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NEW ZEALAND FRESHWATER FISHERIES MISCELLANEOUS REPORT NO. 30

ASSESSMENT OF THE FLOW-RELATED EFFECTS OF THE WAITAKI POWER SCHEMES ON THE AQUATIC RESOURCES OF THE LOWER WAITAKI RIVER

by

J P. Graybill

G.D. James

I.G. Jowett

J.R. Young*

Report to: Electricorp

Freshwater Fisheries Centre

MAF Fisheries

PO Box 8324

CHRISTCHURCH

* Canterbury Regional Council, Timaru

Servicing freshwater fisheries and aquaculture

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Enquiries to: The Librarian
Freshwater Fisheries Centre
PO Box 8324
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CONTENTS

	Page
1. Introduction	1
1.1 Hydro-electric Development	1
1.2 Minimum Flow	1
1.3 Flow Regime Studies	3
1.4 Fisheries Resources	5
2. Comparison of Historical Flow and Fisheries Records	5
2.1 Flow	5
2.2 Historical Flow Patterns	5
2.2.1 Seasonal Pattern	6
2.2.2 Pattern Changes Over Time	6
2.3 Historical Fisheries Records	15
2.3.1 Narrative Summary - 1914-1989	20
2.4 Interpretation and Comparison of Historical Flow and Fisheries Records	24
2.4.1 Angling Conditions	24
2.4.1.1 Effects of River Control Works	26
2.4.2 Fish Stocks and Runs	27
2.4.3 Overview	29
3. Relationship Between Flow and Water Level	30
3.1 Introduction	30

Page

3.2 Stage Dampening 31

3.3 Flow/Water Level Relationships 37

3.4 Impact on Aquatic Resources 40

3.5 Effect of Flow Reduction on Salmon Spawning Depths 40

4. Fish Stranding 42

5. Redd Dewatering 43

6. Potential Impacts to Other Aquatic Resources 45

6.1 Macrophytes, Periphyton, and Benthic Invertebrates 45

6.2 Native Fish 46

6.2.1 Stranding 47

6.2.2 Reproduction 47

6.3 Salmon and Trout Spawning Behaviour 48

6.4 Adult Salmon Migration 49

6.5 Salmon and Trout Fisheries 49

6.6 Non-Salmonid Fisheries 49

7. Summary and Recommendations 50

8. Literature Cited 51

Appendix I. Minimum, maximum, and range of flows at Waitaki Dam for each day in 1967, 1974, and 1985. 57

Page

TABLES

1. Events in the development of the Waitaki scheme affecting flow patterns in the lower Waitaki River. 2

2. Average time for a crest of water to travel from Waitaki power station to various points downstream. 36

3. Change in water level for a flow charge of 100 m^3/s in the Waitaki River downstream of Waitaki Dam. 39

FIGURES

1. Long-term natural (simulated) and regulated flow at Waitaki Dam, 1973-85. 7

2. Scattergrams and regression lines for mean summer (January-March) and winter (July-September) flow at Waitaki Dam, 1927-1988. 8

3. Hydrograph of lower Waitaki River flow at Waitaki Dam, 1927-1985. 9

4. Hydrograph of simulated natural flow at Waitaki Dam, 1927-1985. 10

5. Hydrograph of mean daily flow at Waitaki Dam, 1941-1943. 12

6. Hydrograph of 3-hourly flow at Waitaki Dam, 1966-1968. 13

7. Hydrograph of 3-hourly flow at Waitaki Dam, October 1967. 14

8. Hydrograph of 3-hourly flow at Waitaki Dam, 1974-1976. 16

9. Hydrograph of 3-hourly flow at Waitaki Dam, March 1974. 17

10. Hydrograph of 3-hourly flow at Waitaki Dam, 1984-86. 18

11. Hydrograph of 3-hourly flow at Waitaki Dam, May 1984. 19

12. Hydrograph of lower Waitaki River flow at Kurow, 27 April-5 May 1989. 32

Page

13. Hydrograph of lower Waitaki River flow at Kurow, 0600 4 May - 1200 5 May 1989. 33

14. Water levels (stage) recorded at seven sites on the lower Waitaki River, 27 April - 5 May 1989. 34

15. Water levels (stage) recorded at six sites on the lower Waitaki River, 1200 4 May - 1200 5 May 1989. 35

16. Relationship between water level (stage) and flow at 3 sites on the lower Waitaki River. 38

17. Suitability functions for chinook (quinnat) salmon spawning (from Bovee 1978). 41

1. INTRODUCTION

1.1 Hydro-electric Development

The Waitaki catchment has been extensively developed for hydro-electric production by New Zealand's electricity authority (now called Electricorp, EC) over a period of nearly 60-years. Construction began on the first and most downstream of the dams, Waitaki Dam, in 1928. It was largely a run-of-river dam with little storage capacity to provide long-term control of the flow in the lower river. Other facilities were built upstream of Waitaki Dam in subsequent years (see Table 1) which added significantly to the overall electricity production and water storage capacity. The Waitaki scheme presently contributes more than 50% of the total production and more than 80% of the controlled storage in the South Island (EC 1988). As a result the presence and operation of the Waitaki scheme has altered significantly the streamflow patterns of the lower Waitaki River.

1.2 Minimum Flow

By agreement between the then Waitaki Catchment Board (WCB) and EC the minimum flow at Waitaki Dam is 120 m^3/s. On occasion a minimum flow of 90 m^3/s is allowed after consultation with the WCB for such actions as search and rescue, livestock movement, bridge inspection, etc. There are no limitations during emergencies such as power plant failure. The maximum rate of flow change (ramping rate) has normally been 30 $m^3/s/hr$.

TABLE 1. Events in the development of the Waitaki scheme affecting flow patterns in the lower Waitaki River. Adapted from Natusch (1987) and Electricorp information.

1928	Construction began on Waitaki Dam.
1935	Waitaki Dam began generating.
1940–54	Waitaki Dam generation expanded in four steps.
1948	Pukaki Lake control.
1951	Tekapo A began generating.
1953	Tekapo Lake control.
1965	Benmore Dam began generating.
1968	Aviemore Dam began generating.
1977	Tekapo B began generating.
1977	Pukaki Lake control – high dam.
1979	Ohau Lake control.
1979	Ohau A began generating.
1983	Ohau B began generating.
1985	Ohau C began generating.

In mid-May 1984 the instantaneous flow at Waitaki Dam was reduced to about 84 m^3/s to accommodate a scheduled bridge inspection at Kurow. This coincided with the peak of the salmon spawning in the lower Waitaki and the Waitaki Valley Acclimatisation Society (WVAS) observed that salmon redds became dewatered which had the potential to adversely affect salmon stocks. As a result the WVAS requested that the minimum flow be raised from its present level to protect fishery resources.

1.3 Flow Regime Studies

Under the auspices of the WCB a working party was established to consider issues related to flow regime. It was concluded that insufficient information was available which could be used to accurately predict the effects of the existing flow regime on fish stocks and fisheries. We undertook studies funded by EC, to assess the effects of regulated flow on fish stocks and fisheries of the lower Waitaki River. The study objectives were:

1. to assess the effects of past and current flow regimes on fish stocks, fisheries, and other aquatic resources; and

2. to determine a flow regime to counter adverse effects of the current flow regime on these resources.

These flow regime studies are being undertaken in two stages. Stage 1 studies make use of mostly existing information to make assessments of the effects of past and present flow regulation. From these we will assess where information is lacking and whether or not further studies (Stage 2 studies) would be productive.

The findings of the Stage 1 studies are presented in this report and cover the following topics.

1. Comparison of historical flow records and historical fisheries records.

2. Prediction of changes in water level with changes in flow, particularly in salmon spawning areas.

3. Assessment of stage (water level) dampening with distance downstream.

4. Assessment of fish stranding.

5. Assessment of redd dewatering.

6. Review of information on the general effects of flow fluctuations on macrophytes, periphyton, macroinvertebrates, native fish, salmon, trout, and fisheries.

1.4 Fisheries Resources

The lower Waitaki River supports important recreational fisheries for chinook salmon, brown trout, and rainbow trout as well as for a variety of native fish species. The salmonid fisheries are recognised as being nationally important whereas those for native fish species are locally important. The life history of lower Waitaki fishes and the general status of fish stocks and fisheries are described in Graybill et al. 1988.

2. COMPARISON OF HISTORICAL FLOW AND FISHERIES RECORDS

2.1 Flow

The waters affected by the Waitaki power scheme are the 65 km of the mainstem Waitaki River that extend from Waitaki Dam to the sea. The mean discharge from Waitaki Dam is 349 m^3/s. This increases to 364 m^3/s at the mouth with the inflow of tributaries. The mean annual flood has been reduced by an average of 35%, from 1250 m^3/s to 800 m^3/s.

2.2 Historical Flow Patterns

The lower Waitaki flow is regulated to a large degree by hydro-electric reservoirs and power stations with the result that river flow varies with power demand. Daily, weekly, and annual cycles are superimposed on the natural flow regime.

2.2.1 Seasonal Pattern

The seasonal pattern of the "natural" flow regime of the lower Waitaki has been altered significantly by flow regulation (Fig. 1). Natural flow patterns were characterised by high flow in late spring and summer from snowmelt in the upper catchment and low flow in the winter. The general effect of regulation has been an increase in the winter flows with water stored during spring and summer, and a corresponding decrease in the summer flows. This is clearly shown when mean summer (January-March) and winter (July-September) flows are plotted over time (Fig. 2). As a result the monthly mean regulated flows vary little through the year (Fig. 1).

2.2.2 Pattern Changes Over Time

There have been distinct changes in the patterns of flow fluctuations over the course of hydro-electric development. Some of these are apparent in the hydrographs for Waitaki Dam for the period from 1927 through 1985 (Fig. 3). Simulated natural flow at Waitaki Dam is shown in Fig. 4 for comparison. (Note: In Fig. 3 flows shown prior to mid-1965 were recorded as mean daily flow while flows thereafter were recorded 3-hourly. Therefore the abrupt change in appearance in the hydrograph in mid-1965 is an artefact.)

