them.

Although rainbow trout in general do not grow to quite the size of brown trout, (they reach a maximum size in the Waitaki of about 65 cm or 3 kg) they compensate the angler by being vigorous fighters.

Angling for rainbow trout is carried out throughout the river and along with brown trout angling is most popular early in the fishing season from October to late December before the quinnat salmon start to run.

At least 75% of the rainbow catch of 3,000-5,000 fish is taken by bait fishermen, the remainder of the catch being divided equally between spinner and fly methods.

Minor changes have occurred in the size of rainbow trout caught by anglers, but no long term trends are evident. For example, fish averaged 40 cm in 1965, 42 cm in 1972, 38 cm in 1975 and 50 cm in 1977.

Rainbow trout are nowadays managed in a similar fashion to brown trout, the last major liberation of hatchery reared fish being in 1974.

Quinnat Salmon (*Oncorhynchus tshawytscha*)

Quinnat salmon were initially established in the Waitaki River by liberations from the Government hatchery on the Hakataramea over the period 1901-1907. The stocks in the Waitaki built up rapidly, fish migrating up to headwaters of the Waitaki and spawning in rivers such as the Dobson, which flows into Lake Ohau. In 1935 the Waitaki Dam was constructed. The fish pass built into the dam was incorrectly designed (see Fig. 1) and failed to work properly. Hence the salmon runs dropped from possibly 100,000 to 10,000-20,000 adult fish.

The adult salmon, ranging in length from 40 - 112 cm and in weight from 1.4 to 21.8 kg enter the river from January to April and slowly swim upstream to their spawning grounds. Surveys have been carried out on the Hakataramea River from 1962 and on the main river from 1976 onwards to monitor the numbers of salmon spawning. No long term trends are apparent, the numbers varying considerably from year to year. Most of the salmon spawn April to July in the side streams of the main river and in the larger tributaries (> 1-2 cumecs) such as the Hakataramea. Salmon spawn in water on average 33 cm deep (range 14-58 cm) and in faster flowing water (mean = .64 m/sec, range 0.16 to 1.50 m/sec) and in coarser gravel than trout (Table 2). Although they can bury their eggs up to 30-40 cm deep in the gravels, their eggs can still be washed away by floods. For example, on May 23 1979, because of an industrial dispute, an increase in flow of 512 cumecs was recorded which caused great damage to spawning grounds.

TABLE 2 - Some Observed Redd Characteristics of Salmonids in the present Lower Waitaki River (unpublished data from S.J. Wing).

<u>Species</u>	<u>Water Depth (m)</u>		<u>Water Velocity (m/s)</u>	
	<u>AVE</u>	<u>RANGE</u>	<u>AVE</u>	<u>RANGE</u>
Brown Trout	0.31	0.12-0.83	0.55	0.14-1.19
Rainbow Trout	0.31	0.12-0.68	0.51	0.19-0.97
Quinnat Salmon	0.33	0.14-0.58	0.64	0.16-1.50

The young salmon emerge from the redds from late July until early September and live and grow in backwaters and side braids of the main river and in tributary streams, until they are large enough to migrate to sea. Some fish migrate or are washed out to sea as fry and perish. The principal out-migration normally occurs from November to January when the smolts range from about 5 - 10 cm in length. Recent studies on juvenile biology, salinity tolerances of young salmon, and on their environmental requirements will be published later. In 1978 and 1979 several thousand young salmon were marked with a coded wire

FIG. 1. Inoperative fish pass at Waitaki Dam, built in 1935. The failure of this pass reduced the runs of adult quinnat salmon up the river from perhaps 100,000 to below 20,000 today.



tag inserted into the cartilage of their forehead as part of a study into the survival of these young fish. Because of the time delay before the adult salmon return the results of this study will not become available until 1983.

Anglers fish for salmon (generally using the specialised equipment of large spinning rods and reels and spoon baits) principally in the lower reaches of the main river (Fig. 2) from January to early April. The fishery has been intensively studied in recent years and there is a wealth of information on catch rates, angler origins, etc., which is both published (Waitaki Valley Acclimatisation Society, 1978) and on file in F.R.D. The salmon fishery is one of the best in the country (Fig. 3) and it is estimated that about 30% of the New Zealand catch comes from this river (Graynoth, 1972). As several of the other major fisheries, such as those on the Rakaia and Rangitata Rivers, are threatened by water abstraction or irrigation schemes, the percentage of the total catch and relative importance of the Waitaki River may grow in the future. The Waitaki catch of salmon varies from about 1,000 to 3,000 per annum.



FIG. 2. The lower reaches of the Waitaki River. This area is the habitat of many fishes including several native species and is also the main salmon angling area and a popular trout angling site. In the salmon season, when a good run is on, there may be over 300 anglers fishing in the lower reaches while a good whitebait run may bring up to 100 whitebaiters. Fishing for other native species is also done here.



FIG. 3. A fine quinnat salmon caught in the Lower Waitaki River by S.J. Wing. Waitaki quinnat range from 40 to 112 cm in length and 1.4 to 21.8 kg in weight, with an average of 8 kg.

Although this may seem low, it is not insignificant because the fish are large (average 8 kg) and like all salmon, difficult to catch (10 to 50 angling hours per fish). The best guide to the importance of the fishery is perhaps the effort anglers expend to catch these fish. In 1975-76 it was estimated that anglers spent about 31,500 man hours actively fishing for salmon.

On a weekday during the salmon season from 90 to 180 anglers normally fish the lower river whilst on weekends the number could occasionally exceed 300. Without doubt the salmon fishery is of major importance and must be carefully managed and protected. An economic assessment of its angling value has been prepared (Graynoth, 1972).

Attempts to commercially 'ranch' sea run salmon have been undertaken since 1976 by a Watties/ICI consortium at a site near the Morven/Glenavy irrigation race intake. Results to date have been inconclusive. Proposals to establish a salmon ranching hatchery on the Hakataramea River have been received and others can be expected in the future. If these developments are successful the value of the river for salmon angling will be much increased and the commercial returns could be substantial.

Sockeye Salmon (*Oncorhynchus nerka*)

Sockeye salmon are abundant in Lake Ohau and the Waitaki hydro lakes. Occasionally fish migrate, or are swept downstream, past the Waitaki dam into the lower river. In March 1977 a small run of fish, probably less than 100, ascended the Hakataramea River to spawn. The fish ranged from 32 to 36 cm in length and had lived all their life in freshwater. In recent years there have been no reported sightings or captures of sea run (anadromous) sockeye salmon and at the moment it seems unlikely that a sea run stock could be developed in this river.

Brook Char (*Salvelinus fontinalis*)

In recent years populations of small resident brook char have been discovered in tiny upstream tributaries of the Hakataramea River. These fish are probably descendants of escapees from the old Hakataramea hatchery. The stocks will not be affected by power development.

5.3 NATIVE FISH

Two species of eels are found in the Lower Waitaki system. Light to moderate stocks of the longfinned eel *Anguilla dieffenbachii* are found in slow flowing areas of the main stream and tributaries, under cover and in muddy areas. They feed on both insects and other fish. The juvenile glass eels enter the river from the sea from August to December and gradually disperse around the system. Adults migrate seaward to spawn from March to April, probably in deep areas of the Pacific and die after spawning. At migration adult males average 22 years of age, females 33 years. Males average 65 cm in length, females 120 cm.

The other eel species is the shortfinned eel *A. australis* which is of similar habits to the longfinned, but does not grow to such a large size and is not usually found as far up the tributary streams. Migration times are similar, but the ages less, males migrating after 13 years of age, females after 19 years; males average 48 cm in length, females 64 cm.

Eels are fished commercially in the Hydro lakes and in Lake Ohau. It is believed that immigrant juvenile eels cannot surmount the spillway at Lake Benmore. Therefore, unless stocks are maintained by artificial

means, then the eels in the upper lakes will slowly die out. In the lower river several tonnes of eels are caught per annum by commercial and recreational fishermen.

The lamprey *Geotria australis*, another eel-like fish, is common in many areas of the river. The young, ammocoetes, are found buried in sandy or muddy areas of the main river and tributaries where they remain for several years, feeding on micro-organisms. They migrate to the sea at about 110 mm in length, become parasitic on fish and then, after about 2 years, return to spawn in late winter-early spring. They travel some distance upstream and into the tributaries and spawn in a sandy or muddy area, dying soon afterwards. The adults range in size from 45 cm to 60 cm. Because they travel at night or during a flood they are seldom seen but are present in moderate numbers. Although formally valued by the Maoris as a food, they are seldom caught in this river.

There are five species of bullies in the Waitaki. The redfinned bully *Gobiomorphus huttoni* is found in the main river and tributaries in moderate numbers. The giant bully *G. gobioides* is found in small numbers in the lagoon and tidal areas. The bluegilled bully *G. hubbsi* is found up to 10 km upstream in moderate numbers. The common bully *G. cotidianus* is very numerous in most areas of the main river and tributaries and important as trout food. The upland bully *G. breviceps* is also numerous and found in most areas. It is important as a food for larger fish.

All bully species spawn in freshwater and all except the upland bully, whose young live in the rivers and tributaries, have juveniles which migrate to sea during the spring and summer and return as adults the following summer. Therefore, up and down stream access is essential. All species feed on small invertebrates and all are themselves useful as food for larger species.

In this river four species of galaxias make up the whitebait catch. The main species, the inanga *Galaxias maculatus* lives in the lower river and tidal areas. It spawns from February to April in the tidal zone on grasses and rushes during a high spring tide. The eggs hatch when immersed by the next spring tide. The larvae are washed out to sea returning from August to December, six months later, as whitebait. The banded kokopu *G. fasciatus* is also present in the whitebait catch. Adults live in some of the smaller tributary streams in pools where suitable cover is available. They spawn in these areas from autumn to early winter. The koaro *G. brevipinnis* is another whitebait species, the adults living high up in the upland streams in fast water (Upper Maerewhenua and Hakataramea). It also spawns from autumn to early winter in the adult habitat. Juveniles of this species are capable of climbing obstructions such as waterfalls, dams and spillways, and a large lake population exists in the hydro lakes further upstream. A rarer species is the giant kokopu or native trout *G. argenteus*. Adults are found in the tidal backwater areas where there is heavy cover.

The whitebait run in this river is fished for on an amateur basis only, with most fishing being done within 1 km of the mouth using small hand held gauze nets. During "runs", up to 100 fishermen may be present. The average catch is 500 gm, although catches of up to 20 kg per person have occurred. As these fish do not home, this river could contribute to, or benefit from, other rivers in the vicinity. Fish of the whitebait species are also important as food for the larger species of fish and many of the sea birds such as terns and gulls.

Another galaxias species present is the common river Galaxias, *G. vulgaris* which is found in the main river and most tributaries in moderate to high numbers. It spawns in the adult habitat from late winter to spring and shoals of juveniles can be seen through the summer in backwaters and shallows. It does not migrate to sea.

The Canterbury mudfish *Neochanna burrowsius* is found in swampy areas and small streams on the plains to the north and south of the Lower Waitaki. It spawns in these areas and is known to aestivate in drought times. It could be endangered by drainage and irrigation development.

The torrent fish *Cheirmarrichthys fosteri* is found in moderate numbers in fast water in the main river and larger tributaries. Adults spawn in the river, the eggs or young fish are washed out to sea and return at about 25 mm in length.

The black flounder *Rhombosolea retiaria* is also a common species found in backwaters and quiet areas from the sea to at least 36 km upstream. It may spawn in the river or may migrate to the sea to spawn. It feeds on small insects and the occasional fish. This species is a popular food fish, caught by net and spear mainly in the tidal area. The estimated catch over September and April is 5,000+.

In the tidal area the common smelt *Retropinna retropinna* provides a food source for both larger fish and sea birds. Adult fish migrate in from the sea to spawn from August to December and are present, often in large shoals, in the lower river up until autumn. The adults spawn at 2 years of age, they lay their eggs in the lower river and the larvae are washed out to sea after they hatch.

Recently Stokell's smelt, *Stokellia anisodon*, has been caught in the Waitaki River, near to the mouth. Adults of this species are thought to migrate into river mouths in spring and summer, migrate upriver to spawn in freshwater and then probably die. The hatched larvae are washed out to sea where they mature, probably in about two years, before migrating back to freshwater (McDowall, 1978).

Yellow-eyed mullet *Aldrichetta fosteri* are also common in the tidal area. Large shoals of adults and juveniles are common from September to April. They are caught by rod, line, and in nets for food and as bait for sea fish.

A normally marine species, the Kahawai *Arripis trutta* shoals in large numbers in the sea around the river mouth, feeding on smaller fish, from October to April. It is readily caught by anglers using spinning gear for both food and sport. Adults range in size from 50 to 55 cm. Kahawai stomach contents show that some salmon smolts are eaten at times.

Conclusions

It can be seen that the native fish of this river range from those of purely scientific interest, to fish of commercial and food and sporting value. Many of the species, especially those important as food for larger fish, require free access to and from the sea for both adult and juveniles. Most could be easily blocked by man-made obstructions. The tidal area of the lower river is particularly critical and provides spawning and living areas for a number of species. It is essential that this area remains basically unmodified.

6. THE VARIOUS POWER DEVELOPMENT OPTIONS

The M.W.D. have described six development options in their 1979 report. In the options shown in their Figs. 2 and 6, a power canal, similar in character to those found in the Upper Waitaki Power Development Scheme, with a series of low head power stations along it, is situated on the north bank of the river. Running parallel to it is a 400 m wide floodway and a residual river channel. Some of the riverbed is marked to be reclaimed for agriculture or forestry. Options shown in their Figs. 1 and 5 are similar except that the power canal is on the south bank. In option 3 the residual river flow is contained within the floodway and in option 4 the power canal is enlarged to accommodate floods and the residual river is disposed of.

After a detailed examination of the options described we are of the opinion that none is really desirable from a fisheries viewpoint. We believe that the best scheme would be to modify the option shown in their Fig. 5. This is a three channel option and in brief, would involve placing the power canal on the extreme south bank followed northwards by the floodway and then by an extensive residual channel/wildlife area covering the remainder of the flood plain. This option (A) is shown in Fig. 4 enclosed.

We have also examined in some detail option 3, where there is a combined floodway/residual river (see Fig. 3, M.W.D., 1979) and a slightly modified version of their option 4. In their option 4 the power canal has only been marginally enlarged in size. Here we have considered a canal that has been substantially widened to form a series of small hydroelectric reservoirs. These could be similar in appearance to several hydro lakes (Waitaki, Ruataniwha, Roxburgh) or to wide deep rivers such as the lower Clutha. This option (C) is shown in Fig. 5 enclosed.