From the beginning of the flow records in 1927 to about 1947 the regulated flows are virtually indistinguishable from simulated natural flows. From 1948 to some years before 1965 it is likely that the daily range in fluctuations became progressively wider although records are not

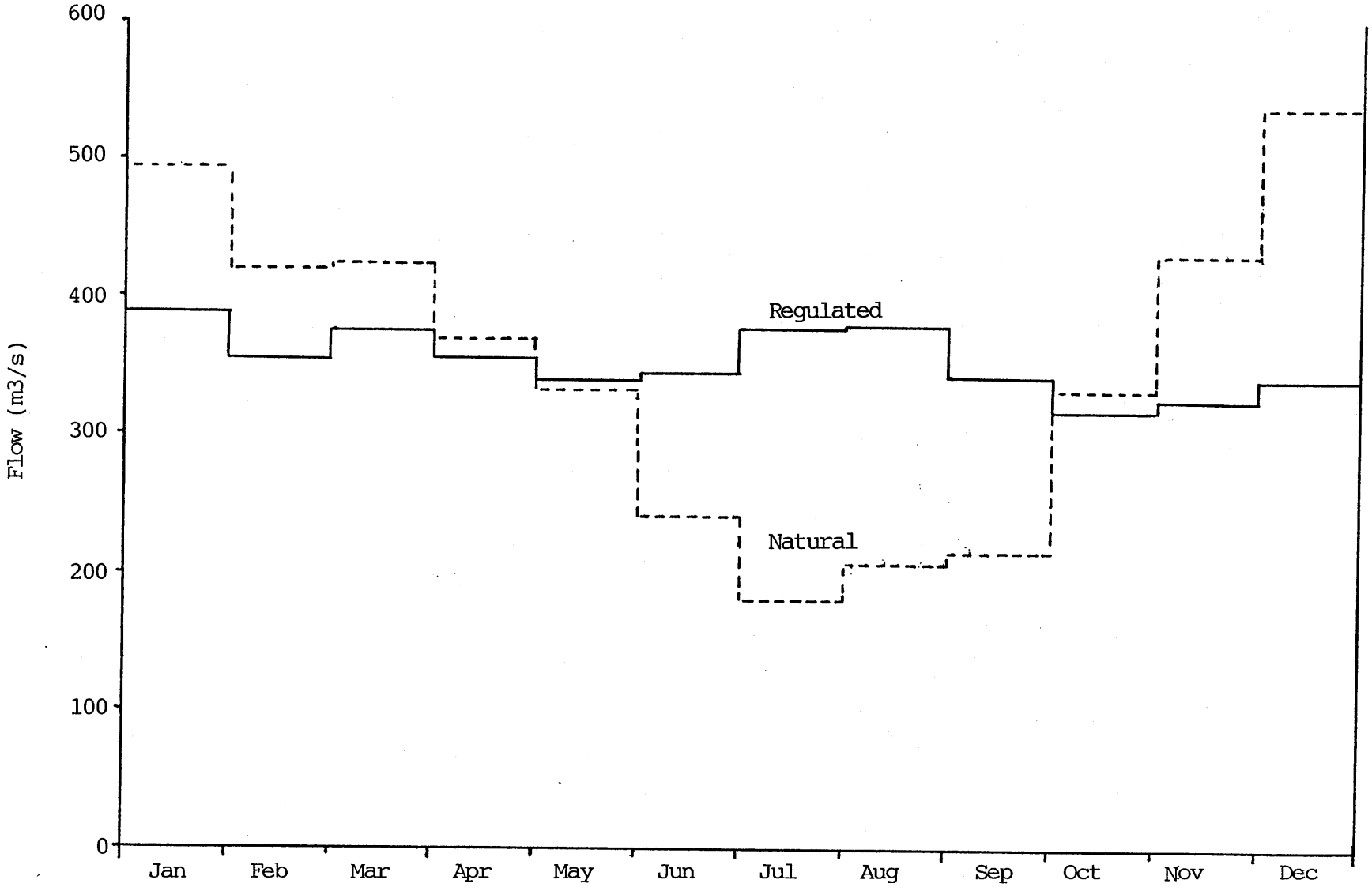


FIGURE 1. Long-term natural (simulated) and regulated flow at Waitaki Dam, 1973-85.

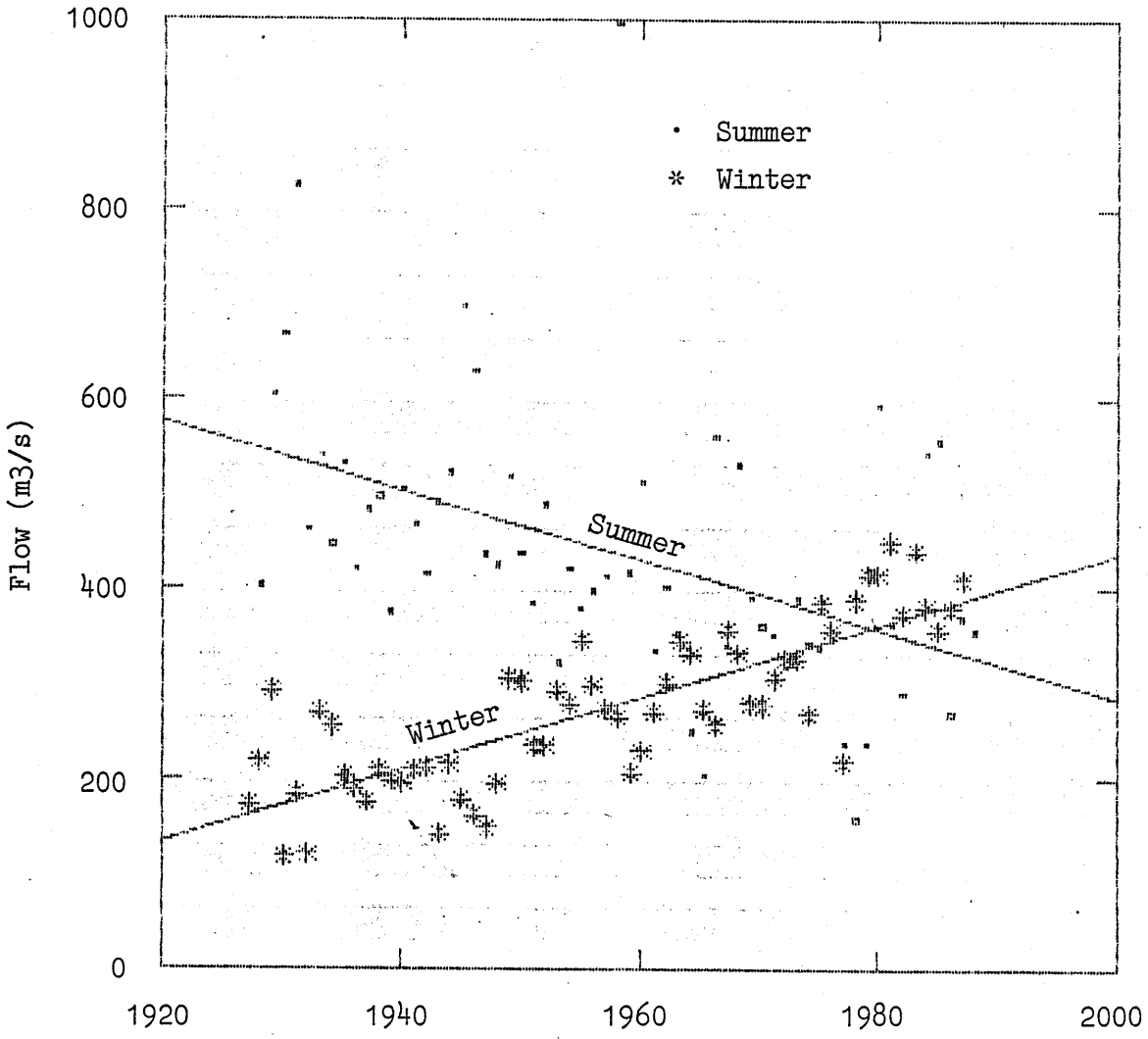


FIGURE 2. Scattergrams and regression lines for mean summer (January-March) and winter (July-September) flow at Waitaki Dam, 1927-1988.

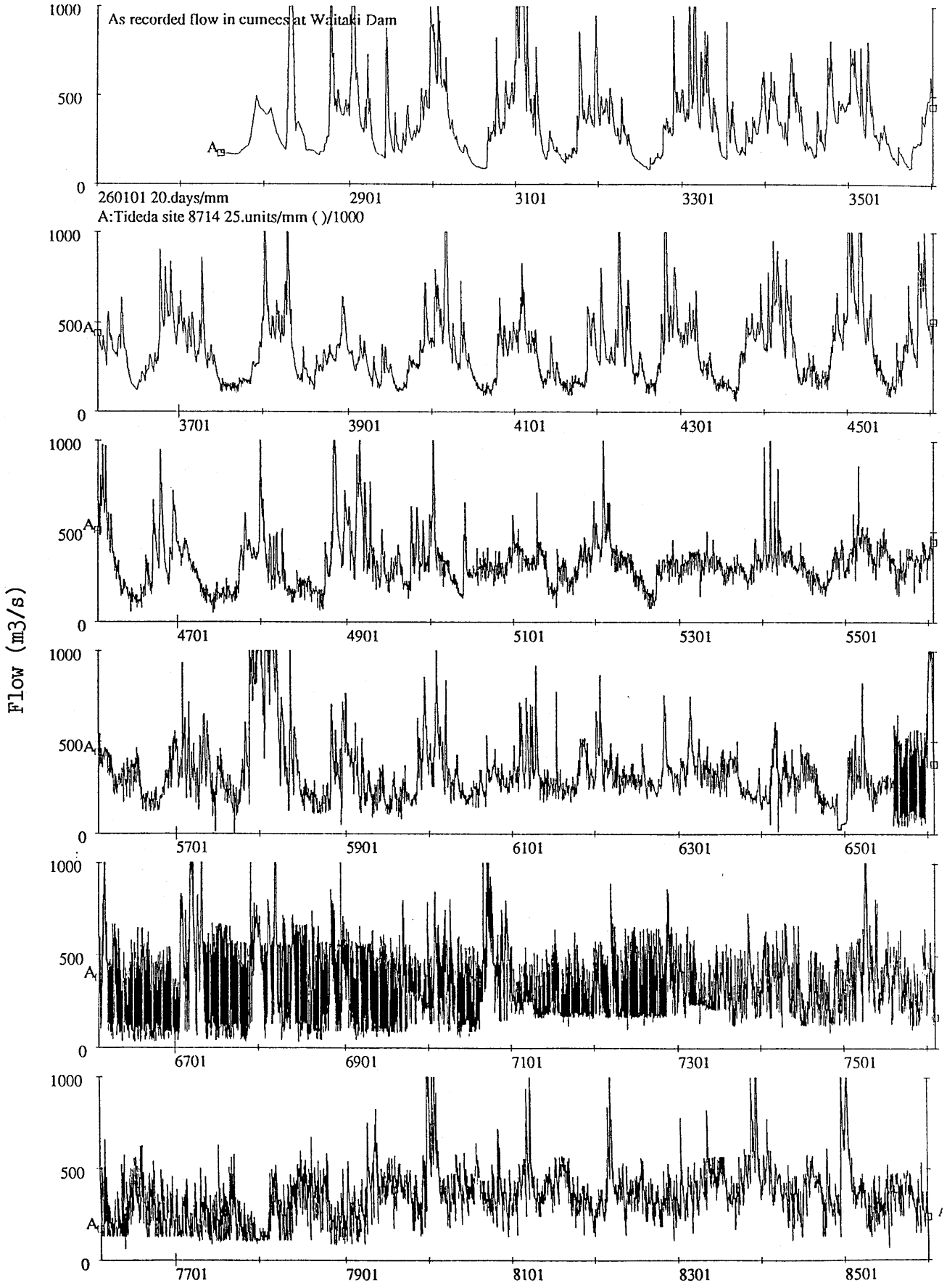


FIGURE 3. Hydrograph of lower Waitaki River flow at Waitaki Dam, 1927-1985. Flows shown prior to mid-1965 were recorded as mean daily flows while those after were 3-hourly. (Source: Hydrology Centre, Christchurch).

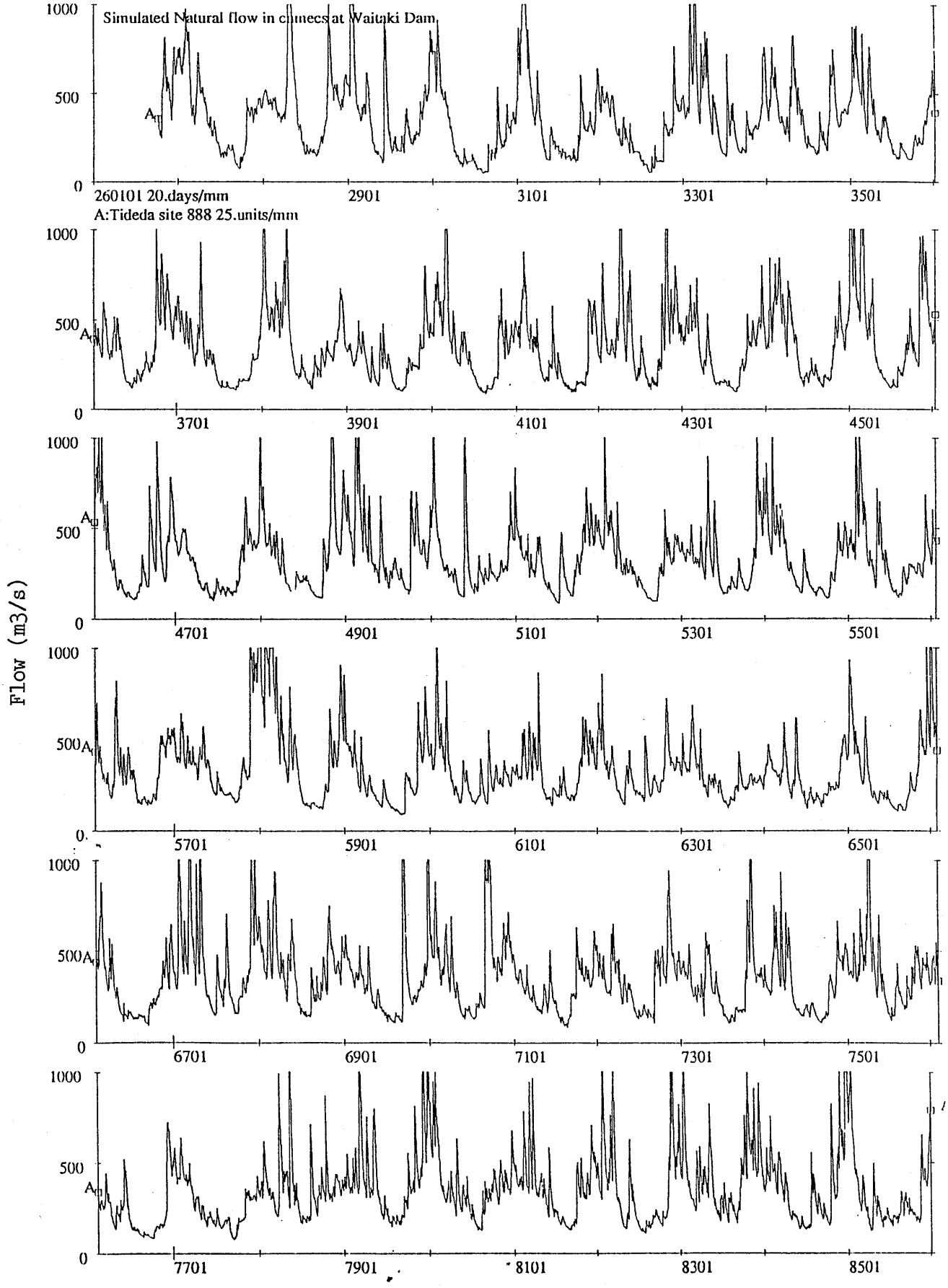


FIGURE 4. Hydrograph of simulated natural flow at Waitaki Dam, 1927-1985. (Source: Hydrology Centre, Christchurch).

readily available to show precisely how this occurred. Suffice it to say that by mid-1965 flow fluctuations had probably developed to the widest possible range. From mid-1965 through 1972 the hydrograph shows a pattern typical of daily hydro-peaking operation with fluctuations often ranging from about 100 m^3/s to over 500 m^3/s each day. From 1973 to 1985 the peaking pattern has continued but has been much less severe than that of 1965 to 1972.

To assess how these flow patterns may have affected fish it is useful to look at representative periods in more detail. The periods chosen are 1941-43 when regulated flow reflected natural flow; 1966-68 when flow fluctuations were most severe; and 1974-76 and 1984-86 when flow fluctuations became progressively less severe. Appendix I contains tables of the minimum flow, maximum flow, and range of flows at Waitaki Dam for each day in 1967, 1974, and 1985.

Flow variation in the 1941-43 period was in general relatively gradual (Fig. 5). Floods and freshes showed a natural pattern of quick onset to a relatively sharp peak followed by a progressively more gradual recession.

The 1966-68 hydrograph (Fig. 6), outside the periods of high flow, is dominated by daily flow fluctuations. Flows typically ranged each day from a minimum of about 100 m^3/s to a maximum of over 500 m^3/s, a difference of over 400 m^3/s each day (Fig. 7). The minimum daily flow for each month was commonly between 40 and 45 m^3/s (Appendix I). High flow events were characterised by gradual onset to a truncated but prolonged peak followed by gradual recession.

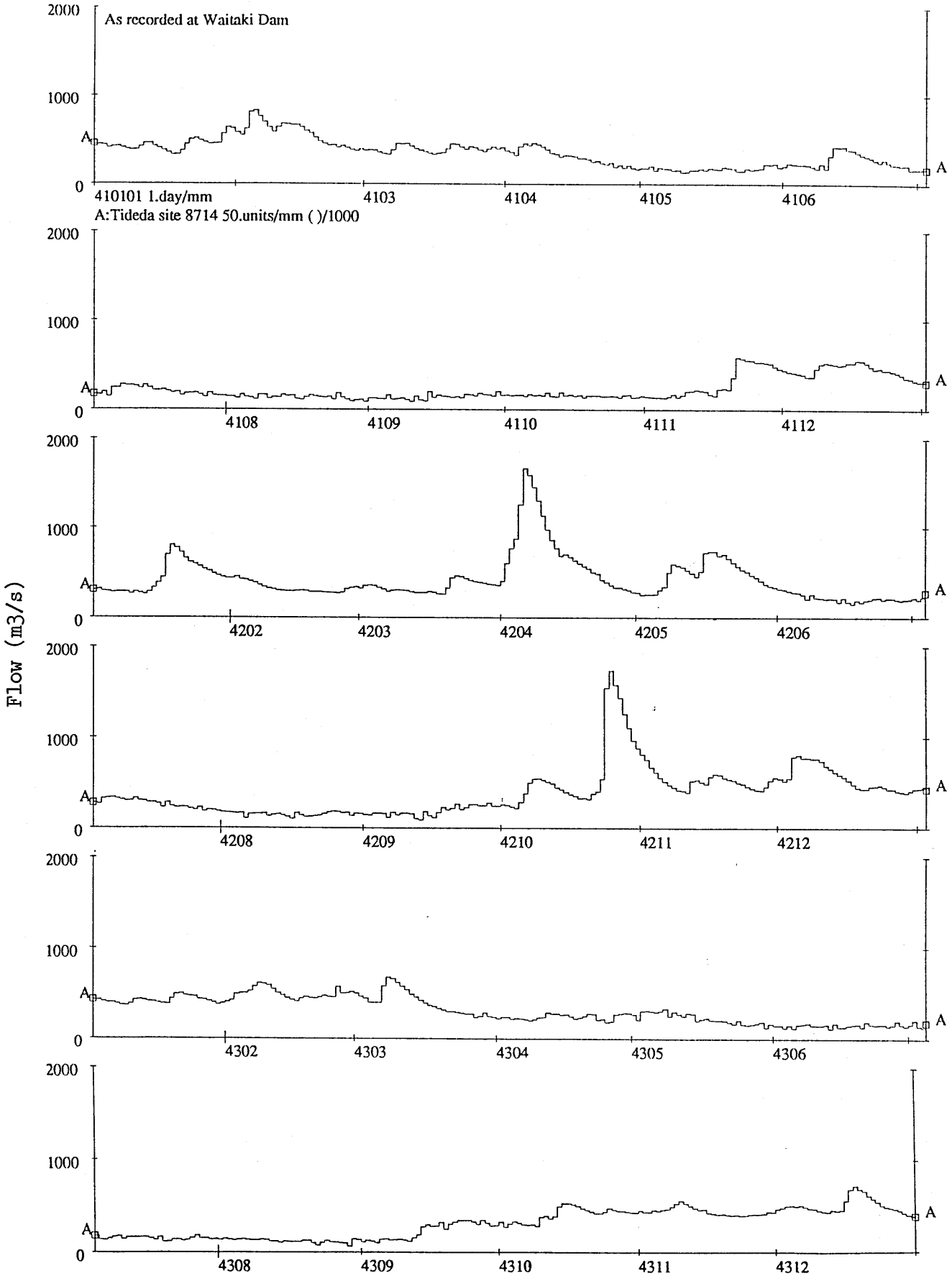


FIGURE 5. Hydrograph of mean daily flow at Waitaki Dam, 1941-1943. (Source: Hydrology Centre, Christchurch).