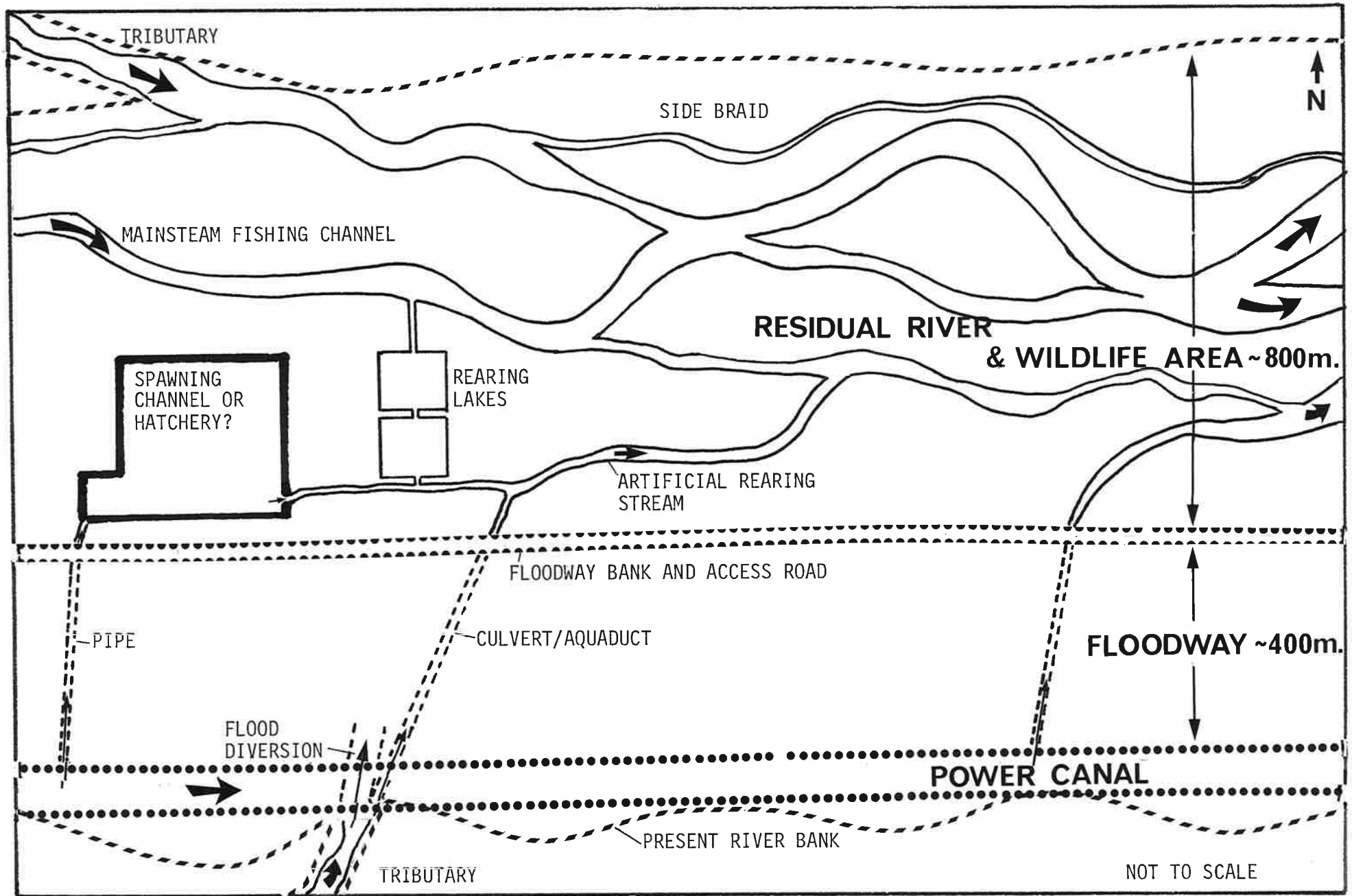


FIGURE 4. Possible Design for Option A. A Three Channel Option.

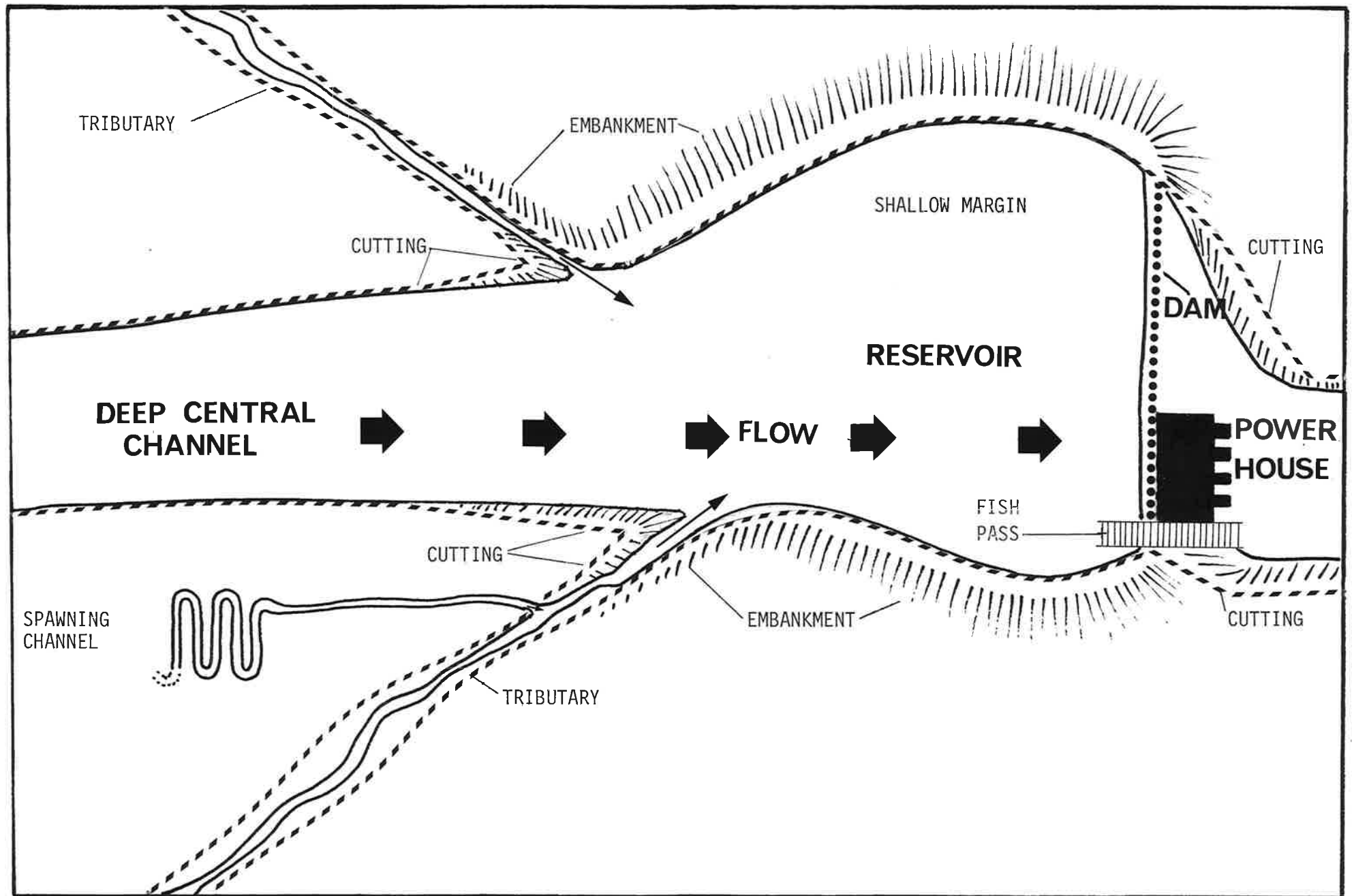


FIGURE 5. Possible Design for Option C. A Chain of Hydro-electric Reservoirs

7. THE THREE CHANNEL OPTION (A) - A POWER CANAL, FLOODWAY AND RESIDUAL RIVER

7.1 THE POWER CANAL

Location

In Fig. 4 the power canal has been sited on the south bank, followed northwards by the floodway and then the residual river. This arrangement was chosen as the south bank is the most suitable side for the construction of a power canal (M.W.D., 1978) and it simplifies the diversion of the flood waters from the Hakataramea River to the floodway. This scheme also preserves the stable willow lined channels opposite Duntroon, which are important for fish spawning and angling.

However, provided features important to fisheries interests are not seriously affected, such as fish passage between the residual river and tributaries, the final configuration of the channels is not considered to be very important.

The canal will extend from an intake structure upstream of Kurow to 4 km above the mouth of the Waitaki River. The water directed into the canal will be from both the upper catchment and tributaries upstream of the intake.

Fisheries Structures

Fish Passes

Fish ways could be constructed to allow fish migration up the canal from the lower river. But, the demand for a fishery in the canal may not be very great because of the supposedly reduced angling quality of such waters. (This aspect is discussed later).

If fish are unable to gain access to the power canal, fish migrating upstream from the sea will become trapped below the lowest tailrace. We recommend that fishways be constructed to transport these fish from the tailrace to the residual river. The fish guidance facility needed could be similar to the powerhouse collection system of fishways built at the Bonneville Dam on the lower Columbia River, U.S.A.

Fish Screens

We do not recommend that fish screens should be constructed on the uppermost intake. These will be virtually impossible to operate and clean because the volume of water is so great.

Water Abstraction

Facilities will need to be constructed to release flushing flows from the intake structure and power canal down the residual river. Floods from tributary streams are probably unsuitable as they may occur too infrequently and contain high silt and bed loads.

Water for irrigation should be supplied from the power canal and not from the residual river. Experiences at the Bells Pond irrigation intake on the lower Waitaki, and elsewhere, have shown there are often conflicts between the water needs of irrigators and fisheries interest. If water was removed from the residual river expensive fish screens, similar to those constructed on the Wairehu Canal in the Tongariro Power Scheme, will be needed.

Physical Features

The power canal will probably have a capacity of 525 cumecs (M.W.D., 1978) with a top water width of 80 m, depths of up to 11.5 m and

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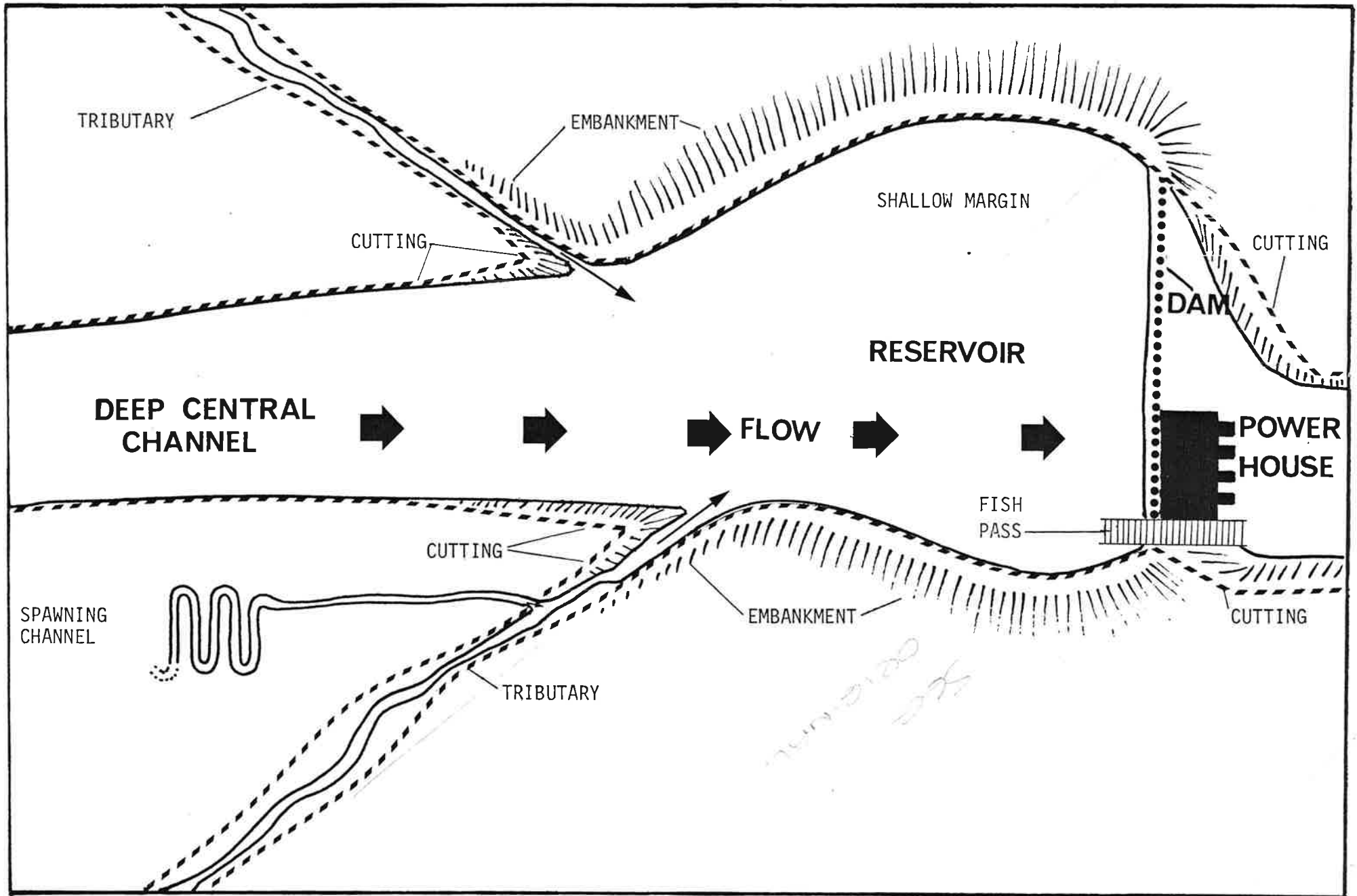


FIGURE 5. Possible Design for Option C. A Chain of Hydro-electric Reservoirs



FIG. 6. Tekapo-Pukaki Power Canal from below Tekapo A. This canal has an average top width of 39.6 m, an average depth of 5.3 m, a capacity of 120 cumecs, a water velocity of 1.06 m/s and a slope on the sides of 3:1. The proposed lower Waitaki Canal will have a top width of approximately twice this canal, depths up to 11.5 m, a capacity of about four times this canal (525 cumecs), but a similar water speed and slope on the sides.

contain water flowing at a peak velocity of 1 metre per second (M.W.D., 1979). The sides of the canal will have a 3:1 slope and will be lined with gravel. Small boulders may be placed in the littoral area to prevent wave erosion (Fig. 6).

As the canal will be designed and constructed for maximum hydraulic efficiency, water velocities will be very constant and there will be few still areas or backwaters where fish can shelter and rest from the mainstream current.

The water clarity and characteristics will probably be, at least initially, as described in section 4.2 for the Waitaki River.

Biological features

Prediction of the biological features of the proposed Lower Waitaki canals is difficult because of the lack of studies on such artificial canals. Hence, it will be useful to undertake some studies on the physically similar power canals in the Upper Waitaki Power Development Scheme. The most benefit will probably come from a study of the canal draining Lake Ohau as it is less turbid than the other canals, therefore it will more accurately simulate the expected situation in the proposed Lower Waitaki canal.

The following statements are, of necessity, based on cursory observations of the existing Waitaki canals and on a knowledge of the habitat requirements of fish and other aquatic life.

Aquatic Plants and Plankton

Aquatic plants are found through the hydro lakes, in stable braids of the lower Waitaki and in the Aviemore Spawning Race. If there is suitable substrate for anchorage, it could be possible that some beds of plants such as *Myrophyllum* sp., *Potamogeton* sp. and *Elodea canadensis* could develop along the margins of the power canal and possibly to depths of 5 m or more (see Brown, 1975).

Additional aquatic plants will include green filamentous and other algae attached to rocks along the canal margins, together with phytoplankton originating from the upper hydro lakes. Phytoplankton and zooplankton densities will probably be initially similar to those in Lake Waitaki. L. Whitehouse (pers. comm.) found the total dry biomass of zooplankton lost each week from Lake Waitaki ranges between 150 kg in July to 13,000 kg in January. The components of the zooplankton included rotifers such as *Keritella cochlearis* and crustacea such as *Boeckella dilatata*. However, in Lake Waitaki the development of both zooplankton and phytoplankton is likely to be seriously inhibited by the high rate of water renewal (calculated mean retention time, 1972-1975 of 1.5 days) (L. Whitehouse, pers. comm.). Therefore, it seems likely that zooplankton and phytoplankton development will also be inhibited in the power canal and what plankton there is present will be mainly from production in the upper hydro lakes.

Invertebrates

The structure and abundance of the invertebrate communities formed in the canals will depend upon many controlling factors. These include the type and stability of the habitats formed, temperature regimes, the supply of food, and the natural seasonal variations in abundance of the community. Weed beds (if present) and shallow marginal areas could support a fairly rich and abundant fauna, especially when the water is clear and glacial silt levels are low. The invertebrates likely to be present will include mayfly and stonefly nymphs, caddisfly, dragonfly, beetle and chironomid larvae together with snails, flatworms and other forms.

The deeper parts of the canal could be populated by annelid worms, chironomid larvae, sandy cased caddis larvae and snails.

Fish Stocks

The abundance and species of fish present in the canal system will depend to some extent upon whether fish passes and/or fish screens are constructed at the power stations. If present, fish passes will allow fish, including quinnat salmon, to enter the canal from the lower river. On the other hand, fish screens by diverting fish from entering the upper end of the canal, would severely reduce fish recruitment into the canal but perhaps decrease fish turbine mortalities at the dams.

If the power canal is not deliberately stocked with fish and if fishways and fish screens are not constructed, as suggested in this report, then the power canal would become populated with fish migrating downstream from Lake Waitaki. Initially many of the migrants will survive, as turbines of modern design generally have a fish passage efficiency of 85% or more (Bell, 1973). These fish could include upland and common bullies, the koaro and common river galaxias, eels, brown and rainbow trout and landlocked sockeye salmon. The numbers drifting downstream could be quite significant, as evidenced by the impingement of fish cooling water screens at the Waitaki Dam Power Station. However, of all these fish species, the upland bully is believed to be the only species which can successfully reproduce in the power canal.