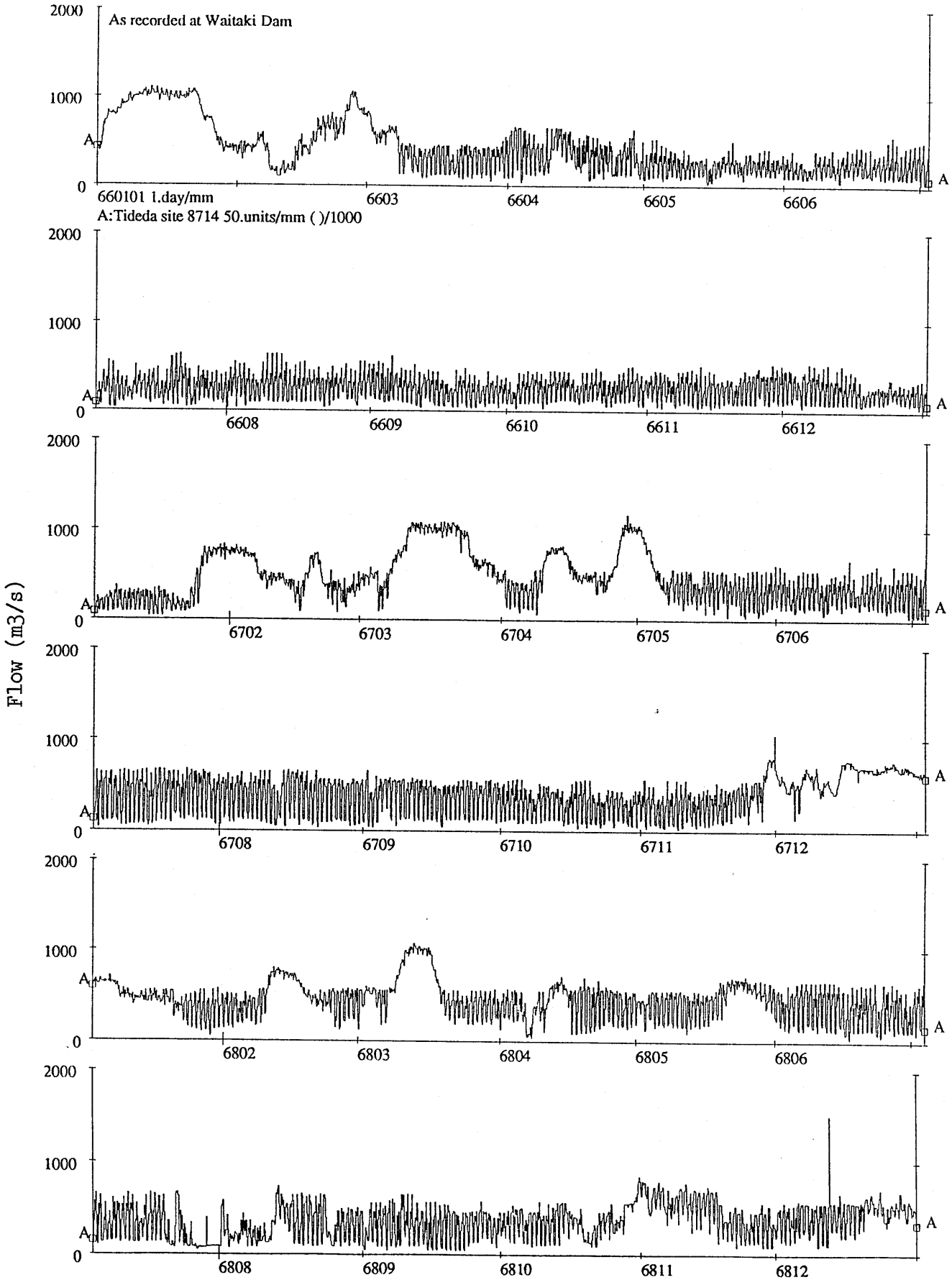


FIGURE 6. Hydrograph of 3-hourly flow at Waitaki Dam, 1966–1968. (Source: Hydrology Centre, Christchurch).

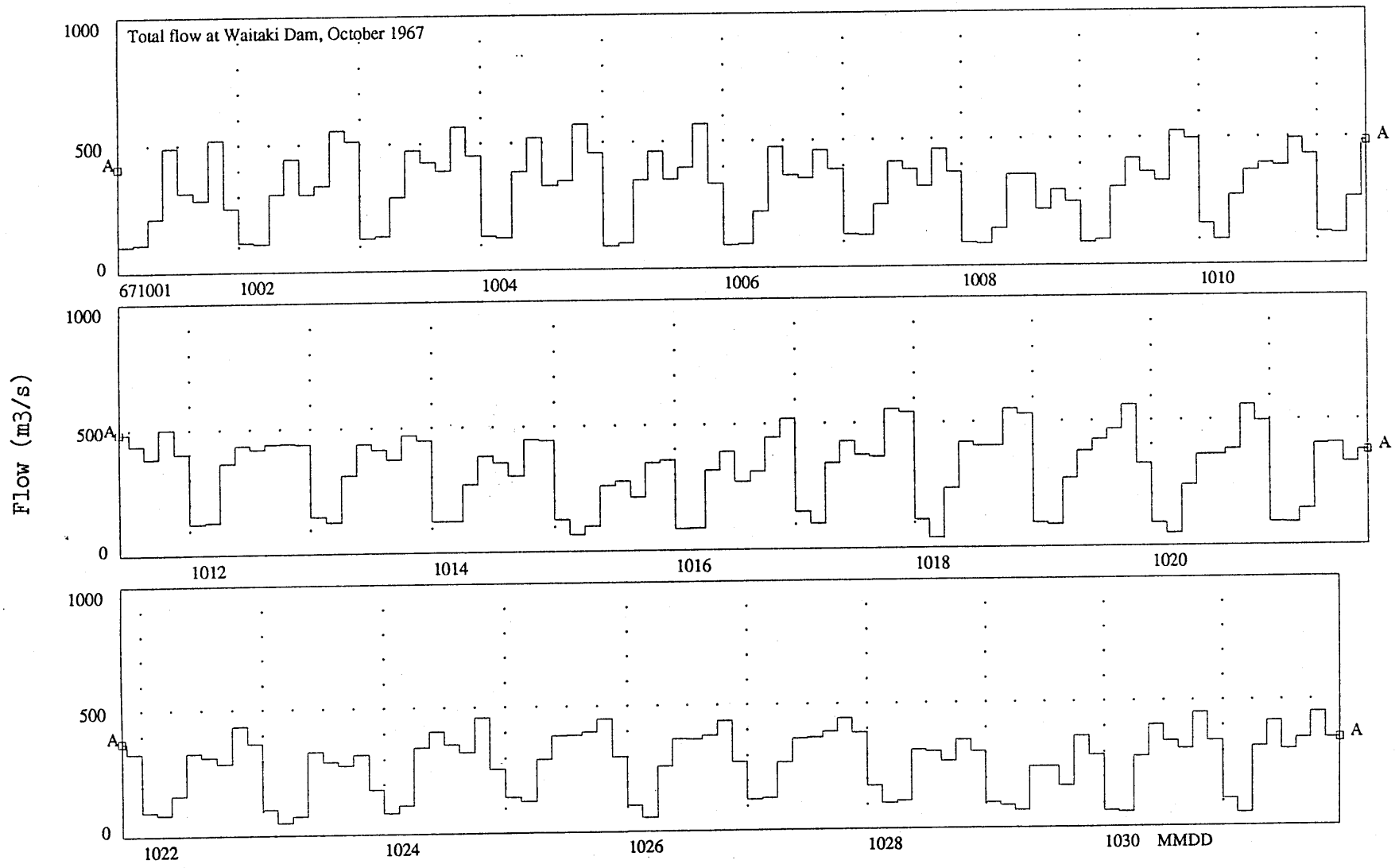


FIGURE 7. Hydrograph of 3-hourly flow at Waitaki Dam, October 1967. (Source: Hydrology Centre, Christchurch).

The 1974-76 hydrograph (Fig. 8) shows an irregular pattern. Flow fluctuations were still occurring but were much less consistent, not necessarily daily (Fig. 9), and much less severe than those in 1966-68. Low flows sometimes occurred at weekends but not consistently. The pattern during high flow events was similar to that in 1966-68. The minimum flows in 1974 were rarely less than about 120 m^3/s and the mean monthly minimum flow was usually greater than 200 m^3/s. The mean monthly range in flow was just over 100 m^3/s (Appendix I).

The 1984-86 hydrograph (Fig. 10) like that for 1974-76 was also irregular but the daily flow fluctuations (Fig. 11) were even less consistent and less severe. The minimum daily flows in 1985 were rarely less than about 150 m^3/s and the mean monthly minimum flow averaged about 300 m^3/s. The daily range in flow averaged between 50 and 60 m^3/s (Appendix I). The low flow event that occurred on 19 May 1984 during the peak of the salmon spawning season is shown on Figs. 10 and 11.

2.3 Historical Fisheries Records

Comments about lower Waitaki fisheries were compiled from WVAS annual reports for the period 1914-1989 to assess changes in angling and angling conditions over the period of hydro-electric development. They were usually qualitative in nature and not necessarily comprehensive but they should reflect major impressions or problems of the times. In addition several long-time lower Waitaki anglers were interviewed for their impressions of changes in angling and angling conditions. Both sources

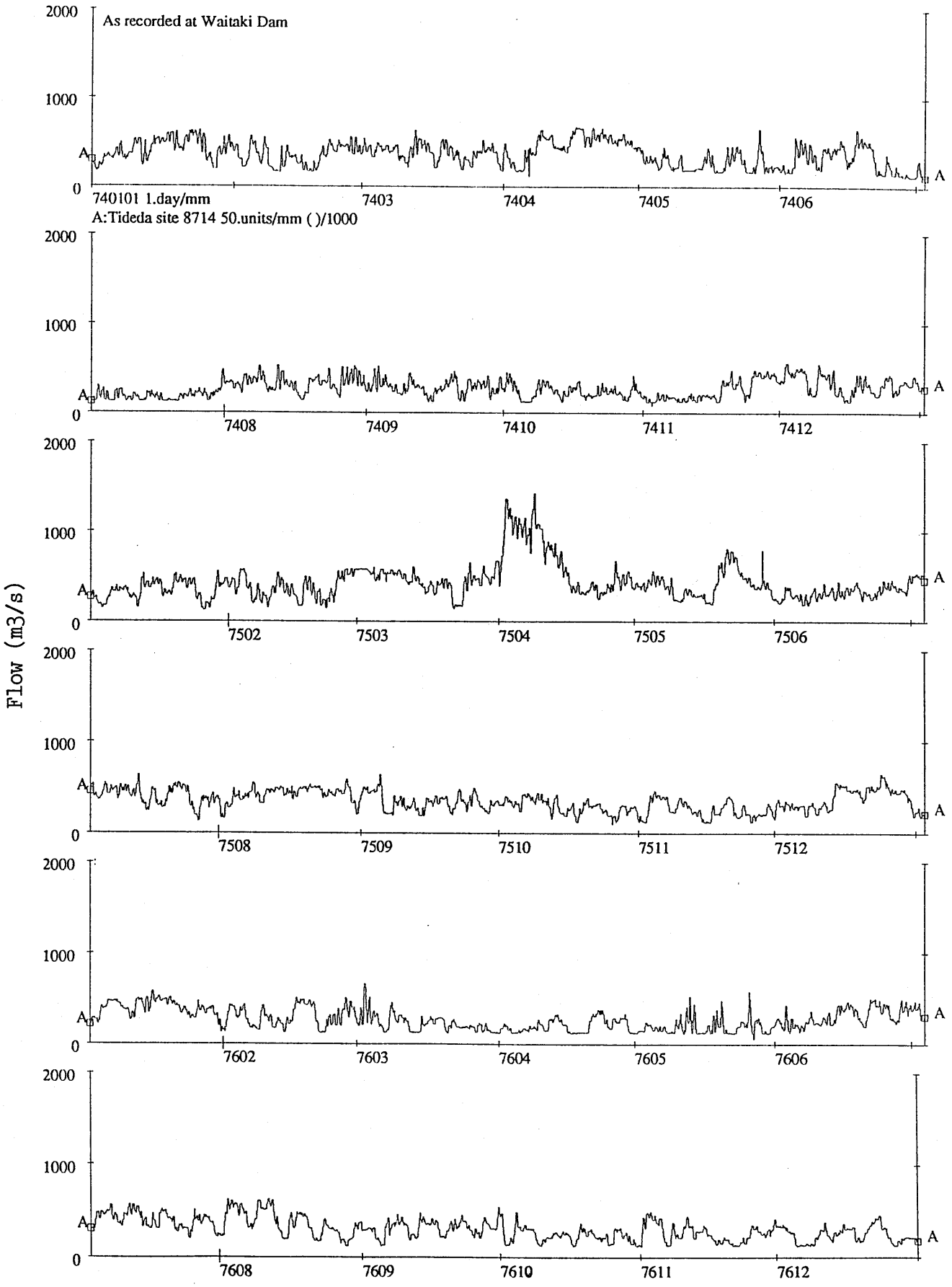


FIGURE 8. Hydrograph of 3-hourly flow at Waitaki Dam, 1974-1976. (Source: Hydrology Centre, Christchurch).

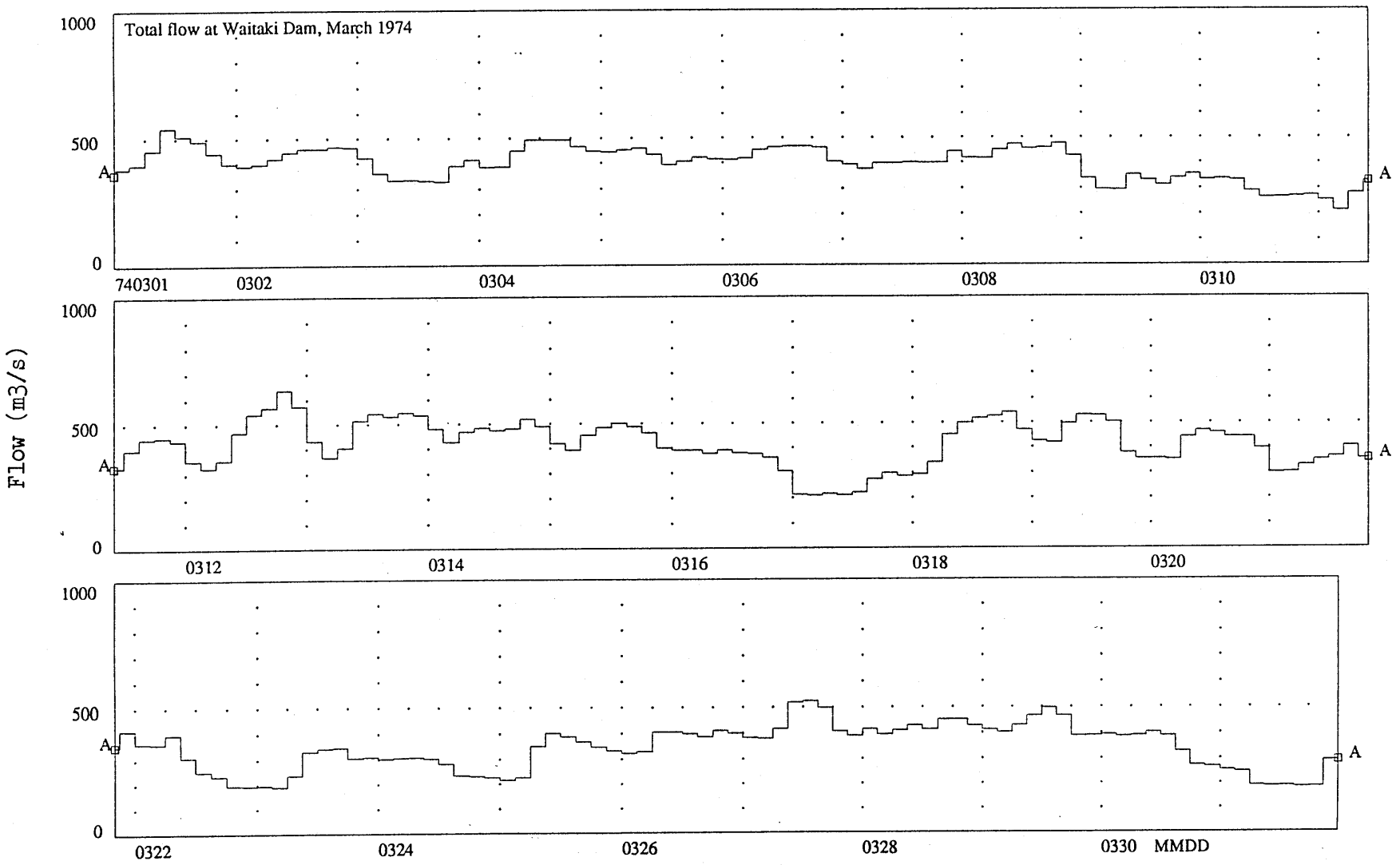


FIGURE 9. Hydrograph of 3-hourly flow at Waitaki Dam, March 1974. (Source: Hydrology Centre, Christchurch).

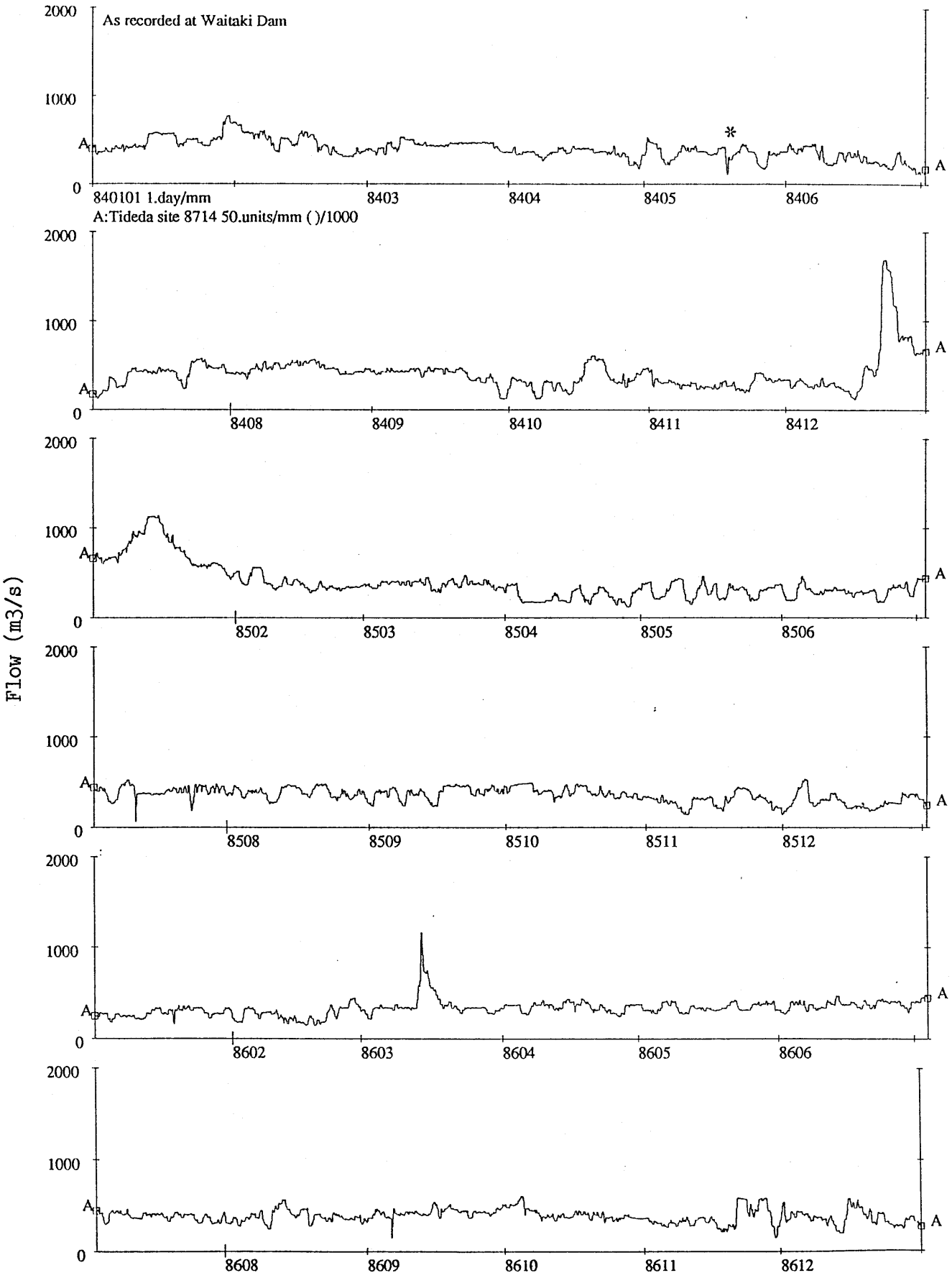


FIGURE 10. Hydrograph of 3-hourly flow at Waitaki Dam, 1984-86. (Source: Hydrology Centre, Christchurch).