Development of fisheries in the Power Canal

Some angling is undertaken in the upper Waitaki Power Canals, especially where landlocked quinnat salmon and trout congregate, such as below the diversion gates at the head of the Ohau canal and above the Ohau 'A' power station intakes. Presumably angling would be undertaken in similar locations along a lower Waitaki Power Canal.

Angling does not seem to be popular along uniform reaches of the Upper Waitaki power canals (Fig. 6). This could be because of a generally poor fishing environment, that is, lack of diversity in water types/habitats, uninteresting surrounds, in some canals poor water quality because of high silt loads or at the least low fish stocks and the fish difficult to locate.

The popularity of fishing in the power canal will depend to some extent on the size and abundance of the fish present. If quinnat salmon are to be present they will require fishways to be constructed so that adults can migrate in from the sea. Trout numbers are unknown but it is of interest to note that some diving and netting studies carried out in the unscreened Rangitata and Wilberforce Diversion Races indicated that these channels contain very few resident fish.

Angling could be difficult because the steep 3:1 slope of the power canal banks may be dangerous and also make it hard to use fly fishing techniques and to land fish; while deep trolling from boats will probably be prohibited for safety reasons. However, angling may be encouraged and made easier by the construction of piers and other facilities such as provision of aerial or aquatic cover to attract fish and the creation of backwaters.

Even if the fishing in the canal was good, we suspect many anglers will not fish the canal because of its unattractive, barren and artificial nature and also because of the difficulty of employing certain angling methods. We are of the opinion that, to many anglers, the quality of the fishery and the fishing environment will in no way compensate for or equal that found in the present Waitaki River.

Conclusion

In conclusion, we consider that the canal, in comparison to the original Waitaki River, will result in a substantial decline in the abundance and diversity of fish species present. Although more research is needed, it also seems unlikely that a high quality fishery could be developed in the power canal. Therefore, to compensate for the loss of the Waitaki River, some form of compensation flow or a residual river will be required. Nevertheless, reasonable attempts should be made to develop fish stocks and fisheries in the canal as this could reduce the pressure on the residual river and possibly permit smaller amounts of water to be left therein.

7.2 FLOODWAY

The floodway will have to accommodate maximum floods in the region of 2,800 cumecs originating from the upper Waitaki and 1,500 cumecs from the lower tributaries (M.W.D., 1979). It is considered that floods of this size can be carried in a floodway approximately 400 m in width boarded by low embankments (M.W.D., 1978 and 1979). The floodway will be free of obstructions and possibly grassed.

In order to maintain a natural environment we consider that the floodway should be constructed between the power canal and the residual river/wildlife area. It should extend from the canal intake structure to the lowest power station and should be designed to accept floods from

the Upper Waitaki and from the lower tributary streams. Some method, possibly aqueduct(s) and culvert(s), will be necessary to pass water from the south bank tributaries under normal conditions into the residual river and at times of flood into the floodway.

Water from the Hakataramea and Upper Waitaki could be combined in a single channel and flow a short distance downstream from the first diversion structure to a ponding area and second control structure. During normal flows water not diverted down the power canal at the upstream intake will pass directly down the residual river and during floods or at times of low power demand the excess water could be diverted into the head of the floodway at the second control structure.

Fish will be swept, or swim upstream, into the floodway during floods and become stranded when the water recedes. The effects of this on the rivers' fish stocks is unknown. If studies showed it to be significant, it would be desirable to investigate means of mitigating such losses. Fish salvage programmes or a small residual flow in the floodway after a flood may be a solution.

At the downstream end of the floodway fish trapped below the lowest tailrace adjacent to the southern bank will ideally be passed to the residual river adjacent to the northern bank. To achieve this, the floodway could be terminated above the final power house and the residual channels be directed across the riverbed below the floodway by stopbanks and other structures; thus the residual river will then flow adjacent to the stopbank by the tailrace below the last powerhouse. The stopbank should prevent water from the residual river entering the ponding area below the tailrace of the powerhouse, which will be up to 7 m below the riverbed level. Fish trapped below the tailrace could then enter the residual river by means of a fishway over the stopbank. However, problems may arise at times of flood with the diversion structures at the end of the floodway. These may require continual maintenance.

7.3 THE RESIDUAL RIVER

Main functions of the residual river

From a fisheries viewpoint the main functions of the residual river are as follows. First and most importantly the river is to act as a spawning and rearing area for salmon and trout and a habitat for resident trout. Secondly it is to support salmon and trout angling. Thirdly, it should retain the current river's potential for use in the future by, for example, a salmon ranching industry. Finally its function is to maintain current aquatic communities, native fish stocks and fisheries.

The relative importance of these various functions should be discussed and decided upon because sometimes their demands will conflict. For example, the control of river flows, to enhance salmon and trout production, could seriously affect the stocks of some native fish such as the torrent fish.

In addition to fisheries uses, the residual river will also be used by recreationalists other than anglers, for example, jet boaters, and provide a habitat for wildlife.

The basic design

Evidence, collected during our recent field studies and from the scientific literature, indicates that fish are scarce in the very large main channels of the lower Waitaki and that the fish stocks can be decimated by major floods and violent fluctuations in flow. If

the residual river is designed so that flows are controlled and the best use is made of the available water, by for example, diverting water from the main channels to smaller more productive side channels, then it should be possible to maintain the current and potential fish stocks and fisheries while releasing large quantities of water for hydroelectric generation.

We consider the best plan would be to have one or two large main channels which would be used for angling, bounded by a series of small side braids and backwaters, which would be used as salmon and trout spawning and juvenile rearing areas. The river would commence at a ponding area and control structure below the Hakataramea and terminate upstream of the State Highway 1 road bridge. The river would steadily increase in size downstream; possibly receiving water from the power canal as well as from both north and south bank tributaries. Water from the power canal could be used feed the required fishery facilities such as spawning channels, (thus eliminating the need to pump water from the ground, residual river or tributaries). Flood diversion structures would be constructed at the mouths of the tributaries to pass floods and their sediment and debris loads to the floodway. Flows down the river would be monitored and controlled to meet fisheries requirements. The total average discharge required could range up to 100 cumecs, depending upon the success of this design. However, it may be impossible to determine the precise amount of residual water required over the long term because future trends in recreational and other fisheries demands upon this resource cannot be predicted. For example, if salmon ranching successfully develops, a high demand could eventuate for Waitaki water.

For this reason, a procedure should be established whereby the allocation of water from the Waitaki to the various users would be reviewed on a regular basis - say every 5 years.

The residual river/wildlife area and its vegetation will have to be managed to optimum fish and wildlife uses. For example, infestations of willows, gorse and other plants may have to be periodically removed to allow anglers access and to prevent streams from either becoming too heavily shaded and unproductive or unfishable.

Width of the Residual River Floodbed

The floodbed and width of land around the residual river must be as wide as possible in order to make the most economic and productive use of the water in the residual river. There are several reasons for this.

Firstly, fish production and the production of their invertebrate food organisms are generally directly related to the area of submerged stream bed. A narrow confined and channelised river will be far less productive, as much of it will contain water velocities and depths far in excess of optimal levels, hence water will be wasted. Therefore, to avoid such wastage, the mainstem river channel(s), the sidebraids and tributaries should follow a long sinuous or braided course using the whole width of the residual channel flood bed.

Secondly, it is also important to production that an optimal pool/riffle sequence be maintained down the various channels and this again requires some degree of lateral movement.

Thirdly, space will be required parallel to the mainstem channel to accommodate side braids, tributary streams, riparian strips of vegetation and artificial salmon and trout spawning and rearing areas. These could be small streams, small lakes, spawning channels or even a hatchery.

Finally, we consider it important that the rivers present potential for increased recreational use should be maintained. Space is required for future camp sites, access road, hiking tracks, boat launching ramp, picnic areas, etc.

Studies will be needed to determine the precise width of floodbed required for the residual river and the wildlife area. At the moment it seems quite probable that the full width of the existing river will be required to accommodate the canal, floodway, and residual river (as in Fig. 4).

Waitaki River Below the Residual River

The residual river, power canal and floodway will all terminate near the state highway bridge, about 4 km up from the river mouth. As described above, the power canal outlet of about 300 cumecs will flow on the southern side of the riverbed, the residual river flow of for example, 50 cumecs, will possibly cross the riverbed below the floodway to flow initially adjacent to the power canal outflow. Consequently there would be little or no flow down the northern side of the old riverbed. At present the lower reaches of the river (Fig. 2) are extremely valuable as a habitat for both native and exotic fish and support several fisheries. Therefore, it is important that the reaches of river below the power scheme remain relatively untouched. To achieve this, some control works and possibly some study of the situation will be needed.

The mainstem fishing channel(s)

The principal function of the mainstem fishing channel is to support salmon and trout angling. Other functions include providing a migration route for fish such as salmon, eels and koaro; and also as a habitat for native fish and large trout. A limited amount of salmon and trout spawning and rearing of juvenile salmonids will also take place.

Interests outside those of fisheries will need to share the mainstem water. These other concerns must be also taken into account in the design of the main channels.

Salmon angling

Salmon angling in the Waitaki River, although carried out in a variety of water types, is largely concentrated in the deep main channels and in deep holding pools, the "salmon holes". Because of the turbidity of the water, anglers fish 'blind' hence the hooking and capture of a salmon is an unpredictable and somewhat rare event and this is part of the attraction of Waitaki River salmon angling.

At present, the main salmon fishery is located downstream of the main road bridge (Fig. 2) except in years when there is a good run of salmon and angling extends the whole length of the river.

Aerial surveys of trout and salmon angler density undertaken in the 1976/77 and 1977/78 seasons showed an average of 18 and 15 anglers per km respectively, were fishing the 3.8 km of river below the main road bridge, whilst only 0.4 and 0.6 anglers per km were fishing the 61 km of upstream river (W.V.A.S., 1978). It has been suggested that if the aerial counts had been taken in the evening or earlier in the mornings, density ratings upstream of the bridge would have been higher ranging from 1.2 to 1.8 anglers per km (W.V.A.S., 1978). Taking these figures into account and even allowing for a major increase in the angling effort in the future, as has recently occurred in the Upper Rakaia River, there does not seem to be any need for more than a single

mainstem channel for angling. Although, as discussed later, other mainstem channels may be required for trout production.

To maintain the features of the present salmon fishery in a mainstem channel, it should also be large, fairly fast flowing with deep holes and slightly turbid water. It should be of sufficient size to make it fairly difficult to catch salmon or the fish will be too vulnerable to the expert angler or poacher.

In size and character a fishing channel could be similar to the breakaway channels on the north bank opposite Duntroon (Fig. 7) which are shown in the aerial photograph in M.W.D. (1979). Measurements from the aerial photograph indicate the main channel width there ranges from about 20 to 50 m with an average width of 30 m.

Resident Trout Stocks and Trout Fishing

The mainstem fishing channel(s) must support good numbers of large brown and rainbow trout and also must be suitable for trout angling.

At the moment the lower Waitaki River supports very large numbers of sizeable trout and a high quality trout fishery. This may be so for a variety of reasons. The river and its tributaries contain extensive spawning grounds of high quality and has numerous small tributaries and side braids suitable for the rearing of young trout. However, we believe that the main factor is the extensive area of suitable habitat available for large trout.

A number of factors in this habitat appear to be important and different from salmon angling requirements. Firstly, the extensive shallow riffle areas which produce, in total, large numbers of invertebrates which drift downstream to provide ample food supplies for trout. Secondly, although floods do occur, they may not be of sufficient magnitude, particularly since the hydro development of the catchment, to harm adult trout. Finally, many of the channels are large, deep and fast flowing and, although they may be an unsuitable habitat for resident large trout, they serve as escape areas and cover for these trout. Hence, one would expect to find large trout feeding and resting in the shallow, slow flowing margins along most of these channels.

The proposed residual river mainstem fishing channel(s) should be capable of supporting equivalent numbers of adult trout to those found in the present river. This will be difficult and will require considerable study.

One of the problems is that we do not know, and it may be impossible to obtain precise estimates of, how many adult trout are normally present in the river. In the absence of accurate statistics, a reasonable approach will be to obtain estimates of the yield and potential maximum -sustainable yield of trout that are or could be harvested from the present river. The current crop is estimated about 14,000 trout per annum (pages 14,15) but the potential maximum sustainable yield could be much higher (20-30,000?). Another uncertainty is the future angling demand, which is at present unknown because of variables such as the fuel crisis.

Probably the major problem is that of producing high numbers of large trout using only a minimum amount of water. For discussion purposes below we assumed that the objective is to maintain the present crop of about 14,000 trout at an individual average weight of about 1.1 kg, in a residual river with a single mainstem channel. This will require a stock of at least 21,000 takeable trout (see Burnet, 1979); the extra fish being required for breeding and as compensation for natural



FIG 7. Stable willow lined channels in the Waitaki River opposite Duntroon. This type of channel is similar to those planned for the residual river in Option A and to the proposed research channels in the area.

mortality. The single mainstem channel does not have to support the entire stock of 21,000 trout. It will, however, have to support a major proportion of this stock, especially if, as suggested later, the side braids and backwaters are modified to maximise the production of juvenile salmonids. We therefore consider that the mainstem channel will have to support about 80% of the stock and crop of adult takeable trout, i.e. about 16,800 and 11,200 fish respectively.

The meandering mainstem fishing channel of the residual river will be about 68 km long (direct distance $\times 1.2$). Therefore, it would need to support a stock of about 250 fish per km. If it was a single stem channel averaging 30 m in width, and trout averaged 1.1 kg in weight, trout stocks would average 9.1 g/m² and angler's catch 6.0 g/m².

Based on a preliminary study of trout densities, sizes and cropping rates in New Zealand rivers it seems very unlikely that a single 30 m wide channel could support these stocks and cropping rates.

Figure 8 shows the relationship between trout densities and the size of fish caught by anglers in some Wellington and Hawkes Bay rivers and streams. The maximum density recorded was only 140 trout per km and here the trout were relatively small (mean = 0.66 kg). For trout averaging 1.1 kg the highest density recorded was about 60 trout per km. In some of these waters stocks may have been limited by floods, high water temperatures and other factors. Nevertheless a five fold increase in stock density, even in a controlled managed mainstem channel, may be rather difficult to achieve.

Also, the cropping rate of 6 g/m^2 is probably rather high. Cropping experiments in the South Branch, a small (3.2 m wide) stable and highly productive brown trout stream near Christchurch, indicate an average crop of 11 g/m^2 (annual range over 6 years 3-18.5 g/m^2) could be safely taken from this type of stream (Burnet, 1979). However, in the Waitaki the fish are older and larger and it is possible more of the trout production will be lost due to natural mortality (see Allen, 1951). Further studies are needed on this aspect.

Studies on other New Zealand streams show that the density of trout stocks per km seem to be more closely related to the length of channel and possibly to the extent of bank cover, than to its width (Fig. 8). Therefore, the solution to stocking problems in the residual river may be to either divide the upper reaches of the channel into 2 or more channels, or to increase the amount of water flowing down the residual river and to have 2 or more mainstem channels throughout its length.

The channel(s) will need to be designed to maximise the production of large trout and to be protected from the adverse effects of floods. Production of fish and their food organisms may be directly related to the amount of overhanging vegetation and submerged stream bed, and streams with both riffles and pools may be more productive than those with single types of habitat. Studies will be required to look at such factors and to thus achieve a high performance design. However, we envisage that such a channel will have deep pools with adequate cover and space for large trout and also have a high production of large food items such as cased caddis larvae, mayfly nymphs, snails and small native fish such as bullies.

Alternative designs are possible. For example, a channel could either consist of a series of wide moderately shallow riffles interspersed with deep pools or it could be a deep slow flowing continuous channel similar to the rivers found below lakes - such as the Clutha below Lake Wanaka, which contains excellent trout stocks.

Trout anglers, especially those who fish with fly, would prefer clear water so that they can spot and stalk their fish. It is also important that, at least in some places, easy access to the river is provided.

If the trout stocks are confined to a narrow channel, careful management may be required to prevent overfishing.

Conflicts between salmon angling and trout angling and production needs may necessitate a partitioning of the resource with the needs of the salmon angler being met only in the lower reaches of the residual river, where information shows that much of the present salmon angling is carried out.