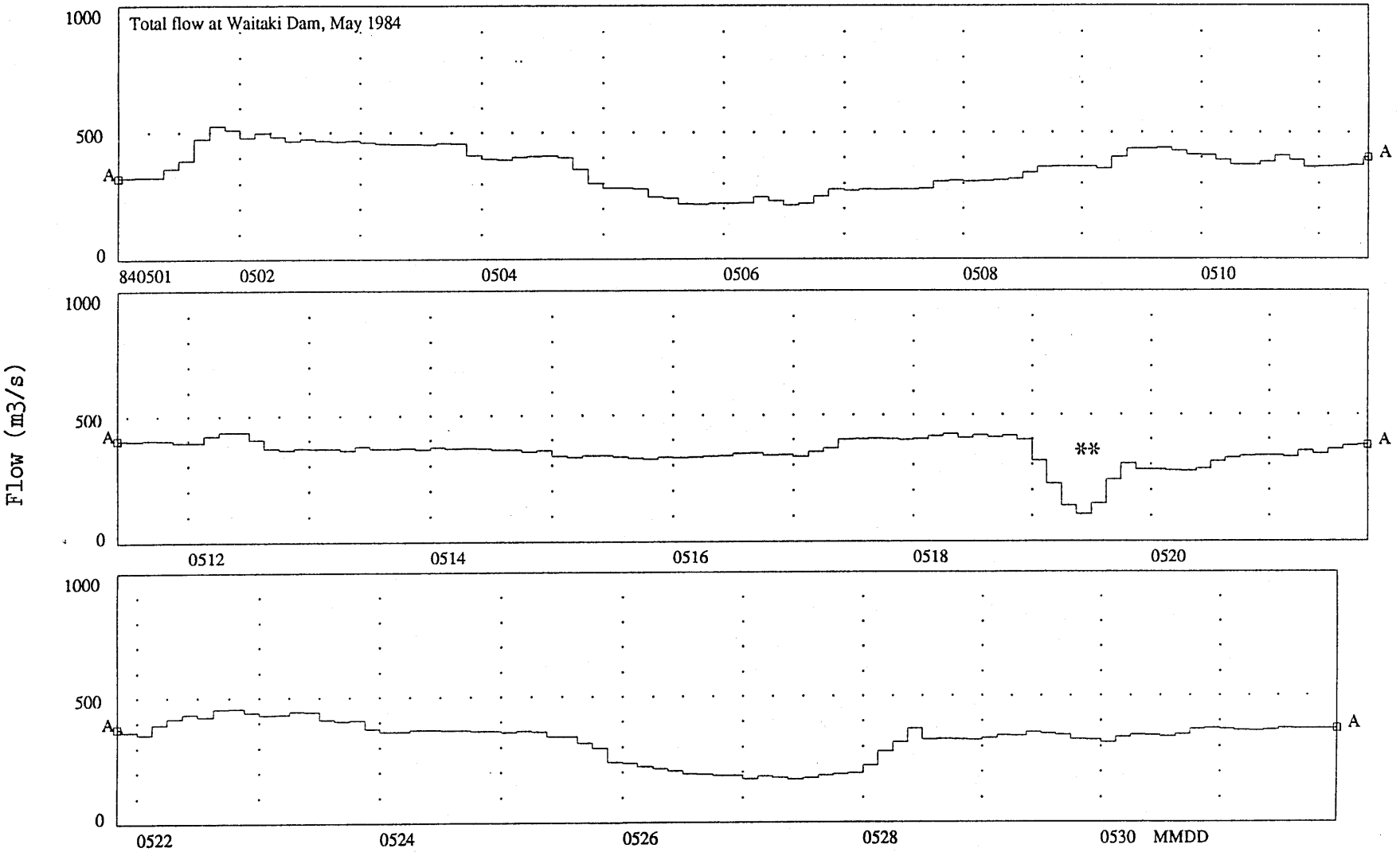


FIGURE 11. Hydrograph of 3-hourly flow at Waitaki Dam, May 1984. (Source: Hydrology Centre, Christchurch).

provide a useful basis for comparison with historical flow records. A narrative summary of changes in angling and angling conditions based on comments from annual reports and interviews is presented below.

2.3.1 Narrative Summary - 1914-1989

The annual reports prior to 1920 mention the excellent trout fishing at the Waitaki mouth. The first record of good numbers of salmon in the lower Waitaki was in 1918.

Between 1920 and 1930 floods and unfishable conditions were a common problem for anglers at the Waitaki mouth. There was still no mention of trout fishing in the lower Waitaki other than at the mouth, where trout over 15 lb were not uncommon.

Between 1931 and 1935 floods continued to be a major problem with the river sometimes being unfishable for the entire salmon season (February to April).

In 1935 many salmon were seen below the new Waitaki Dam, but few salmon or trout were caught. Rainbow trout, which had been liberated for many years in the upper catchment, were seen for the first time in the Hakataramea River following completion of the dam. [It seems likely this was a result of their migration up river being obstructed by the new dam.]

In 1938 (after Waitaki Dam completion) there were still long periods of discoloured water conditions in the river. Trout over 10 lb caught near the mouth were noteworthy.

The 1939 report mentioned for the first time trout fishing in the Kurow area, which was described as very good. The salmon season was also very good. [Since no mention was made of floods this year, it seems possible flows were more conducive to good angling. This is borne out by the hydrograph during early 1939 (see Fig. 3).]

From 1940 to 1946, trout fishing in the Kurow area was good whenever the river was not in flood. For four of the seven years, the river was unfishable for most of the season, and in the other three years for part of it. Floods and discoloured water were apparently a major problem for anglers at this time. Salmon runs were apparently variable, but poor water conditions made meaningful assessment difficult. A very poor salmon run was noted in 1943, some eight years after the completion of the Waitaki Dam. This was the first record of a poor run following the dam's completion, but many of the intervening years had been unfishable.

From 1947 to 1949 came the first reports of good to very good trout fishing in the middle reaches between Ferry Road and Kurow. There were still long unfishable periods in 1949, however.

In 1950 river conditions were good. The only mention of trout fishing was at the mouth where good numbers of trout up to 10 lbs were taken, including many rainbows. This is the first mention of rainbows in the lower river.

By 1951 rainbows were reported in fair numbers in the lower river, but anglers were complaining of "slabby fish" thought to be the result of flow fluctuations "causing unstable feeding grounds". In 1951, 1952, and 1954, there were reports that the fishing around Kurow was not very good, and this was blamed on flow fluctuations caused by the control dams at Lakes Pukaki and Tekapo. Increased numbers of rainbows were noted in the lower reaches in 1953 with fish of 4-7 lbs being caught.

From 1954 to 1967 trout fishing was variously described as good to excellent in different sections of the river and in different seasons. Unfishable conditions still occurred but received less comment than previously. One angler interviewed thought salmon angling during the first half of this period was the best that had occurred between 1948 and the present day. Another interviewee felt that there had been a general decline in salmon numbers since the early 1950's, but had noticed little change in trout abundance.

Anglers interviewed also commented that before the commissioning of Benmore Dam in 1965, they had had to cope with marked daily fluctuations in river level. At Ferry Road a side channel which was waist deep in the early morning would be only ankle deep by midday. Water levels would begin rising by mid afternoon, resulting in a useful period of angling at this

site between the hours of 10 a.m. and 4 p.m.. After 1965, anglers noticed the water was generally clearer, and the 10 to 4 rule could no longer be used. However, the 1966 annual report contains references to correspondence with the Electricity Department, suggesting that fluctuating flows were causing concern after Benmore was commissioned.

The 1968 annual report noted that fishing had deteriorated "possibly because of much bulldozer work and a changing river bed". [River control works were begun by the WCB in the mid-1960's (See Section 2.4.1.1).]

By 1970, however, (following the completion of the Aviemore Dam) the river above Duntroon was fishing "the best it had for many years". River flows were noted to be more stable than previously.

From 1971 to 1976, trout fishing in the Waitaki River was often described as "excellent". In 1973 it was reported that "it can now be regarded as one of the best fly [fishing] rivers on the East Coast of the South Island". During 1971 and 1972 the comments were applied to the upper half of the river, but latterly appeared to apply to the entire river. In 1973 it was also noted that river control works [by WCB] were confining the river, and "two of the best spawning side streams [presumably side braids] were lost to the fishery, both in the middle reaches".

From 1977 to 1980 there were no comments on the Waitaki River fishery, but in 1981 it was noted that "bottom feed production in the middle and upper reaches is still affected by the heavy silting some two years ago

[from upper Waitaki hydro construction], and though rainbow trout were in reasonably good condition, the browns were generally poor". By late 1984, it was stated that the "river was improving with the silt free flows experienced over the last 15 months". In 1985 it was noted "some minor sedge [caddis] hatches were starting to return in the upper areas, and we can only hope that the river returns to it's pre Ohau Silt Loading Era and the magnificent fishing that was destroyed in such a short time". This year was described as "one of the best salmon seasons since the good old days". The 1987 report noted that the trout fishing was improving year by year west of Duntroon, although it had not reached the levels of the 1970's. Two experienced anglers interviewed believed that the numbers of sedge (caddis) insects hatching in the reach between Kurow and Waitaki Dam had recovered by 1989 to between a third and a half of the levels in the 1970's.

2.4 Interpretation and Comparison of Historical Flow and Fisheries Records

The comments from annual reports and anglers appear to reflect mainly the river and angling conditions and only indirectly reflect the actual status of the fish stocks and runs.

2.4.1 Angling Conditions

Prior to dam construction and into the mid-1950's frequent reference was made to floods and unfishable river conditions. This reflects the natural flow pattern with high run-off in the spring and summer (Figs. 1

and 3). After the mid-1950's less mention was made of floods and unfishable conditions which probably reflects the effects of increased storage and the general reduction of spring and summer flows (Figs. 1 and 2). This reduction would have had a beneficial effect presumably on general angling conditions.

The annual reports for the early 1950's begin to mention flow fluctuations caused by dams and their potential effect on trout 'feeding grounds'. It seems likely that flows were beginning to fluctuate more widely during this period and by 1965 to 1973 the pattern was well developed. For this latter period interviewed anglers referred to these severe fluctuations and how they effectively restricted useful angling to the hours of 10 a.m. to 4 p.m. when the flow was low. However, both interviewed anglers and the annual reports pointed to the early and mid-1970's as exceptionally good for trout fishing. This apparent contradication seems to be mainly explained with reference to improved conditions for angling. With the construction of Benmore and Aviemore dams in the mid-1960's water clarity improved because the reservoirs intercepted some of the sediment. So that while the hours for angling were restricted the conditions were better. When water was low and clear during the 10 to 4 period, the fish would have been more confined (lower water), easier to see (clearer water), and probably easier to catch.

If the anglers' observations on sedge (caddis) numbers are indicative of conditions particularly in the upper reaches, it is likely that the invertebrate food supply also improved with the clearer water. This is an effect that appears to be common in other systems below both natural and man-made lakes (Winterbourn 1987 and references therein).

The situation for salmon angling is more difficult to interpret. Present day salmon anglers prefer slightly turbid water for the best fishing conditions. Whether or not the increased water clarity was enough to cause salmon fishing conditions to deteriorate is unknown. It seems unlikely, however, since the water in the present day Waitaki tends to show a slight increase in turbidity between Waitaki Dam and the mouth and there were no such references in the annual reports. The reduction in summer floods would have been beneficial to salmon fishing as was apparent from comments in the annual reports.

2.4.1.1 Effects of River Control Works

The effects of river control works are superimposed on the issues of flow and fisheries for the lower Waitaki. Beginning in the mid-1960's the then WCB undertook major river control works (Bob Hall, pers. com.). These included willow clearance over major areas of river and the general confinement of the river to a 400-m fairway. In-river works resulted in bed instability in places with sediment being "filtered" during the normal flows then resuspended at higher flows when the bed shifted (Bob Hall pers. com.). This process is likely to have been exacerbated by the flow fluctuations from power generation at least in the period when flow fluctuations were more severe.

Willow clearance was an issue commonly raised by interviewed anglers. Willow clearance reduced the number of root wads in the river bed which formed scour holes and provided cover for salmon and trout. The effect of

willow removal was to reduce the amount of salmon "holding water" and the number of "salmon holes" used by anglers. The effect on salmon angling would have been detrimental while the effect on salmon migration was probably little. Trout habitat was probably reduced somewhat.

Attempts to confine the river to a 400-m fairway along with the possible effect of less frequent flooding reduced the active river width and the number of river braids (Ministry of Works and Development 1984). As an example, aerial photos from 1943 (at flow of 307 m^3/s) show an active river width of about 2 km with about 10-13 braids while those for the same section in 1982 (at flow of 430 m^3/s) show an active river width of about 0.8 km with about 5-6 braids. The effect on angling would be to reduce the number of smaller braids available to anglers and the availability of fish to anglers by reducing the amount of habitat for fish.

In the mid-1980's the then WCB abandoned the 400-m fairway policy, largely on economic grounds, in favour of less intrusive works such as willow spraying (Bob Hall, pers. com.). From then on mechancial means were used less often for river control and in the future the river will be allowed to attain an active width of about 1000m. This should result in increased bed stability and reduced silt levels. In the long term fish stocks and other aquatic resources should benefit.

2.4.2 Fish Stocks and Runs

Because of the qualitative nature of the fisheries records it is difficult to document specific changes in fish stocks but some general trends and relationships do seem apparent.

Early in the century the annual reports mention the presence of trout (presumably brown trout and possibly mainly sea-run) only at the mouth. In 1939, four years after the completion of Waitaki Dam, the first mention was made of trout fishing in the upper reaches near Kurow which was described as very good. By contrast rainbow trout were first seen in the Hakataramea River (upper reaches of lower Waitaki) in 1935, possibly being blocked by the new dam. They do not feature in reports for the lower part of the river until 1950. These references probably do reflect an actual change in distribution but it is possible that they are simply an artefact of the reporting.

It is likely that the trout stocks in the lower Waitaki have developed to the significant extent they have because of the beneficial attributes that the dams provide such as increased food and nutrients from the upstream reservoirs and reduced sediment and flood flows. In the Rakaia River, a river with catchment features similar to the lower Waitaki such as source, morphology, etc., but no dams, trout have not become as dominant a feature (Unwin and Davis 1983) as they have in the lower Waitaki.

The number of salmon spawning in the lower Waitaki system has been estimated for the period from 1975 to 1986 (James and Deverall 1987). These vary from about 4000 to 16000 spawners per year, a range that is not uncommon for salmon runs. No particular trends are apparent and there are other major factors that can affect salmon runs besides the flow regimes during their freshwater phase. One of the interviewed anglers felt, however, that there had been a general decline in the salmon runs over the past 30 or so years.

2.4.3 Overview

Comparison of historical flow and fisheries records appear to have some contradictory elements. Flow fluctuations (both frequency and magnitude) from about the late 1950's to the mid-1970's would be considered severe by most fisheries standards. Such fluctuations have been documented to strand juvenile salmonids resulting in large numbers of mortalities (Graybill et al. 1979, Hvidsten 1985). The effective fishing time in the Waitaki would have been reduced not to mention the possible risk to life and limb from such fluctuations. During this same time substantial in-river works were occurring that increased bed instability and silt load, decreased the number of small braids which presumably reduced the amount of fish habitat especially for juveniles and the availability of water suitable to trout angling, and reduced the type of water in the main braids suitable for salmon angling such as "salmon holes". Yet the angling records highlight the 1970's as being very good for trout angling. The detrimental effects indicated above may have been countered somewhat by the reduction of flood flows and clear water which would have benefited trout angling, and to a lesser extent salmon angling. Also since anglers opinions on a fishery in a large river like the lower Waitaki probably reflect more often changes in angling conditions than changes in fish numbers, it seems quite possible that the good fishing of the 1970's was more the result of improved angling conditions than a large increase in fish numbers. Recent angler observations indicate, however, that trout angling in the middle and lower reaches of the river is still less successful than it was during the 1970s, presumably as a result of other influences such as increased silt load and substrate instability.

There is no quantitative information to indicate a change in status one way or the other for fish populations in the lower Waitaki related to historical flow patterns. Suffice it to say that fish stocks have developed in the lower Waitaki through a time when the flow regime should have been detrimental to fish. Since that time flow fluctuations have been reduced substantially so that conditions should have improved for fish stocks.

3. RELATIONSHIP BETWEEN FLOW AND WATER LEVEL

3.1 Introduction

Flow reductions in the lower Waitaki River also reduce river levels and have the potential to dewater salmon redds as well as adversely affect other aquatic resources. Water levels were recorded during habitat surveys carried out at 2 sites in 1983 (Riddell and Jowett 1983). Additional studies were undertaken in April/May 1989 to assess the dampening of stage (water level) with distance downstream to determine if some areas of the lower Waitaki are potentially more impacted than others by flow fluctuations (i.e., that the change in water level is greater in some areas than in others for a given flow change at Waitaki Dam). The measurements from both of these studies are used in this report to estimate the magnitude of the flow reduction which would be sufficient to expose salmon redds.

3.2 Stage Dampening

Foxboro water level recorders were installed on 27/28 April 1989 at seven locations along the length of the lower Waitaki River. These were sited in mainstem braids at or near (from upstream to downstream) Kurow bridge, Otiake River, Duntroon, lower Waitaki irrigation scheme intake, Jardines Road, Ferry Road, and SH 1 bridge. Flows were monitored at the hydrometric station downstream of Waitaki Dam (Fig. 12). On 4/5 May 1989 the flows were ramped down from the then operating level of about 440 m^3/s to near the minimum flow level of 120 m^3/s and then increased to about 400 m^3/s (Fig. 13). The seven water level recorders were removed at the conclusion of the survey on 5 May 1989.

The following conclusions were reached from the data collected from the stage dampening studies (Figs. 14 & 15).

1. The amplitude of power station releases were significantly smoothed by the time flows reached the Otiake River, some 12 kms downstream of Waitaki Dam (Fig. 14).

2. The range of levels recorded when the flow was reduced from about 440 to 120 m^3/s (a difference of 320 m^3/s) indicates that the level variations in mainstem braids became generally less with distance downstream. (See Section 3.3 for more detail).

3. For a change of flow at Waitaki Dam the time of travel of the crest to various points along the river was calculated as shown in Table 2. The average rate of travel of the crest was 1.7 m/s. [Note: the average rate of travel of the troughs would be somewhat slower.]

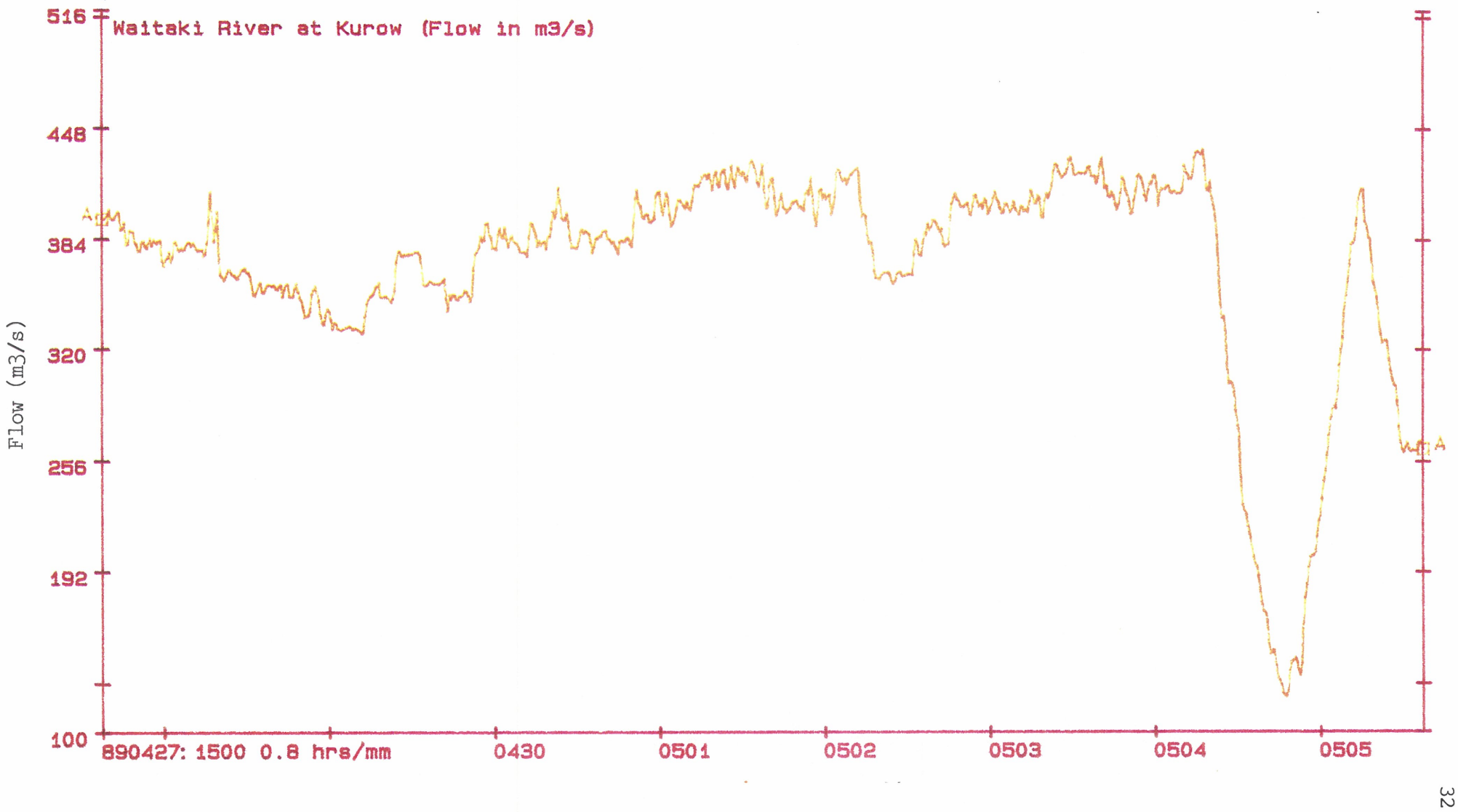


FIGURE 12. Hydrograph of lower Waitaki River flow at Kurow, 27 April-5 May 1989.