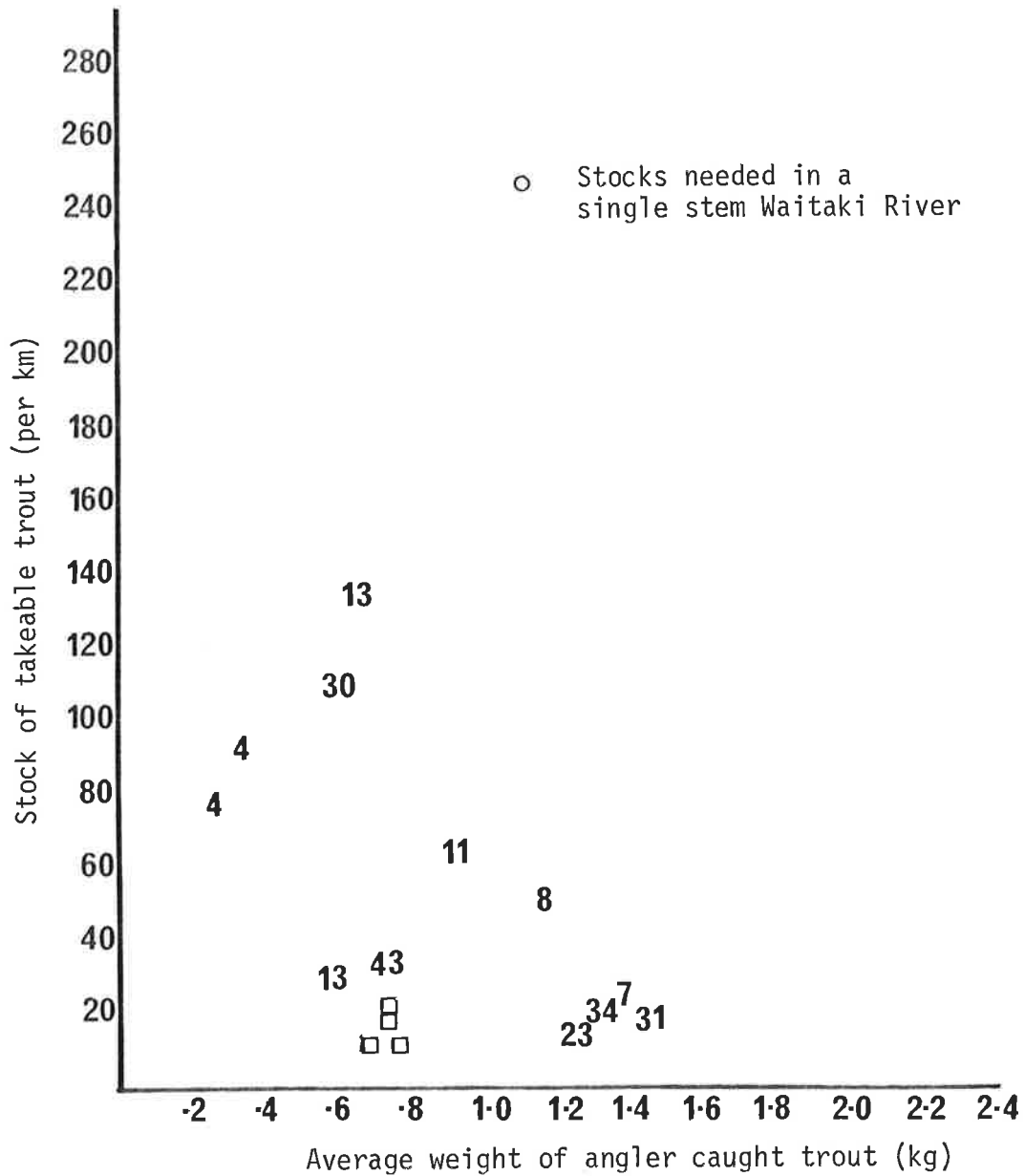
Fish passage

The mainstem channel must also permit fish to migrate upstream and downstream throughout its length. Because of the size of channel

FIG. 8. Relationship between stock of takeable trout present in some Wellington and Hawkes Bay Rivers and the average size of trout caught by anglers.

Numerals refer to brown trout rivers and indicate the approximate mean width of the river channel in metres.

□ = rainbow trout rivers. (Derived from table 10, Graynoth, 1974).



being considered it seems unlikely that water depths would ever limit passage. It also seems unlikely that water temperatures would be very different from those found at present in similar sized channels.

Biological problems may be more important. The absence of floods may inhibit migration - floods are certainly needed as a stimulus in small streams, although their importance in a large channel is uncertain.

Floods and turbid water may also be needed to flush juvenile salmon smolts seaward and so reduce predation by adult trout and eels to a minimum. If trout are particularly abundant, predation on migrating native fish such as whitebait and smelt could also be high.

Native Fish

The mainstem channel is also to be a habitat for native fish and in particular for those species which require turbulent water flowing over shallow boulder and riffle areas such as the torrent fish and bluegilled bully. It must also support common and upland bullies, species which are important trout food.

Other native species may be accommodated downstream of the main road bridge and in tributaries and side braids.

Salmon and trout spawning and rearing

This is not the prime function of the mainstem channel but undoubtedly some salmon and trout spawning will occur. The subsequent survival and growth of the fry will largely depend upon the availability of a suitable habitat. No doubt some will live in shallow slack water areas along the margins of the channel. Most salmonid spawning and rearing will occur in the side braids and tributaries.

Conclusions

Although this is only a preliminary study of the mainstem fishing channel(s), it seems clear that significant amounts of water will be needed for salmon and trout angling and to maintain the trout stocks. There are indications of conflicts between the requirements of trout and salmon anglers and because of the reduction in the rivers size it may be necessary to partition the resource. Also, much study will be needed to determine the present and possible future stocks and designing the channel so that it will support a majority of these fish stocks, using a minimum amount of water.

Side braids and backwaters

These waters are common along the course of the lower Waitaki River, their extent varying between locations and with discharge. The side braids and backwaters support several species of native fish and act as nursery areas for salmonids. The side braids are also important as spawning areas. Some angling is carried out in these areas as a few large trout are present.

Side braids and backwaters should be retained alongside the mainstem fishing channel(s) in order to preserve the present features and character of the river and to support the functions listed above. Salmon and trout spawning and rearing is considered to be the most important function of these areas and the one which should be used for defining their extent, design and hence water requirements.

Space required for salmonid spawning and rearing

Although the maximum number of fish which a stream can support depends upon a variety of factors, Allen (1969) has shown that in a number of

trout and salmon streams, densities normally range from one fish per m^2 , where fish average 5.5 cm in length, to 1 fish in $100 m^2$, where fish average 25 cm in length. These values have been used to calculate the space required to rear juvenile salmon and trout in a future residual river.

Assuming an average salmon run of 15,000 adults, a smolt to adulthood survival rate of 5% and a 10 cm smolt space requirement of $6 m^2$, it is calculated that about 180 ha of suitable stream habitat will be needed to rear juvenile salmon to the migratory smolt stage. Trout may need about 210 ha of suitable habitat, assuming an annual production of 21,000 takeable trout averaging 25 cm in length (present angler size limit) will be required (page 31). Studies are needed to determine the validity of these assumptions and hence the accuracy of these space requirements.

Much less space will be required for salmon and trout spawning grounds. In natural streams about $17 m^2$ of stream bed is the area required by a pair of spawning quinnat salmon and $7 m^2$ will probably be sufficient for trout (see Bell, 1973, Chapter 7). Based on spawning runs of 15,000 salmon and 7,000 (?) trout, a total spawning area of only 15 ha will be required and this area could be reduced to about 1.5 ha by the constructions of artificial spawning races.

These separate area requirements for spawning and rearing can be combined to some extent. However, juvenile trout and salmon eat similar foods and studies at Glenariffe, a tributary of the Rakaia River, have indicated that interspecific competition does occur. Therefore, to accommodate all these species of salmonids, perhaps 400 ha or more of habitat will be required for salmonid spawning and rearing.

Design considerations

If these spawning and rearing areas were confined to side braids and backwaters along the mainstem channel(s), a major net work of side channels will be required (possibly 6 channels each 10 m wide, extending along the 68 km of mainstem river). Such a scheme may pose innumerable problems in hydraulic design and in river management. A more practical maximum will be only 2 side braids, each 10 m in width. Therefore, to augment salmonid production, tributary streams and probably artificial spawning and rearing areas would be needed.

Studies will be required to establish design and flow requirements of the sidebraids and backwaters. Much is already known about the habitat requirements of salmonids (for example, see Table 2, p. 15). Whether these needs can be met, given hydraulic and other constraints, is not known.

Tributary Streams

The tributary streams and rivers entering the lower Waitaki support some angling and/or populations of salmon, trout and native fish. In the future these tributaries will become important as sources of water and as spawning and rearing areas for fish living in the residual river. Some tributaries may also be suitable for use by salmon farms and, if required, fish hatcheries.

Although surveys have been undertaken, we do not have accurate estimates either of the numbers of salmon and trout spawning in the tributaries or of the numbers of juvenile fish produced. Further studies are needed to help in determining the present potential of the tributaries for trout and salmon spawning and rearing areas.

Fish Passage

To maintain the populations of migratory species of fish in these tributaries it is important that fish access to and from the residual river is not hindered. Ideally all tributary streams should flow directly into the residual river. However, there may be problems in achieving this with the south bank tributaries. First, construction costs of several aqueducts and/or culverts may be too high. Secondly, there may be some design problems in developing a functional passageway for all flow conditions. Therefore, some south bank tributaries may have to run parallel to and south of the power canal and amalgamate with other south bank tributaries, before crossing the power canal and floodway to the residual river.

Flood diversion structures

Floods totalling up to 1500 cumecs could originate on occasions from these tributaries (M.W.D., 1979). Floods of great magnitude could severely damage the residual river, fish stocks and other facilities in the residual river/wildlife area (see Option B).

However, the smaller more frequent floods are necessary for the maintenance of the river's general character and fauna (see Woods, 1964). For example, they will remove excessive algal and macrophyte growths from shallow riffles and thereby maintain the important and characteristic fish and invertebrate communities dependent upon these riffle areas.

Therefore, flood diversion structures should be built that are carefully designed and tested so that freshets of various sizes and durations can be passed down the residual river and excessive amounts of water can be diverted into the floodway. The structures would have to operate safely, automatically, not hinder fish passage under low and normal flow conditions and be unaffected by flood debris and bed loads.

Studies will be needed to determine the approximate frequency and features of the freshets required in the residual river and to determine on which tributaries and where such structures should be located.

7.4 MAINTENANCE AND ENHANCEMENT OF THE SALMON AND TROUT POPULATIONS

Although this three channel option is thought to be one of the best, it still may not be possible to maintain current salmon and trout populations under this option. In particular there maybe insufficient rearing areas for juvenile salmonids (page 36) and insufficient habitat for large trout (page 31). There could also be, at times of flood, significant losses of fish into the floodway, and possibly fish losses caused by either high levels of super-saturated nitrogen or predation.

It is therefore necessary to consider the advantages and disadvantages of other techniques whereby the fish stocks could be maintained. Information on the cost/benefits of these techniques is also relevant to the basic design of this option. For example, it may be more economic to enhance trout and salmon production in tributary streams than to divert water from the power scheme down side braids of the residual river.

Techniques to increase the production of eggs and fry

The following techniques could be used:

- (a) Improvements could be made to tributary streams entering the lower Waitaki. These could include the addition of extra spawning gravel, the raking and cleaning of present gravels, improvements

in fish access, eradication of eels and other predators and improvements to water supplies. Surveys are needed to determine what is necessary and to estimate the potential increase in fry production which could result.

- (b) Spawning channel(s) could be built. These channels are designed to accommodate spawning salmon and trout and to rear their ova and young fry. The channels range from about 4 to 12 m in width and contain approximately 45 cm deep water flowing at about 45 cm per sec. over graded gravels, ranging in diameter from 1.2 to 5.0 cm (Fig. 9). Spawning channels also require associated nursery areas or special facilities for the rearing of juvenile salmon and trout.

A large spawning channel could be constructed at the head of the residual river or alternatively several small channels could be built at intervals down the river's course (Fig. 4). As spawning channels should ideally be supplied with silt free water, their location and size will be influenced by the presence or absence of suitable clear water sources, such as springfed streams or groundwater. However, if necessary, Waitaki River water could be abstracted from the power canal. Experience at the Aviemore spawning race indicates that the resultant siltation of the spawning gravels will not result in excessive additional costs, due to annual cleaning of the gravels.

If spawning channel(s) are needed the considerable amount of overseas information available on the design, costs, capacity and effectiveness of spawning channels could possibly be used in construction and design.

- (c) Ripe salmon and trout could be stripped and their eggs artificially fertilised and raised. Ripe, wild adult fish could be obtained by trapping or a brood stock could be reared in raceways or ponds. The ova could be incubated in hatchery troughs, Washington trays, upwelling gravel boxes, incubation channels, or even be planted in natural stream gravels using planting forks.

It has yet to be demonstrated whether or not additional salmon and trout spawning gravels and fry production will be required. At the moment it seems possible that if the tributary streams are fully utilised and if sufficient side braids are constructed parallel to the mainstem channel(s), under this option there will be no need for additional spawning grounds.

Techniques to increase the production of adult and juvenile trout and of salmon smolts

The following techniques could be used:

- (a) The rearing and holding capacity of tributary streams could probably be increased by the use of appropriate stream management techniques. The methods used could include water harvesting and the reduction of water abstraction in the tributaries; the control of excessive numbers of predators, such as eels and shags; channel modifications; the management of riparian vegetation and the improvement of food supplies by supplemental feeding and/or addition of fertilisers, sugar, etc.
- (b) Salmonid rearing channels or additional side braids could be constructed at suitable sites alongside the mainstem fishing channel(s). In some locations there may be insufficient width in the floodbed to constrict these channel(s) or the water supplies may be unsuitable.



FIG. 9. Aviemore Spawning Channel. This hair-pin shaped stream was the first artificial spawning channel to be built in New Zealand. It is 1 km long and was designed to accommodate 3,000 adult trout, have a depth of 0.30-0.45 m, bed width of 5.5 m, velocities up to 0.45 m/s and a constant fall totalling 1.5 m over the entire length. The channel provides some spawning grounds for trout and salmon from Lake Waitaki, now unable to spawn in tributaries above the Aviemore Dam. Fish gain access to this channel via a ladder at the far end of the right hand side and the controlled and constant water flow is supplied from the station auxiliary turbine to the left hand side end of the channel.

- (c) Attempts to increase the individual size of the takeable fish could possibly be made by supplementary feeding or the enhancement of food supplies by, for example, the introduction and improvement of stocks of bullies and other forage fish.
- (d) Small lakes could be used as salmon rearing areas. These have already been shown to be useful. At Glenariffe a maximum annual return of about 100 adults per 1.5 ha lake has been shown.

Although lakes are expensive to construct and maintain, they have the advantage of only requiring a small through-flow of water (about 0.03 m³ s per lake). Such rearing lakes would need careful construction for optimum fish production and drainage. The water source should be screened or enter through buried perforated pipes to keep out fish predators and confine salmon fry. Lights and islands with trees or shrubs would both attract aerial insects for food and provide the shade needed to keep temperatures down. Fry could be supplied by a hatchery or a series of Washington tray incubators.

- (e) Lakes Aviemore and Waitaki (total area 3,000 ha) could possibly be used as rearing areas for young salmon. Adult salmon could either be trapped in the Lower Waitaki and trucked to the lakes and released, or their eggs could be stripped and reared; the fry being released into the lakes. Smolts migrating downstream would need to be trapped above the hydro stations and eventually diverted into the residual channel.

Although this technique has worked on the Columbia River (U.S.A.), it is unlikely to work here. It is probably too labour intensive and is also fraught with problems, for example, the fry could be eaten by brown and rainbow trout.

- (f) The salmon and trout stocks in the lower Waitaki could, in theory, be maintained by the release of hatchery reared fish. However, there are a number of problems - a hatchery of the size required would be large and expensive to construct and maintain, a large supply of high quality water would be required and special precautions would need to be taken against disease outbreaks. It also appears that once released, hatchery reared trout cannot successfully compete with wild trout. Consequently, after many years of failure, most acclimatisation societies have now ceased stocking rivers with hatchery reared trout. Hatchery reared salmon, recently liberated in some New Zealand experiments, have also not had a marked success with the overall survival rates from ova to adult being similar to those found naturally. There may also be problems of little genetic variation in hatchery supplied populations. Studies are in progress elsewhere to determine the optimum size and age of release for particular river systems and to determine factors causing hatchery reared salmon mortalities in the wild. The use of hatchery reared juveniles in other enhancement programmes should also be carefully considered as the construction and maintenance of even a small hatchery could be expensive.
- (g) The residual river stocks may be assisted by importing fish reared elsewhere. Transfers could be made, for example, of brown trout reared in local irrigation races and/or ditches. However, this type of stock assistance is very labour intensive, there are problems associated with trying to catch trout for transfer, the fish transferred may be the wrong species or have the wrong behaviour for the new habitat, they may migrate back to their place of origin, or could damage existing fisheries.

The techniques listed above may not all be suitable or necessary in a future residual river. Some techniques may only be of value for salmon, others for trout.

Studies will be required into the present production of juvenile fish and the potential production from tributary streams. Given this information it will then be possible to calculate the numbers of fish which need to be produced in other ways and to undertake studies into the best technique to use.

7.5 CONCLUSION FOR OPTION A.

This option suggests the construction of a power canal, floodway and residual river. The residual river must fill many uses. From the fisheries point of view it should support a similar sized fishery to that in the present river and maintain the present river's potential for development. The design of the residual river will take a great deal of study and it may be that it will be impossible to determine the precise amount of water required over the long term, therefore provision will have to be made for revision of the water allocation. It is envisaged here that the residual river will follow a sinusoidal path down a wide floodbed, the mainstem will be designed for fishing and adult trout habitat, while the side braids and tributaries will be designed for juvenile salmonid production. Several methods are available to fisheries managers to increase the production of salmonids and it is likely that at least some of these will have to be employed.

A fishery may develop in the power canal and thus decrease the pressure on the residual river, but we believe it will be basically of poor quality.

We believe that this option is the best of those presented in this report from the point of view of maintaining the fisheries, as well as the wildlife and present river environment for other users. Its main attribute is the provision of a residual river, not subject to frequent floods or damming.

8. THE TWO CHANNEL OPTION (B) - A POWER CANAL AND A COMBINED RESIDUAL RIVER/FLOODWAY

8.1 INTRODUCTION

This option will be similar to Option A in that power will be generated in a power canal. However, the residual river paralleling the power canal will also accept flood flows from the Hakataramea River and other tributaries of the lower Waitaki as a floodway will not be constructed (Fig. 3 M.W.D., 1979). The residual river will have to receive floods from the diversion structure upstream of Kurow. This diversion structure will also mark the beginnings of the power canal. The power canal is likely to be similar, from both the hydroelectricity and fisheries point of view, to that described and discussed for Option A (section 7.1). Therefore, it may be constructed to accommodate flows of up to 525 cumecs. At times when electricity demand is low, when there is a powerline failure or flows exceed the canal capacity, water may be spilled over the diversion structure and into the residual river.

The residual river in this option may be superficially similar to that of Option A. It is likely that it will normally hold a similar volume of water and most certainly it will have to maintain the same fisheries functions. These have been outlined and discussed in Section 7.3. The residual river floodplain width will depend on design and, as with Option A, the north/south arrangement of the power canal/residual river is likely to be based more on engineering considerations rather than fisheries. For the purpose of this report we have assumed the power canal will be on the south bank.

The power canal and residual river/floodway will terminate, as for Option A, about 4 km upstream of the river mouth.

The characteristic feature of this option is that the residual river must accept flood flows from both the upper and lower Waitaki catchments. These will have a damaging effect on instream structures, banks and the aquatic fauna and fisheries. To determine their impact information is needed on the features of the floods - their magnitude, duration, frequency and timing and on associated features such as water quality. The floods have two separate origins and are hence considered separately and then the combined effect is described and discussed.

8.2 FEATURES OF THE FLOODS

Floods from the Upper Waitaki

Features of the Upper Waitaki floods were determined by examination of simulated discharges at the Waitaki Dam from 1927 to 1977 (prepared by Jowett, M.W.D. Power Division, Wellington). If N.Z.E. operating policy, the power supply or demand, changes significantly in the future, then this simulation data will be invalidated as a guide to future discharges. However, at present these are the best data available.

Floods were assumed to occur when flows exceeded 525 cumecs (the possible power canal capacity). A lower figure may be more realistic, especially at times of low power demand, therefore the estimated floods are probably smaller and less frequent than may happen in practice.

Another assumption is that the residual river has a constant base flow of 40 cumecs at the diversion structure. Forty cumecs was chosen as a reasonable but purely arbitrary value and although a constant value was used, in practice adjustable and therefore variable flows may be required to reduce the magnitude of floods in the lower river. Based on these assumed figures, excess flows (floods) will occur in the lower Waitaki when the discharge from the Upper Waitaki exceeds 565 cumecs.

TABLE 3 - Estimated frequency of floods down a combined residual river/floodway over a 100 year period.

Flood magnitude (daily mean cumecs) peak flows	Numbers originating from the			Time minimum flows in category exceeded (years)
	Upper Waitaki	Lower Tribs.	Total	
50- 99	13	approx. 600	approx. 600	.10
100-149	13	178	191	.27
150-199	6	51	57	.54
200-299	9	38	47	.8
300-399	13	19	32	1.2
400-499	13	13	26	2.0
500-599	5	0	5	4.3
600-699	3	6	9	5.6
700-799	2	0	2	11
800-899	1	0	1	14
900-999	2	0	2	17
1000+	4	0	4	25

Floods from the lower tributaries

Flow records are available for the Hakataramea River for the period 1964 to the present day. These values have been used to estimate the flood flows from other tributaries for which M.W.D. 1977 lists the mean flows (Table 1). Ignoring the tributaries that will be above the diversion weir, the mean flow for those below the Hakataramea totals 11.32 cumecs or 2.18 x the mean flow of 5.2 cumecs in the Hakataramea. The total flood flows for the lower tributaries could be simulated by multiplying the Hakataramea flood flows by 3.18. However, it is unlikely that floods from all the tributaries will be synchronized so a lower factor of 2.5 has been used. The residual base flow of 40 cumecs has been added to the estimated flood flows and the totals presented in Table 3. The high frequency small freshes, the entry of groundwater into the river and the degree to which the residual river flows will move into the groundwater table of the old riverbed have not been assessed.

Magnitude and frequency of floods

Based on the 50 years of simulated hydrograph records, Table 3 shows the numbers of floods of different magnitudes expected in the residual river over a 100 year period.

Each year one will expect a flood of 250 cumecs or larger, every 10 years a flood of 700 or larger and every 25 years a flood of 1,000 cumecs or larger. A 100 years flood may be in the region of 1,700 cumecs.

The timing and duration of floods

Examination of a 20 year sample of the hydrograph records from October 1927 to October 1947 showed that floods exceeding 200 cumecs in the residual river are only likely to originate in the upper catchment from

January to early May, with the majority of floods occurring in February. Similar sized floods from the Hakataramea and other tributaries will occur from June to September, while smaller floods, and freshets from the tributary streams, will occur throughout the year. These features can be seen in figure 10, a simulated hydrograph for the year 1967.

The same records show that, on average, there will be 0.85 floods per year, 8.5 days in which flows will exceed 200 cumecs in the residual river, and as to be expected, the larger floods will last the longest. The records showed that floods from the upper catchment, peaking at a daily mean of 250 cumecs, lasted 3 days, at 700 cumecs, 18 days and at 1,000 cumecs about 28 days. Floods issuing from the lower tributaries are of a much shorter duration, lasting 3 days at the most. The average duration of the Upper Waitaki floods was 10.1 days, and the tributary floods only 1.5 days. The difference is due to the hydro-lake storage of the Upper Waitaki system.

8.3 IMPACT OF THESE FLOODS ON THE RESIDUAL RIVER

Introduction

It is difficult to predict with any certainty the impact of these floods on the residual river. This is because of the complexity of the physical and biological processes and interactions; also because of the absence of detailed information on the hydraulic geometry of channels in braided rivers and in the Waitaki River in particular. There is in addition very little relevant published information on the impact of floods on the benthic invertebrate and fish stocks in large New Zealand rivers.

After considering alternative approaches it was decided that an assessment could be made by systematically tracing the effects of floods on hydraulic features, such as water velocities and bedloads and then determining how these changes affected aquatic weeds, invertebrates, fish stocks and fisheries.

An attempt was made to theoretically calculate and model the effects of floods on the physical features of the residual river (Appendix). A representative cross section of the lower Waitaki was selected for study and simulated changes in water depths (see Fig. 11) and hence velocities were calculated. Water velocities were used to determine the size of gravel moved during floods and attempts were made to determine the degree of movement of the river bed and bed loads. The impact of floods was also found to be dependent upon the width of the flood plain (Fig. 11) and channel training works.

Based on these studies the following conclusions were obtained on the effects of floods of various sizes on the physical features of the residual river.

Base flows of 40-50 cumecs

Examination of the historical data indicates low base flows could persist for comparatively long periods. In Figure 10, during a wet year, flows were stable for a 6 months period from May to November.

Through the period between floods the residual channels will develop an algal flora on their beds and invertebrate and fish stocks; on the banks and flood plain vegetation will develop. These changes will have normally small effects on the general shape of the channels, but greater effects on substrate composition and compaction.

FIGURE 10

OPTION B. SIMULATED FLOWS IN THE COMBINED FLOODWAY/RESIDUAL RIVER DURING 1967.

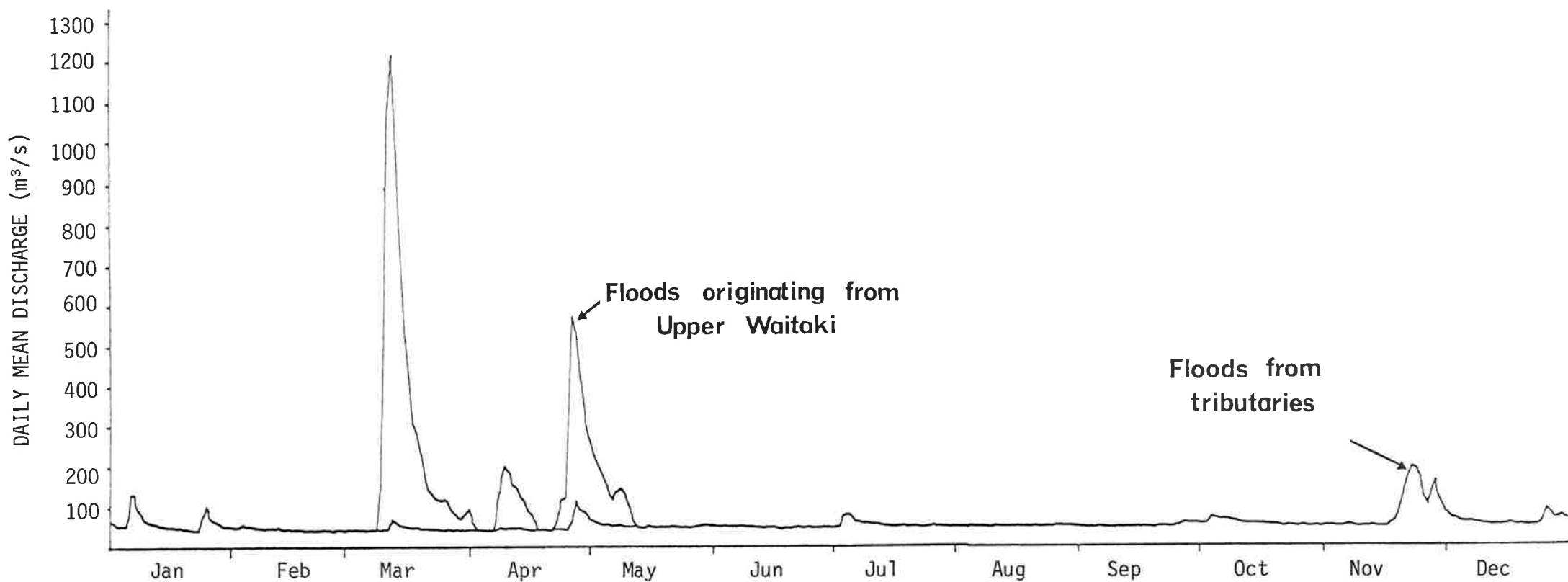
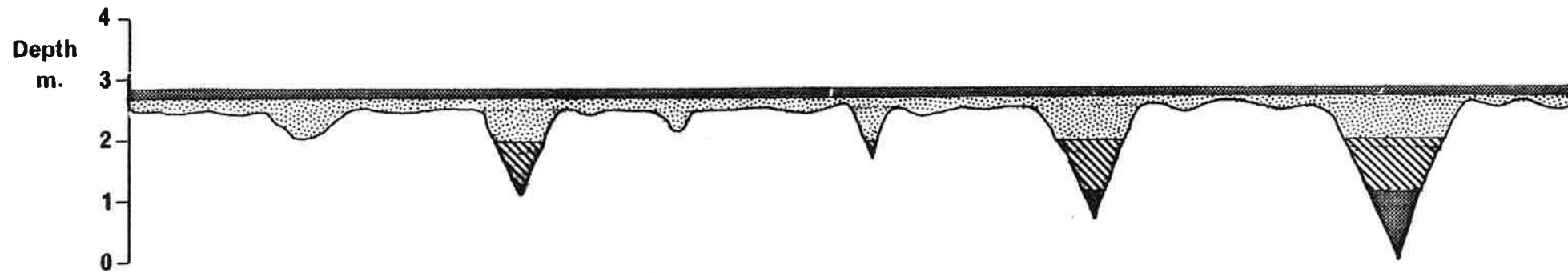
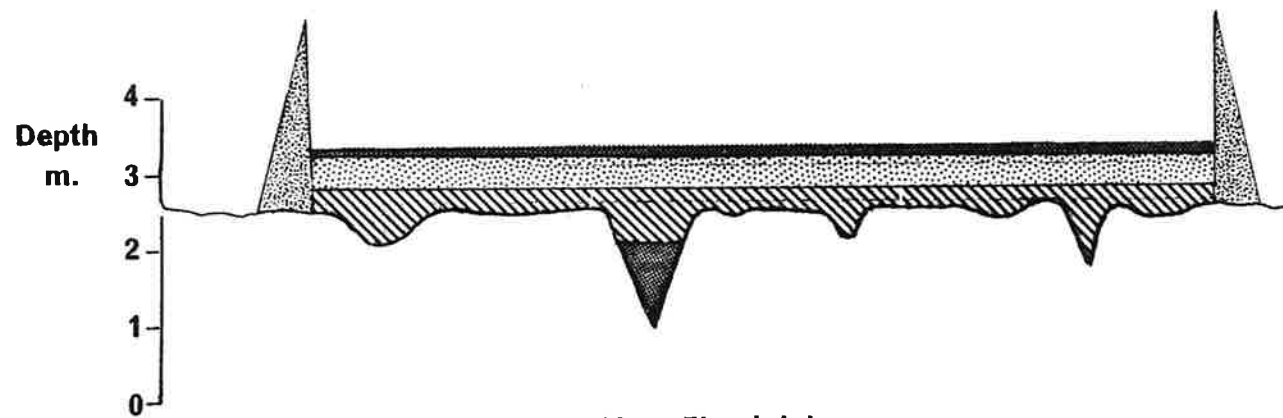


Figure 11 Model illustrating changes in channel widths and depths in floodplains of different widths during flows of 40-1000 cumecs.

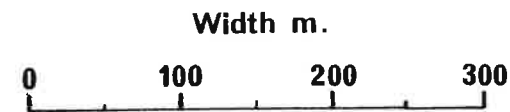
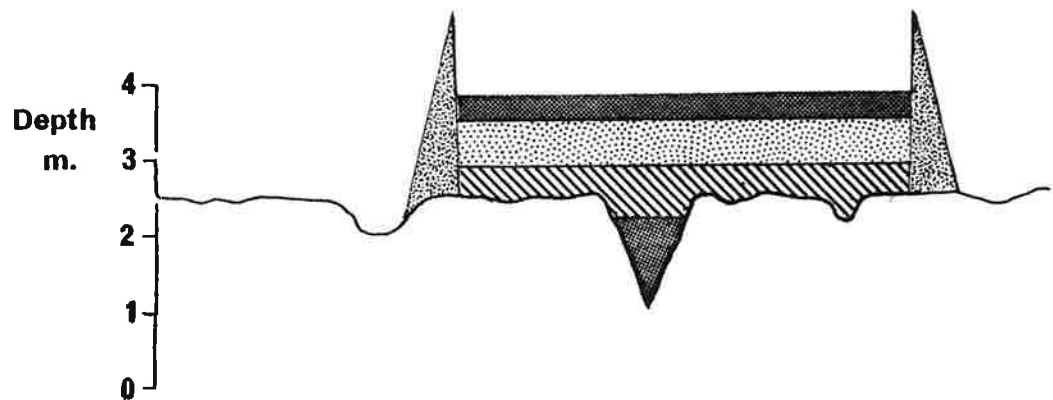
1200 m. Floodplain



600 m. Floodplain



300 m. Floodplain



KEY

Stopbank

Water level at;

	1000	Cumecs
	700	"
	250	"
	40	" (Residual flow)

The number of channels present will depend on the width of the flood plain and river management practices.

In a wide 1,200 m flood plain, as in Figure 11, the water will probably flow in about 1 to 3 principal channels, with smaller side streams and groundwater in the margins of the flood plain. In a more confined 300 m flood plain it is much more probable that the water will be confined to a single deep channel scoured out by floods.

Channel depths, widths, water velocities and other features will vary between pool and riffle sections and depend upon the stability of bank vegetation. Channels will probably be deeper and more confined in a wide flood plain because the vegetation on the banks will be stable and less affected by floods than in a narrow flood plain. A general indication of the hydraulic features of channels at various discharges is given in Table 4 and is based on the relationships described in the Appendix.

A single channel containing 40 cumecs of water will be about 45 m in width up to 1.1 m deep and contain water flowing at up to 2.1 m/sec (Table 4). The central region of the channel bed will contain stones ranging from 10-15 cm in diameter left after floods, and only small amounts of finer material. Bedloads will be very low. The margins of the channel may contain beds of finer substrates left after floods.

Annual floods of 250 cumecs

Floods peaking at about 250 cumecs daily mean are estimated to occur about once a year. The actual instantaneous peak volume of the flood could be considerably higher and high flows will on average last less than 3 days.

In a confined 300 m wide flood plain, as illustrated in Figure 11, it seems quite probable that in some localities the water will overtop the channel banks and a thin layer of water spread out over the flood plain from stopbank to stopbank. In other localities the channel will degrade and deepen to accommodate floods of this size.

In the example shown in Figure 11 the main channel contains about 170 cumecs with the remainder of the water being spread out over the flood plain. The water will be up to 2 m deep in the centre of the channel travelling at 3 m/sec and transporting stones of up to 5-10 cm in diameter (Table 4). The greatest relative change in velocity will be at the margins of the channel and small stones such as those used for salmon and trout spawning will be dislodged and transported.

In the initial phases of the flood there will be a considerable increase in water turbidity and suspended sediment loads as dry marginal areas become inundated and overland flow occurred then sand, small pebbles and gravel will start moving in the deeper and swifter regions of the channel.

The amount of shingle which will be moving at flows of around 250 cumecs is not known. Data from the Tongariro River indicates bed loads increase markedly between 60 and 100 cumecs and in the Tongariro a bedload of about 3,600 tonnes per day will be expected at 250 cumecs.

Observations by Woods (1964) and in recent years by Cudby and Jowett (Jowett, 1979) indicate that 250 cumec flows will be more than sufficient to turn over the gravels, remove excess algal growths and break up the armoured bed of the river.

TABLE 4 - Hydraulic Characteristics of channels with 5 to 1,000 cumec discharges, including the diameter of stone transported in channels with 20 and 40 cumec base flows.

Discharge (m ³ /s)	Width (m)	Depth (m)		Velocity (m/s)		Diameter of stone size transported (cm)		
		Mean	Max.	Mean	Max.	Centre	20 ^x	40 ^x
5	21	.26	.52	.9	1.2	4	-	-
10	27	.34	.68	1.1	1.5	5	-	-
20	35	.44	.88	1.3	1.7	6	-	-
40	45	.57	1.14	1.5	2.1	7	1	-
100	64	.80	1.61	1.9	2.6	9	3	2
250	90	1.13	2.26	2.4	3.3	12	5	4
700	133	1.66	3.33	3.2	4.2	15	9	8
1,000	152	1.90	3.81	3.5	4.6	16	10	9

x indicates the diameter₃ of stone moved at the margins of a channel with respective (20 or 40 m³/s) base flow.
Centre refers to the centre of channels with either 20 or 40 m³/s base flows

Also, observations after the June 1980 floods in the Hakataramea River (mean flow 5.2 cumecs) when flows reached 260 cumecs indicated that the stream bed was substantially modified by floods of this magnitude.

The situation in a wider 600 or 1,200 m flood plain may be quite different. In a 1,200 m flood plain the river will be similar to what it is at present. In the model cross section, Figure 11, the water is contained within 4 channels having discharges of 1, 25, 60 and 164 cumecs. It seems most unlikely that the water will be confined to a single channel or will overtop the banks and cover the flood plain. This means that the flood flows in each channel are smaller and hence there will be less disruption of the river bed and substrates. In reality the main channel flows are more likely to be less than 164 cumecs and in the region of 100 cumecs. Nevertheless, this is still a substantial flow and may result in a reasonable bed load and hence changes in stream morphology and substrates. In the Tongariro flows of 100 cumecs transport about 100 tonnes per day. Fine 2 cm diameter gravel at the channel margins (Table 4) may still be moved and this could affect trout and possibly salmon redds. It is also likely that dry channels will be filled, causing an initial increase in silt loads as vegetation and earth is washed out.

Floods of 700 and 1,000 cumecs

These are major floods and mean daily discharges of these amounts should occur at intervals of about every 10 and 25 years respectively. High flows will probably last for over 1 week, and possibly much more.

The model (Fig. 11) indicates that even a 1,200 m wide flood plain will be inundated with water during these floods. This means that the water velocities and substrate movement in the main channels will not be as great as expected, because much of the water flows over normally dry land.

During these large floods the river tends to flow directly downstream and they may not be quite as destructive as smaller floods that are confined to particular channels which undergo erosion and lateral migration (B.J. McKenzie, pers. comm.).

It is suspected that there will be a considerable amount of scour and deposition in a narrow flood plain during these floods because of the uniform high velocities and absence of retaining vegetation on the floodbed.

Observations of the effects of the June 1980 flood of 700 cumecs in the narrow channel of the Maerewhenua River revealed the massive force and destructive powers of floods of this size. The stream bed was substantially modified and considerable amounts of flood plain soil and vegetation removed.

Bedloads could be well in excess 1,000 tonnes per day and could be as high as 10,000 tonnes (Griffiths, 1979). In the major channels stones of up to 13 cm in diameter, and possibly larger, will be moved by water velocities up to 4 m/sec. Observations in the present Waitaki River tend to confirm these calculations which indicate few salmon and trout redds will be left intact.

Although we have little detailed information on the effects of floods, it is fairly evident that floods in the residual river/floodway of Option B will cause considerable destruction upon the flora and fauna communities (see Fig. 12). Excess flows of 250 cumecs in the present river do not even represent a doubling of the average daily flow. However, in a residual river of 40 cumecs, such floods will increase the flow over six times. Of course the width of the floodplain, number of channels, floodplain management policies and origin of the flood will influence the impact of such increased flows.

The width and development of the flood plain

The width of the flood plain is a critical factor controlling the hydraulic geometry of the stream channels. The impact of floods in flood plains of 1,200 m, 600 m and 300 m in width have been considered in the model (see Fig. 11 and discussion above).

The present flood plain varies in width from about 1,600 m to 800 m and if the power canal is built at the extreme south bank, at most locations about 1,200 m will be available for the flood plain.

Periodic floods could place severe restrictions on the extent to which the flood plain could be developed for recreational, agricultural and fisheries purposes. Buildings and other structures such as hatcheries, spawning races, campsites, roads, etc., will have to be located in areas where the risk of flood damage was low or were otherwise protected by extensive and expensive flood protection works.

These problems will only occur in a wide flood plain - in a narrow flood plain these buildings could be located outside the flood banks. Such problems are also less likely to occur if the river can be contained within the existing channels as outlined under scheme 1 in the Appendix.

With a wide flood plain, problems are foreseen in the excessive growth of willows, gorse, broom and other vegetation. The control and management of this vegetation would be expensive. If a wilderness was permitted to develop the access of anglers and other recreationalists will be greatly hindered.

The number of channels present will be determined by design features such as the width of the flood plain, river flows and channel training works. However, in general it will be impractical to control the numbers and dimensions of pools, riffles and other water types within

the channels because most normal stream improvement works will be destroyed by the periodic floods. Managers will also have no control over the fact that in a wide flood plain there could be considerable water loss into the groundwater or passage through permeable gravel banks.

After floods have passed the residual flow will probably be redirected into a few main channels (see Appendix). Exactly what the beds of these channels are like after much greater volumes of water have passed, and how much of the pre-flood biota will remain is unknown. It is possible that after major floods in narrow floodbeds that much of the residual river side vegetation cover, important to fish and fish food production, will be non-existent.

However, some mitigation of the impacts of floods may be achieved with flood routing down dry channels, plus considerations in channel design, e.g. entrenched channels, deflectors to reduce water velocities and possible further control of lake storage. Lake storage has already reduced the size of upper catchment floods (see W.C.C.R.W.B., 1978).

8.4 EFFECTS OF FLOODS ON FISH AND INVERTEBRATES STOCKS

Introduction

There is very little information on the effects of different magnitudes of floods upon the algal growths, invertebrates and fish of rivers (see Fig. 12). This maybe because of the extremely difficult physical problems in sampling fish, invertebrates and certain hydraulic processes during floods.

However, floods do act as an important reset mechanism (Mundie, 1979) by returning the stream, its substrates, flora and fauna to a basic initial state. After floods with time and increasing maturity, the substrates will become more compacted and the invertebrate fauna increase in abundance and diversity. The actual rate of recovery in the Waitaki and elsewhere depends upon the magnitude of flood disturbance and the conditions during the period of recovery. For example, in the Horokiwi (Allen, 1951) the rate of recovery was slow because of subsequent floods.

Processes operating during floods

Suspended sediments

In the initial phases of floods, rivers may contain high levels of suspended sediment which may reduce the light supply, hence inhibit the photosynthesis of algae and macrophytes in the river. It may also affect invertebrates filter feeders and induce gill bacterial disease in, or even suffocate, fish. Once deposited, the sediment could destroy redds by reducing oxygen levels and by blocking the exist of fry. It could also reduce the interstitial crevices in the bed, i.e. destroy habitats of very young fish.

In the Waitaki there is likely to be high quantities of suspended glacial silt present during floods, which because of the controlled nature of the catchment, may remain for a considerable period. In the summer this is likely to reduce angling quality, while in the winter/spring large amounts of deposited suspended sediment silt will adversely effect spawning grounds and reproduction.

Abrasion

Suspended particles (e.g. sand grains and pebbles) will have an abrasive action on algal growth, invertebrates and fish. The extent and



FIG. 12 (a) A braid of the Waitaki adjacent to the south bank, just above the state highway bridge at the Inner Ferry Road, on the 15.8.79. The flow was 0.15 cumecs.



FIG. 12 (b) The same braid as above on the 15.1.80. The flow was estimated at 30-50 cumecs.

effects of this abrasion are unknown.

Bed Movement

Again little is quantitatively known about the effects of bed movement upon the flora and fauna of rivers. Presumably, at times of bed movement many of the invertebrates and small fish trapped within the bed must become crushed, buried or smothered by the gravels. Some fish and invertebrates, e.g. eels, bullies, amphipods and snails, will find refuge in the macrophyte beds unless these too are dislodged.

Bed movement can also effect the spawning gravels, redds and the salmonids and native fish such as bullies and smelt.

Displacement

Increased water velocities during floods can dislodge certain invertebrates which live attached to or on the upper surface of stones, and cause downstream drift in very large numbers (Hynes, 1970).

Fish may also be displaced downstream, although with some fish species, minor floods or freshets are recognised as triggers to induce migration both into and out of the river. The displacement of fish and invertebrates into channels which subsequently dry up after floods will also cause an unknown level of mortality.

The effects of floods on invertebrates

Case Studies

Hynes (1970) quotes many overseas studies where floods have been noted to reduce stream invertebrate faunas. In New Zealand Allen (1951, p.60) found that, in the Horokiwi Stream near Wellington, a large flood reduced the biomass of invertebrates to 12-30% of its original value. The reduced biomass was maintained by subsequent floods for approximately 6 months.

On the Ophi River in South Canterbury, after a summer of low flows (about 3 cumecs), floods of 100 and 850 cumecs in April and May respectively, completely destroyed the benthos in some areas (Fowles, 1972). Although the benthos was replaced by animals swept downstream, the population of 350 to 2,500 animals per m² was reduced to 100 to 500 per m², which was principally composed of the mayfly nymph *Deleatidium*.

In Roughn's Creek in the Golden Downs State Forest in Nelson the invertebrate fauna was severely reduced by two floods in April, during which there were high bed and silt loads. Two months later the invertebrate stocks were, by comparison to the initial state, still greatly reduced, Trichoptera were down to 1% of their former numbers and chironomids to 0.6%, *Deleatidium*, by contrast, had increased by 40% (Graynoth, 1979).

The lower Selwyn River had low flows of about 1 cumec. A subsequent flood of approximately 16 cumecs was shown to greatly disrupt stream sediments and reduce, for a month or more, algal growths and the stocks of certain benthic invertebrates such as snails and beetles. However, fast water living invertebrates, such as mayfly nymphs and caddisfly larvae, had recovered 3 weeks after the flood (Clark, 1968).

Perhaps the study on a river most comparable to the Waitaki is the ongoing work on the Rakaia, a braided Canterbury river. In 1979

flows of 101 to 296 cumecs extended from mid April to September. During this time the invertebrate stocks (averaging 970-6370/m²) and algal flora built up and developed. In October floods of 690 and 1,700 cumecs (mean daily flow) occurred. These floods resulted in an immediate reduction in both invertebrate numbers (83-453/m²) and species diversity, the post flood fauna was dominated by *Deleatidium*. This situation persisted until the next stable flow period (March-May 1980) when invertebrate numbers (390-1750/m²) and diversity increased again, (P. Sagar, pers. comm.).

From these studies, it appears that in the residual river floods will effect the invertebrates by reducing the biomass and species diversity. The mayfly larvae *Deleatidium* will likely form the principal component of post flood fauna. Chironomid larvae and perhaps fast water living invertebrates may be among the first of other species to appear in the post flood fauna.

The effects of floods on fish.

There have been few studies on the effects of floods on fish stocks in New Zealand. Allen (1951) found about 80-90% of the trout ova were destroyed by major floods, and there was a reduction in the abundance, growth rate, and condition of trout present.

In another New Zealand study Hobbs (1940) showed that trout tend to select relatively stable streambeds for spawning and avoid large areas of unstable bed. He concluded that redds were generally unaffected by normal flood events. However, trout redds are affected by major floods (Hobbs, 1940, p. 44) - perhaps more so than salmon redds, where the eggs are buried deeper in the gravels and are often less affected by silt (Hobbs, 1937, p. 81).

The importance of floods during the early stages of production has been shown overseas. In the Big Qualicum River, Canada, stream flows used to range from 0.39 cumecs to 200 cumecs. The reduction of floods in winter increased the survival rate of salmon eggs and fry and increased the output of smolts (Mundie, 1979).

G.J. Glova (F.R.D., Christchurch, pers. comm.) is of the opinion that in large river systems, the direct adverse effects of floods on juvenile salmonids is generally of minor significance. He emphasizes that large rivers have sufficient diversity of habitat for fish to seek refuge during floods. He cites as an example the effects of a record flood observed on juvenile salmonids in the Stikene-Isbut rivers, a large, braided system in northwest British Columbia (summer monthly average discharge approximately 4,000 cumecs). Following the flood of October 1978, the abundance of juvenile salmonids (ages 0+ and 1+) differed little from those in the pre-flood period, although catch rates were slightly higher at sampling stations in the lower reaches suggesting some downstream displacement of fish. Of greater importance may be the indirect effects of floods, mainly that of losses of benthic invertebrates, the main food source for fish in large drainages.

Glova states that the life stages of juvenile salmonids that are most seriously affected by floods, irrespective of river size, are the incubation and early fry stages. Incubating eggs are either scoured out or buried under, while young fry because of their weak swimming abilities, are in large part flushed to sea.

In a Waitaki residual river it is probable that floods will have a limited direct effect on subadult and adult fish. Some mortality will occur if fish are swept into channels that eventually dry up but

the highest fish mortality is likely to occur from above normal flood events that occur while the very young fish or eggs are still living within the gravel. In the Waitaki the danger period is therefore winter/spring, when floods issue from the tributaries. Important indirect effects on the fish will also occur, for example, destruction of food supplies, habitats and spawning areas.

The effects of floods on the fisheries

Under Option B it is highly likely that the present fishery (and the potential for salmon ranching) will be extremely difficult to maintain in a residual river. We discussed methods of enhancement of the residual river fishery such as hatcheries, river enhancement and spawning races in Section 7.4. In a river subject to comparatively large and frequent floods, many of these programmes would have to be sited in specially protected areas or they may simply prove totally impractical because of repeated floods e.g. instream pool/riffle enhancement.

If reoccurring floods reduce fish food, habitats, numbers and/or spawning areas one resort will be to stock the river with hatchery reared fish. This may prove extremely expensive, and may not be very successful, especially with reference to trout. Other resorts are the possibility of abandoning attempts to save the fish stocks and fisheries in the upper and middle sections of the lower Waitaki River and compensating for this loss by developing the fish stocks and fisheries of the lower reaches of this river. Even if managers are able to keep sufficient fish stocks in the river it is possible that fishing will not be productive on many days because of high water turbidity during and following floods.

Perhaps the final resort will be to rely solely on a fishery in the power canal. Such a fishery has been discussed under Option A (see pages 26, 27) and we consider it to be far below the quality of the present river or even a residual river not susceptible to floods.

Non-sports fish and other wildlife are also likely to suffer under this option. M.W.D. (1979) described a residual river/floodway with little or no flow as "a harsh and inhospitable environment for fish and swamp and waterbirds, and undesirable for most recreational uses". Opposition to this option has also been expressed by the Waitaki Valley Acclimatisation Society (1976).

8.5 CONCLUSION FOR OPTION B.

This option proposes the construction of a power canal and residual river/floodway. Thus, repeated floods in the residual river are likely to be the controlling factor in the success of this option. The effects of such floods will depend on the width of the floodbed, management strategies, frequency of the floods, and features of the floods, such as the amount of bed load carried from the tributaries.

We feel this option, because of the effects of repeated floods, will have very adverse effects on the fish stocks and fisheries, wildlife, and general biota of the Lower Waitaki. Any attempts to maintain the present fish stocks and fishery will probably be extremely expensive. Thus, we believe the present river's fishery and potential for development will be considerably reduced and do not recommend this option.

9. A CHAIN OF SMALL HYDRO-ELECTRIC RESERVOIRS (OPTION C)

INTRODUCTION

The M.W.D. (1979) have described a development option (Fig. 4, M.W.D., 1979) where all flows, including flood flows from side tributaries, would be conveyed downstream through a series of reservoirs. Our slightly modified design is shown in Figure 5. In both plans the south bank of the reservoirs will follow the contour of the land while the north bank will be an artificial embankment. Areas of slow flowing and shallow water will be formed in bays and where tributaries entered the reservoirs.

The reservoirs will have a dual fisheries and power function and compromises will need to be made by both interests. The advantage of this scheme, from a power generation viewpoint, is that the entire flow of the Waitaki River is used for generation and little or no water will be lost down a residual channel. M.W.D. (1978) estimated the potential revenue from electricity generated by one cumec of water at \$300,000 p.a. Thus the potential financial benefits of Option C may be much greater than those of Options A and B, provided that the capital development costs and some other costs, such as the loss of water down fishways, were not excessive and that the maximum generating capacity of the water was used.

From the potential fishery point of view, the reservoirs in this scheme will have to be designed and built for maximum angler use and fish production. They must support both juvenile and adult trout, juvenile salmon and also adult salmon during their upstream migration. To supplement the reservoirs, spawning races, fish passes and possibly hatcheries will need to be included in the design.

9.1 POSSIBLE IMPACTS ON THE FISH STOCKS

This option proposes to change what is now a relatively natural, uncontrolled running water ecosystem into a radically different lacustrine ecosystem. Although, it is difficult to predict the exact nature of the resultant fish stocks and fishery, following overseas experiences with river impoundments, we can outline several possible impacts on the fish stocks.

Impacts on upstream migrants

- (a) The upstream migration of adult salmonids and native species could be blocked or delayed at the dams even if fish passes were constructed.
- (b) Fish may take longer to migrate through the reservoirs than up the river alone, on the way to their spawning grounds. Salmon, for example can lose time wandering about in slack water above a dam and these delays can reduce their chances of reproduction (Baxter, 1977).
- (c) During the construction of the reservoirs, river modifications and blockages may obscure the olfactory and other clues by which salmon and other fish are guided to their spawning grounds (Baxter, 1977). Lost fish maybe forced to breed in unsuitable habitats.

Impacts on downstream migrants

- (a) The downstream migration of juvenile fish may be slowed, hence they could suffer greater losses due to predation. For example, juvenile quinnat salmon take three times longer to migrate downstream through the long reservoirs on the Columbia River, U.S.A.,

than through the original free flowing rivers (Raymond, 1969).

- (b) Fish can also be killed at dams by passing through the turbines or by gas bubble disease. In addition, those fish that are not killed but injured, stunned or sick are probably made more vulnerable to predation. Estimates of the level of mortality at dams is dependant upon the age and species of fish and physical features of the dam such as the head of water, type of turbines, their duration and levels of operation. Generally fish mortality is at least 5% and possibly 15% or more (see Bell, 1973; Long and Ossiander, 1974; Raymond, 1979; Weltkamp and Katz, 1975). Assuming only a 5-15% range in mortality, over 10 dams the culmulative numbers of fish killed could range from 40% to 80%.

Mortalities could be even higher than this in some cases. For example, in 1974 67% of juvenile quinnat salmon were killed when migrating from a tributary and through only two dams on the Snake River, U.S.A. (Raymond, 1979). This high mortality was due to both turbine related deaths and gas bubble disease.

Gas bubble disease in fish is caused by the intake of water super-saturated with dissolved oxygen and nitrogen gases. Gas super-saturation can occur in the spillways of dams and the disease can be caused by levels as low as only 18% supersaturation (Baxter, 1977). Although susceptibility varies with acclimation, age, and between species; high fish mortalities can occur. For example, gas bubble disease killed an estimated 50% of the adult summer quinnat salmon passing Wells Dam on the Columbia River over the period 1967-1969 (Weitkamp and Katz, 1975).

Impacts on fish and fisheries in the reservoirs

- (a) Compared to the present river there will be massive changes in physical features such as water depths, velocities, and substrates and smaller but still significant changes in water quality.
- (b) There will be great changes in the extent of particular aquatic habitats and a general decline in variety of habitats present. Conditions will become quite unsuitable for the survival and breeding of many river dwelling plants, invertebrates and fish, for example, torrent fish. Other biota could suffer from a decline in habitat quality, such as a decrease in food supply.
- (c) There will be great biological changes. Some species of animals will become more abundant, others less so. Significant changes in the degree of competition between and within species could occur and feeding and predation patterns change. For example, adult trout predation on young salmonids may be significantly different in the reservoirs. Changes in food especially may alter such factors as growth rate, for example, for a period after Lake Aviemore was initially filled there was an exceptionally high trout growth rate (Graynoth, 1970). Some of the aforementioned changes could occur rapidly, others may take many years.

9.2 A DESIGN TO MAXIMISE FISH PRODUCTION AND THE FISHERIES VALUE OF THE RESERVOIRS

We have carried out a preliminary study on the ways in which the fish production and fisheries values of the reservoirs could be increased. Considerably more work is required before a design could be finalised. Some of our suggestions maybe impractical or too expensive to put into operation, others may not be as effective as we would wish.

From a fisheries viewpoint the function of the reservoirs is to support both juvenile and adult trout, juvenile salmon, and adult salmon during their upstream migration. The reservoirs will also have to support angling for both trout and salmon.

Features of the reservoirs

1. Extensive areas of slow flowing, shallow water will be needed. Much higher stocks of salmonids and their food organisms are found in these areas than in deep, fast flowing channels. The precise area needed is not known. In Lake Waitaki, when power generation is in progress, there is a strong downstream current generally in the old river channel and the shallow side areas are relatively undisturbed (Whitehouse, pers. comm.). This suggests that in Option C the width of the reservoirs could be increased and flows could possibly be channelled down a deep central section leaving wide shallow areas on both sides. (Fig. 5).
2. The length of shoreline should be increased to a maximum and possibly small islands constructed in shallow areas. Again this should increase salmonid production and will also make the reservoirs more attractive to anglers.
3. The shallow areas should be prevented from becoming choked with aquatic weeds and algae.
4. Boat launching facilities will be needed and the banks should be designed so anglers could fish from them. Where the banks are steep, fishing piers, similar to those in the upper Kaitauna River at the outlet of Lake Rotorua, could be built.
5. Landscaping and the planting of trees, as around the banks of Lake Aviemore, will be needed. Too many trees however, will interfere with access and the casting of fishing lines.
6. Water level fluctuations should be reduced to a minimum. Large short term and even annual fluctuations in water level can severely damage trout and salmon food supplies and greatly reduce salmonid production (see Hunt and Linfield, 1973).
7. Submerged trees and shrubs should be removed before filling to prevent them catching anglers' lines and interfering with boating during low flows. Although this could remove some cover for young fish and spawning habitat for bullies.

Fish Passes

8. (a) Adult salmon will need assistance so they can migrate upstream to spawn and be available for capture in the reservoirs.

In the Columbia River, U.S.A., some salmon use fishways to negotiate 9 dams and climb 187 m in 640 km; others surmount 7 dams and climb over 244 m in about 800 km to reach their respective spawning rivers (Netboy, 1974). In the Waitaki, salmon may have to pass 10 dams and climb 209 m in about 60 km. Based on the Columbia River situation this may be technically possible. However, it will be expensive to construct the fishways; they will use some valuable water, and there is no guarantee that they will be successful.

Fish passes could be located only at the lower power stations. Thus fish will be available in the lower

reservoirs for capture by anglers. The fish will have to be trapped and transported the remainder of the distance to their spawning sites or to a hatchery.

Alternatively, no fish passes could be installed and the salmon could be trapped and transported from the lowest tailrace. We do not recommend this as fish will only be available to anglers in the short reach of river below the scheme and there are also difficulties in the trapping and transport of large numbers of fish.

8. (b) Fishways or trucking may also be needed for native fish and trout, especially if certain reservoirs are lacking in suitable spawning areas or habitat.

Fish Screens

9. (a) Ways will need to be devised to pass the salmon smolts that will be reared in the reservoirs safely downstream past the turbines. Alternatively a collection and transportation system may be needed.
9. (b) Screens to prevent trout and other fish being swept downstream are probably impracticable because of the great volume of water. Experience at Lake Waitaki indicates that although fish will be lost the fishery should not suffer from these losses.

Spillway Flows

10. (a) Spilling of water down dam spillways will need to be kept to a minimum as during spilling fish may be killed by the fall or by gas bubble disease.
10. (b) Spillway deflectors or perforated bulkheads (see Weitkamp and Katz, 1975) may be required to reduce gas supersaturation hence the chances of gas bubble disease.

Spawning channels and hatcheries

11. Special provisions will have to be made for the spawning of fish.
11. (a) Some native fish will spawn around the lake edges and others will use some of the tributary streams. Lake Benmore supports some bullies (the numbers are not known) despite its great fluctuations in water level. It is likely that similar bully populations will exist in the reservoirs of Option C. The survival of other native species will depend upon their access to the tributary streams and as previously mentioned, safe passage of migratory species up and down the river.
11. (b) Salmon and trout ideally need fairly fast flowing water of moderate depth flowing over fine gravel beds in which to construct their reeds (see Table 2). Spawning areas will be absent in the reservoirs and canals of Option C. Therefore, to maintain the present fishery, extensive use may have to be made of existing tributaries and/or artificial spawning races and/or hatcheries.
- (i) Tributary Streams.
The tributary streams will become particularly important for trout and salmon spawning and for the

rearing of young fish. If this option is proceeded with it is essential that the streams are protected from damage and enhanced. Possible methods of stream enhancement include addition of extra spawning gravel, the raking and cleaning of present gravels, improvements in fish access, eradication of predators, control of water abstraction and if possible the improvement of water supplies.

- (ii) Artificial spawning methods.
If the tributary streams were lacking in salmonid spawning gravels then their stocks must be maintained using artificial means, such as spawning races and/or by stocking hatchery reared fish (which have a much higher survival rate in lakes than in rivers, see page 40). Eggs could also be stripped and planted in the available streams. These artificial techniques have all been outlined earlier in this report with reference to enhancement of the fishery in Option A.

Improvements to this design

It is very likely that, if this option goes ahead, the eventual design will differ from that presented here and that much fishery research will be needed. Consideration will have to be given to, for example, the adequacy of food supplies, the survival rates of fish when passing through the proposed turbines, spawning and rearing and features such as fish passes, screens, fishing, piers and other structures. It may also be considered necessary to undertake some field experiments for example, on fish rearing in the existing hydro-lakes. Many other points for study exist or could emerge with further investigation. It may be possible to include other fishery enhancement features such as a small residual river paralleling the reservoirs or adapting a drain to serve some fisheries functions.

Biological features of the reservoirs

The series of reservoirs would be biologically similar to either Lake Waitaki or possibly the new Lake Ruataniwha. In appearance the reservoirs could resemble the lower reaches of Lake Waitaki or a deep, broad, slow flowing, single channel river such as the lower Clutha, punctuated with dams.

Glacial silt would be deposited and weed beds of, for example *Myriophyllum elatinoides* could develop in shallow, slow flowing areas. The lakes could also, in theory, become choked with stones and other debris brought in by the tributaries during floods.

A lake fauna dominated by snails, caddis and chironomid larvae will develop. As in Lake Waitaki (L. Whitehouse, pers. comm.) the retention time of water is likely to be so short that the in situ development of a lake planktonic population of zooplankton and possibly phytoplankton is likely to be inhibited. The species of fish present and their abundance will depend upon the design features mentioned above and on aspects such as stocking practices. Lake dwelling native species such as eels and the bullies *Gobiomorphus cotidinaus* and *G. breviceps* will be present, and the reservoirs will act as a passageway for *Galaxias brevipinnis*, provided these fish have access to the tributaries. Resident populations of brown and rainbow trout and possibly some sockeye salmon will develop. The reservoirs will act as rearing areas for juvenile quinnat salmon, although their value is very difficult to assess, as there are no comparable waters in New Zealand or overseas.

The fishery

The fishery developed in these reservoirs will be very different from that in the present river.

In contrast to the present situation some anglers will fish from boats using trolling, spinning and various fly fishing techniques. Anglers fishing from the shore should be able to use methods similar to those used in the present river (various fly, spinning and bait fishing methods). Hopefully the banks and littoral fringe of the reservoirs will be designed to cater for all the anglers' needs.

The quality of the fishing and whole leisure experience that will exist under Option C is difficult to assess, but will probably be inferior to that found in the present river. We suspect many anglers would prefer to fish in the present river, or in a similar residual river, than in the hydroelectric reservoirs. The reservoirs will be, to many people, less attractive aesthetically; there will be no or little experience of the wilds or nature - a very important element in angling. There are already available, similar fisheries to the reservoirs, such as the other hydro-lakes in the area and lakes in general and it is desirable to have a diversity. The Waitaki River, in many ways, supports a rare and attractive type of angling experience. The fast flowing water, variety of species, large size and abundance of the fish, make angling an enjoyable experience and one in which considerable skill is needed to catch and land fish. The fishery attracts anglers from all over New Zealand and from overseas (W.V.A.S., 1978) and it is very doubtful whether a chain of reservoirs will have the same appeal.

The quality of the angling will also depend upon the size of fish present and their abundance. The size and abundance of trout will probably be similar to that found in Lake Waitaki; which supports an average but not exceptional fishery (Graynoth and Skrzynski, 1973). Salmon will also vary in size, according to their age and conditions for growth in the sea. Their abundance will depend largely upon the unknown smolt rearing capacity of the reservoirs. However, even if salmon are abundant they may be difficult to catch. Adult sea run salmon do not feed in freshwater and it may be that they are only catchable in rivers because they congregate in pools and hence anglers can easily locate them and induce them to snap at lures. In a large deep reservoir they will be more dispersed and may be very difficult to find and catch.

The maximum crop of trout which could be taken from the reservoirs could possibly be estimated, given data on maximum crops in Lake Waitaki (present day crops probably range from 1,500-3,000 trout p.a.) and on the dimensions and other features of the reservoirs. The crop will probably be less than that which will be taken from the present Waitaki River (the current annual catch stands at 3-5,000 rainbow and about 10,000 brown trout) or from a carefully designed residual river. The future potential crop of salmon is unknown.

It is also most unlikely that the total fishery potential of the present river will be met in a canal and reservoir system with respect not only to the sports fishery but to salmon ranching, a commercial eel fishery or other fisheries developments.

9.3 CONCLUSION FOR OPTION C.

This development option of a chain of small hydroelectric reservoirs is not recommended for the following reasons:

- (a) There will be a loss of a running water ecosystem and its replacement with a less diverse lacustrine ecosystem. This will involve not only great physical changes but extensive changes in the aquatic habitats and massive biological alterations. Species of invertebrates and fish, such as the torrent fish, which live in rapid water, will die out. Some of the changes could occur rapidly, others may take many years, therefore the final and total effects will not be known for sometime.
- (b) There is considerable uncertainty as to whether the salmon stocks and fishery could be maintained. Considerable research will be needed into
 - (i) Adult migration problems such as the passage at fish passes, nitrogen and water quality problems.
 - (ii) Spawning grounds and/or hatchery developments.
 - (iii) Juvenile rearing problems such as residualism, trout predation, lack of food, mortality due to water quality problems, turbine and spillway deaths.
 - (iv) Angling and catchability of fish.

Some of these problems may prove insolvable.

- (c) There will be the loss of a famous and high quality trout fishery and its replacement with a fishery of much lower quality. Again much research, into similar problems as outlined above in (b), will be needed.
- (d) The potential of the present river to support salmon ranching and other fisheries developments will be reduced.
- (e) There may be economic and development constraints on this option. For example, it may be expensive to control weed growths or it may not be practical to widen the width of the reservoirs, or permit tributaries with high bed loads to flow into the reservoirs. If such constraints were enforced the fishery will suffer further losses.
- (f) The general decline in attractiveness of the environment for both anglers and other leisure seekers and the replacement of the existing river with an environment already offered elsewhere.
- (g) Fisheries development and management costs, for example research, hatcheries, spawning races, fish passes or a trucking programme will be expensive, may not be as successful as hoped, and may be difficult to carry out on such a large scale.

10. CONSTRUCTION PROCEDURES

The fish stocks and fisheries must be maintained and protected while the power scheme is being constructed as this may take as long as 25 years (M.W.D., 1978).

Experience with power projects such as the Tongariro and Upper Waitaki shows the need for close liaison between M.W.D. and fisheries personnel. In the past many fisheries problems have arisen and not all have been successfully solved. For example, large amounts of silt derived from tunnelling operations have entered the Tongariro River, the Twizel River has been grossly polluted with silt for many years as a result of canal construction and recently part of the Tekapo River has been destroyed, from a fisheries viewpoint, by channelization. In the present lower Waitaki River training works and survey road construction have resulted in productive side streams being damaged and cut off from the main river.

During construction on the lower Waitaki the fish stocks and fisheries could be severely and permanently damaged by floods, together with experimental and emergency discharges from the power canal. Legislation, normally designed to protect fisheries (The Fish Pass and Fisheries Act), will not apply to such a Government sponsored power project; although water right conditions are binding on the Crown and may impose some control.

To maintain and protect the fisheries during power development construction, various steps may be taken. No matter what development option is proceeded with, it seems highly desirable that an independent fisheries inspector, with considerable authority and with some degree of veto power over construction work and the management of the river, should be appointed to the project. The inspector could prevent temporary dams, water and gravel abstractions, etc. that will be extremely harmful to the fauna and possibly the fishing conditions. If a residual river is to be constructed this could be developed first, managed and hopefully protected from the adverse effects of construction. If the fishery is to be within the power canal, consideration and study should be given to maintaining fish stocks in the river during construction. Under no circumstances should the power canal be completed and then a start made on the floodway and/or residual river, fisheries requirements and anglers' needs.

11. CONCLUSIONS

The present lower Waitaki River contains a diverse and abundant fish fauna, many species of which are migratory, and supports a salmon and trout fishery of national importance. It has the potential to support further angling and other recreational pressure and developments such as a salmon ranching industry.

In this report we developed and considered three hydro-electric development options, each, we believe, representative of the developmental themes presented by the Ministry of Works and Development in their 1979 report. We have not considered the possibility of leaving the river as it is and producing (or not producing) energy by other means; this remains an important option. The three options discussed here are effectively a three channel (Option A), two channel (Option B) and single channel (Option C), development of the existing river.

Option C, a chain of small hydro-electric reservoirs, will impose radical changes on the existing river. The present river's fisheries are likely to be adversely affected, in particular the high quality trout fishery and the present rivers potential for salmon ranching could be lost. Other interests such as the eel fishermen, picnickers, native fish fauna and wildlife will also be affected. The angling offered is likely to be similar to that already available in the other hydro-lakes and fisheries developmental and management costs could be expensive. We believe a chain of small hydro-electric reservoirs is an undesirable developmental option.

Option B, a residual river/floodway and power canal, is also undesirable. This option will offer what we consider is a fishery of poor quality in the power canal and a fishery and wildlife habitat in the residual river. However, there will be frequent floods in the residual river and these are likely to make this a very inhospitable environment for fish and other fauna. As with Option C, maintenance of the present fishery will be difficult, fishery maintenance costs high and much research needed.

Option A plans a residual river, power canal and floodway. We believe that development under this option holds the greatest potential for maintenance of the qualities of the present river. The residual river should provide a fishery of far better quality than that which will occur under Option B, because of the accommodation of excess water by the floodway. A suitably designed residual river may also support the present river's wildlife and other uses and the power canal could possibly offer a small secondary fishery. However, it is also likely that considerable funds and much research will be needed to achieve the best results.

Whatever option is proceeded with it will be important to consider the effects of construction procedures on the present or proposed river and try to mitigate these as much as possible.

12. IMPACT ASSESSMENT AND PROPOSED FISHERIES RESEARCH

There is a great need for knowledge about the impact of power development on the lower Waitaki River. N.Z.E. recognised this and agreed to fund, in conjunction with F.R.D., research on the fisheries of the present river and the design of possible alternatives under the proposed lower Waitaki Power Development Scheme.

The planned research programme will involve scientific consultants financed by N.Z.E. working in association with F.R.D. staff and university personnel.

Initially the existing historical information on the invertebrate fauna, native fish, salmonid redd characteristics, trout, quinnat salmon and angling surveys are to be analysed and published. The strengths and weaknesses of this information will be considered in the final design of the subsequent programmes.

Within the interlinking research projects the main topics for study include the sports fishery, adult salmon, adult trout, juvenile salmonids, wildlife and native fish stocks, recreationalists and smaller fisheries, hydrological and engineering studies.

The present sports fishery will be monitored to obtain accurate statistics on angling effort, catch and catch rates. In addition, the fishery will be valued in recreational and in commercial and possibly economic terms. Work will be done to ascertain what anglers will require in the fishery after development. Information on the relationships between adult trout and salmon density, size and species composition and angling efforts, catch rates and maximum sustainable yields will also be obtained. These studies will be undertaken in the present river and in the demonstration channels.

Adult salmon will be studied to determine the size of the present spawning runs and rates of egg deposition. The mitigation of the impact of the power scheme on their upstream migration and behaviour will also be assessed.

Aspects of the biology of adult brown and rainbow trout, such as the fecundity, population structure and diet will be studied in the present river, in the demonstration channels and in existing stable rivers elsewhere in New Zealand. The resulting data will be used to design a productive system (e.g. residual river) which makes the best use of the water available.

Aspects of salmonid reproduction and rearing will be studied by investigating and quantifying the value of the existing spawning and rearing areas. There will also be studies on aspects of smolt migration and survival and the work by Dr Scott and his team in the replicate channels. The required levels of trout recruitment and salmon smolt production needed in a residual river will have to be calculated and methods of meeting these demands determined.

Work will also be required on the value of the present river to other fishery interests such as salmon farmers and to recreationalists other than anglers. As far as possible their needs must be ascertained and met in the design of a residual river. Research into the native fish stocks will also be undertaken.

An important area for study will be the design of any culverts, fish passes and flood diversion structures required in the modified river. It will be crucial to the entire programme that such features are adequately tested prior to incorporating them into the scheme, so that

problems such as those caused by the Waitaki Dam fish pass are not repeated. Another important aspect is the design and timetabling of construction procedures to avoid excessive and unwarranted destruction or channelization of the present river during construction and to detail the formation and protection of any fisheries developments prior to the start of construction on the river.

There are several other topics which will also have to be considered. These include the effects to fish stocks of introduced and native fish being trapped in the floodway after flood waters subside and methods to maintain the features of the present lower reaches of the river below the power scheme. Information on the hydrology of the present river will also be needed to determine the flood diversion structures required and also to help describe the present physical resource used by the fish and fauna.

All the studies planned will be of sufficient depth to provide adequate information for preparation of environmental impact assessment reports and Water Right and Town and Country Planning applications. The studies should also be sufficient to provide criteria for the design of any additional fisheries facilities that are deemed important.

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APPENDIX OPTION B. THEORETICAL MODEL OF THE IMPACT OF FLOODS IN THE RESIDUAL RIVER

A theoretical assessment of the effects of floods on the physical features of a residual river

To predict the effects of floods on the hydraulic geometry of a future residual river, accurate information is needed on features such as the numbers of channels present, their widths, water velocities and depths and on features of the substrates such as the specific gravity and size composition of the gravels. Unfortunately this information is almost wholly lacking for the Waitaki River.

Because of the lack of field data the only practical solution was to theoretically calculate and model the effects of floods on the residual river. A representative cross section of the lower Waitaki was selected for study and simulated changes in water depths (see Fig. 11) and hence velocities were calculated.

The cross section selected was located near Duntroon, 2.4 km east of the S.H. 83 bridge across the Maraewhenua River. The widths of the various channels were determined from measurements taken from the aerial photographs in M.W.D., 1979.

Channel morphology

There was however, no information on the depths or cross sectional shapes of these river channels and therefore it was necessary to determine these features using data from the Rakaia River (M.W.D., Water and Soil Div.). Ten channels ranging in width from 23 to 100 m and in discharge from 22 to 153 cumecs were examined. These channels had an average width/maximum depth ratio of 40 (range 27 to 57) and were in general triangular in shape, steadily increasing in depth from their margins to the central thalweg. The inaccuracies of using the Rakaia data are realised, however, it is not thought that any serious errors will be caused by its use.

Water velocities

Water velocities are dependent upon the depth of the water column, the roughness of the stream bed and the slope of the stream. For the purposes of the model velocity was calculated using Manning's equation assuming a 'n' value of 0.03 (Te Chow, 1964) and using the mean slope of the Waitaki of 0.0032. Based on these figures water columns of 0.5, 1, 2 and 3 metre deep have calculated mean velocities of 1.2, 1.9, 3 and 4 m/sec respectively.

Therefore the relationship between channel discharge (Q) and channel widths (W), mean depths (D) and mean velocities (V) are as follows:

$$W = 11.41 Q^{.375}, \quad D = 0.14 Q^{.375}, \quad V = 0.61 Q^{.25}.$$

Substrates

Visual observations indicate that the riverbed is composed of grey flattened graywacke stones, generally of an oval shape with the short cross axis ranging between 10 and 15 cm in diameter. The central regions of the larger channels are generally armoured with stones of this size and between and below them there are finer gravels and silt. Some channels flow over bedrock.

At the margins of the channels and in slow flowing areas are beds of finer gravel down to 2 to 5 cm in diameter. In the main channels and those subject to lateral movement of the stones often have a thin covering of glacial silt. In more stable areas and during low flow

periods the stones can become coated with a thick (5-10 mm approx.) layer of silt, filamentous algae and slime, and become a hard compacted bed.

Sizes of gravel moved by floods

The particular sizes of gravel moved and bed loads during floods depends upon such features as the composition and stability of the streambed and banks; water velocities and discharges within particular channels and the amount and composition of sediments entering the river system.

Where gravels are uncompacted, such as after floods, and are not armoured and protected by the presence of larger stones and boulders it is possible to calculate the water velocities which move stones of various sizes using the equation $d = 11.R.S$

where d = maximum transportable size of gravel (diameter in mm.)
 R = hydraulic radius and S = slope (Henderson, 1959; Jowett, 1979).

The hydraulic radius was assumed to be equal to the depth and the slope to the mean slope of the Waitaki of 0.0032. Using this formula, gravel of 5, 10 and 15 cm in diameter will be transported when water depths exceed 1.42, 2.84 and 4.26 m respectively. At these depths average water velocities are estimated at 2.4, 3.8 and 5 m/sec. respectively.

These values were compared to those obtained by the use of tractive shear-bed particle diameter equations (Orsborn and Allman, 1976, p. 513) and to the relationships found between water velocity and the erosion and transport of sediment particles e.g. Hjulsom (1935, quoted in Orsborn and Allman, 1976) and Leliavsky (quoted in White and Brynildson, 1967). A good agreement was found, indicating that these values are appropriate for use.

Observations indicate that in reality the bed is generally fairly uniform in composition is not protected by larger stones and boulders. However, the bed does become compacted with time and quite how this effects this equation and relationship is not known.

The movement of salmon and trout spawning gravels

Trout and salmon spawning gravels generally range in diameter from 15 to 80 mm and are hence finer than most lower Waitaki floodbed gravels. The stones are winnowed out and deposited in areas where velocities are generally lower during floods. They normally become compacted in time and may be armoured with larger stones. Therefore, to determine what flows will dislodge and move spawning gravels, it may be best not to use the equation $d = 11.R.S$ but rather a simple expression such as $3 \times m$, where m is the mean flow (see Jowett, 1978). This expression suggests that spawning gravels will be moved in the residual river at flows above about 120-150 cumecs.

The origin of the sediment moved during floods

In the Waimakariri River, a braided shingle river in Canterbury, at least 65% of the gravels in the bed loads are derived locally from the channel bed and banks and not from the upper catchment area (Griffiths, 1979). This is also probable in the Lower Waitaki where there has been no gravel input from the upper catchment since the construction of the Waitaki Dam in 1935 and observations indicate that large amounts of material are eroded from the channel banks during floods, because of the lateral migration and movement of channels.

Visual observations indicate that large amounts of stones, soil and vegetation are carried during floods by tributaries such as the Hakataramea, Penticotico and Maraewhenua. It has also been noted that the sediment derived from the Hakataramea is generally finer than that in the main river. In the future the nature of this sediment may influence the river bed and bed loads of the residual river, and, because of the general reduction of flows in the main river, may accumulate below tributary streams junctions with the main river.

Bedload

We have not been able to obtain data on bedload during floods of various sizes in the Waitaki, or other comparable South Island east coast rivers, and therefore realistic theoretical calculations of bed load cannot be made.

It is of interest to note that the bed load in the Tongariro River in the North Island which is a single channel river of similar slope to the Waitaki, and now has a mean flow of approximately 31 cumecs, is very low below about 70 cumecs, it then starts to increase rapidly reaching 100, 1,000 and 10,000 tonnes per day at 100, 170 and 425 cumecs respectively.

The maximum size of gravel moved increases from about 24-50 mm at 100 cumecs to 75-150 cm at 400 cumecs (Jowett, 1979).

The influence of channel training works

Channel training works could also have a significant influence on how floods effect the fish stocks and fisheries. Three different schemes have been considered in the model and all apply to a residual river/floodway with an average to wide flood plain.

1. The river could be confined during floods to particular channels by increasing the height and strength of the banks. After floods the residual flow will be diverted down one principle channel, the other channels being left dry.
2. The present central floodway, which has been cleared of willows and other vegetation, could be retained, together with overspill channels to either side (see M.W.D. (1978) p. 16).
3. An attempt could be made to simulate a separate residual river and floodway as in option A. The residual channel(s) will be protected against the effects of floods by permeable banks or other control structures at their upstream ends and by stopbanks at appropriate places downstream.

All of these schemes will require continued maintenance to divert water back into the mainstem channel(s) after floods and to keep the floodway clear.

Research

As outlined above, field studies are needed to determine many aspects of hydraulic geometry, bed composition, etc., in the lower Waitaki.

Information is also needed on the height of the banks to determine whether they will be overtopped during floods. Visual observations suggest that banks in the lower Waitaki are generally low, rarely exceeding 0.5 to 1 metre in height and this feature has been incorporated in the model (Fig. 11). Because of this, the first management option, which proposes the containment of flood waters within channels, is not directly applicable to the model.

Despite the lack of information it was found possible to model the distribution of water in various channels across the flood plain during residual flows and during floods (Fig. 11). It is naturally a very simple model and should be refined and developed using actual cross-sectional data from the Waitaki. The model assumes that the water level in all channels is equal and also that flows in all channels increase and decrease proportionally during floods. It is not thought that these assumptions will have introduced any serious errors.