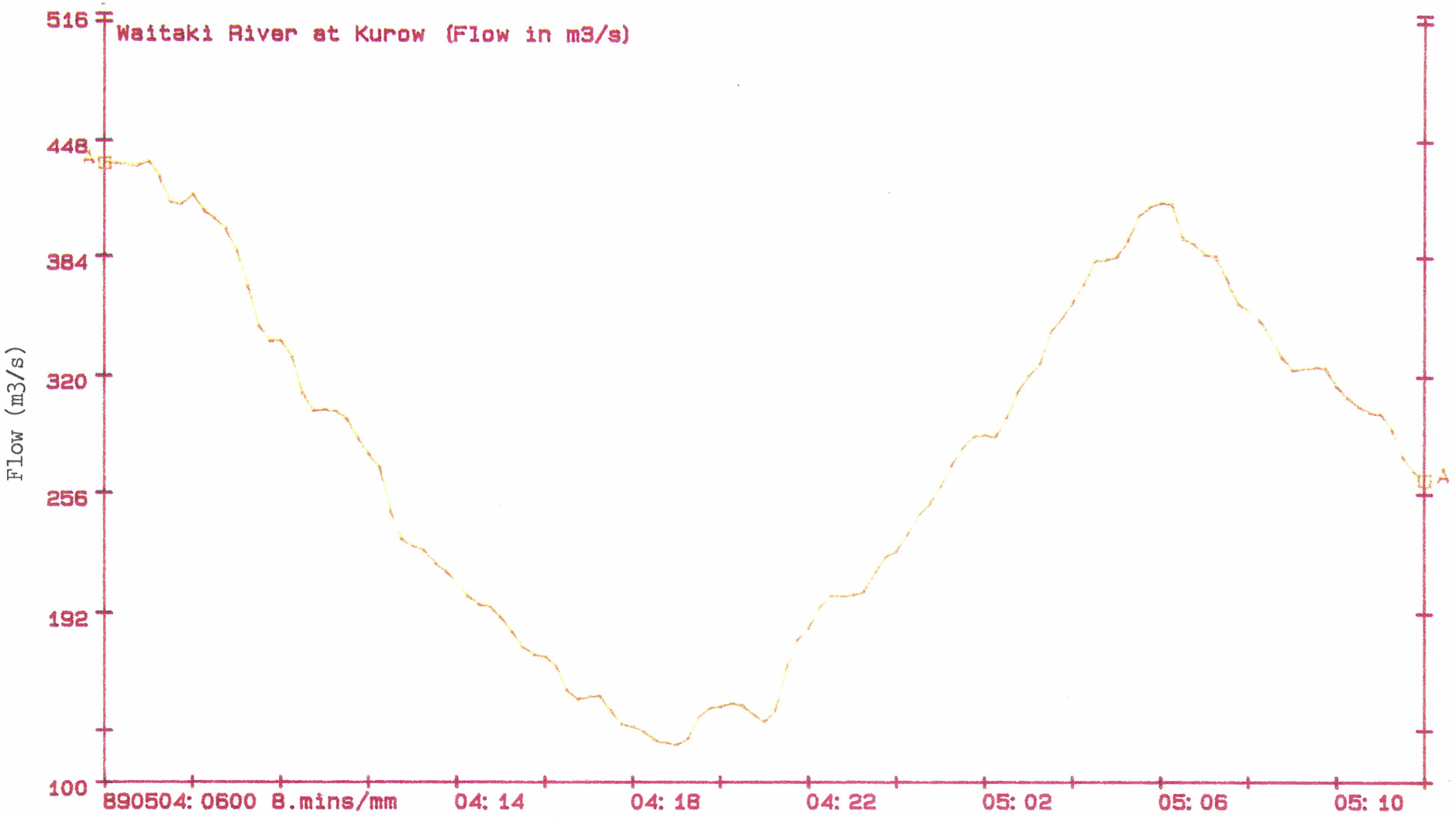


FIGURE 13. Hydrograph of lower Waitaki River flow at Kurow, 0600 4 May - 1200 5 May 1989.

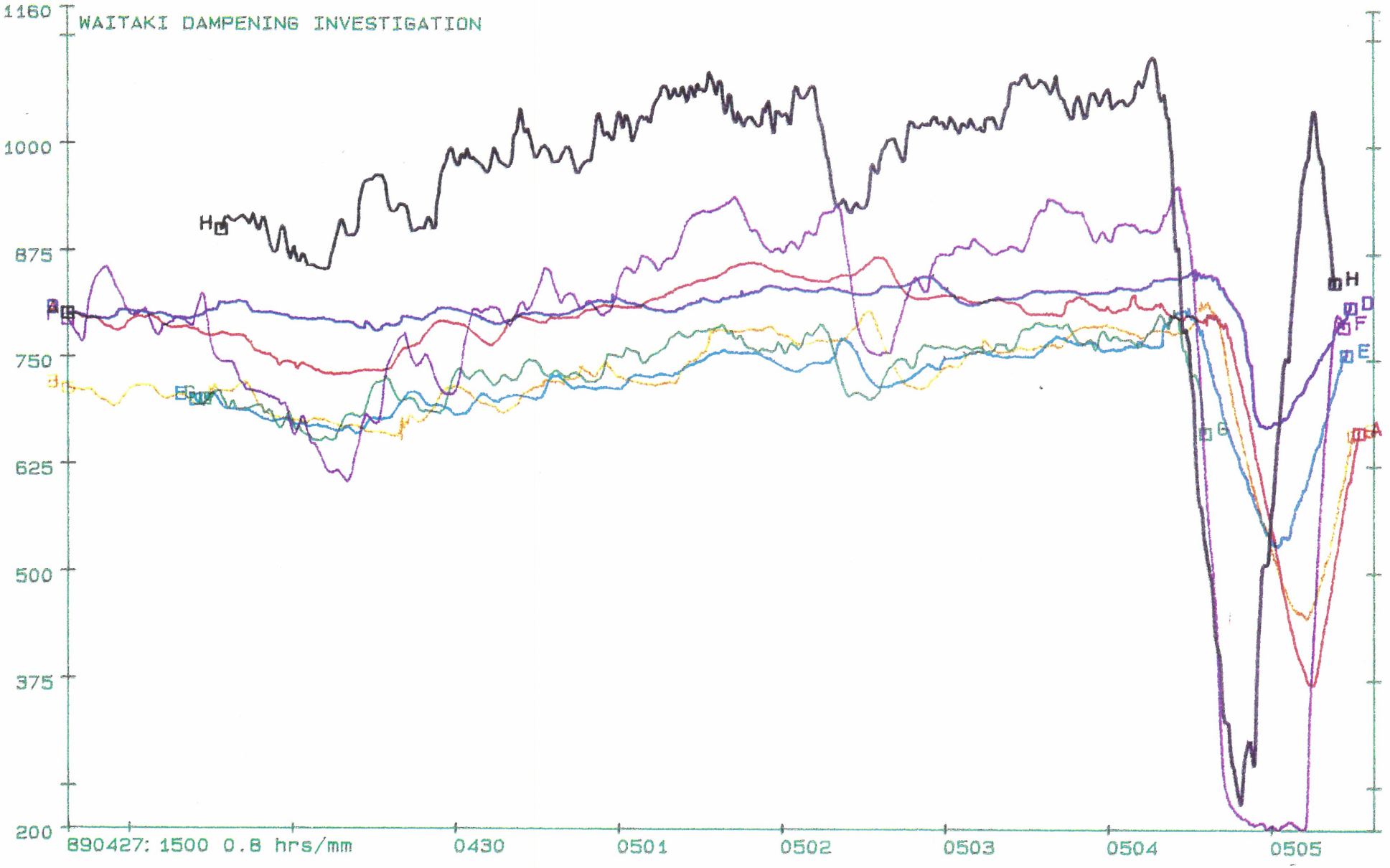


FIGURE 14. Water levels (stage) recorded at seven sites on the lower Waitaki River, 27 April – 5 May 1989.

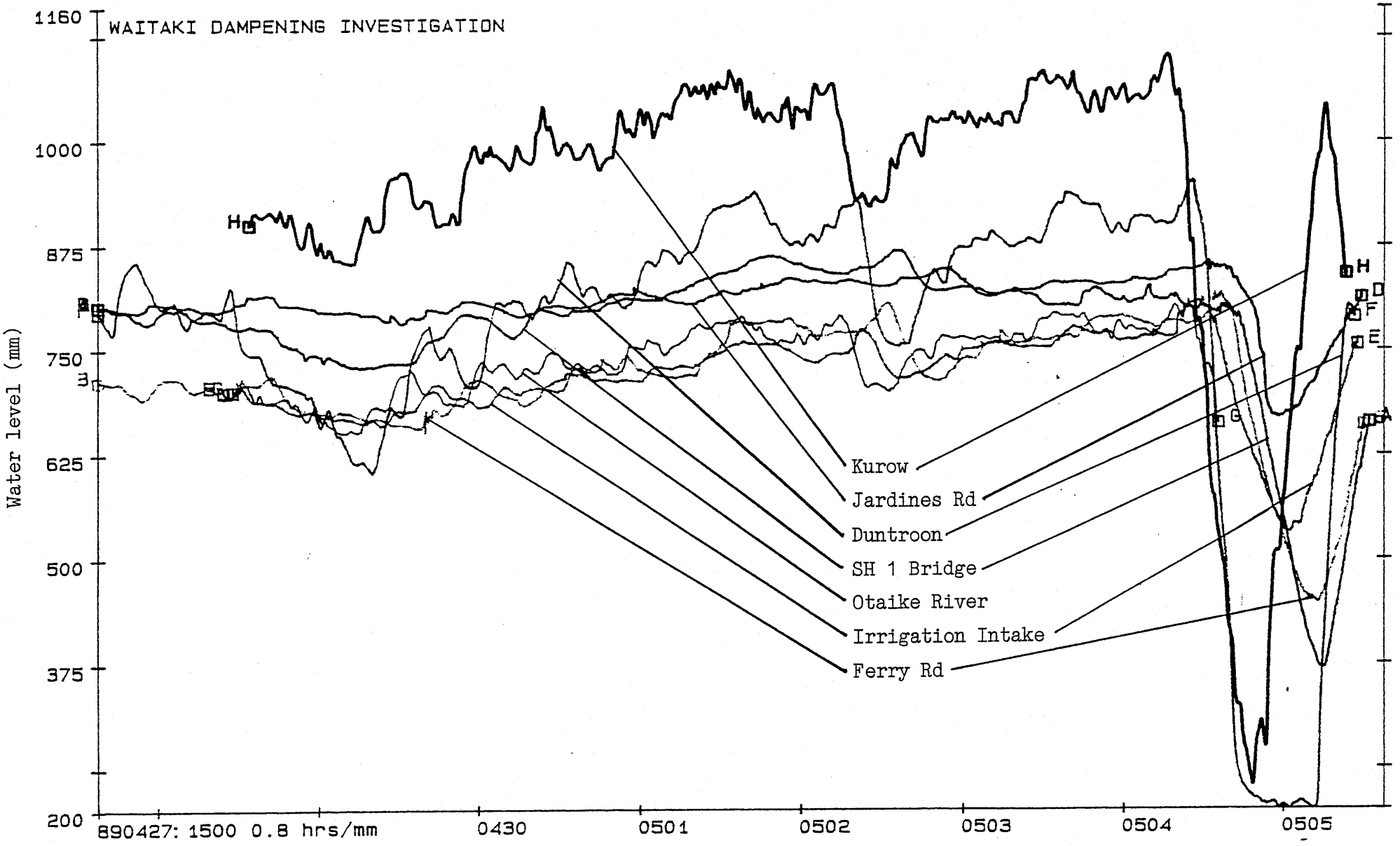


FIGURE 14. Water levels (stage) recorded at seven sites on the lower Waitaki River, 27 April - 5 May 1989.

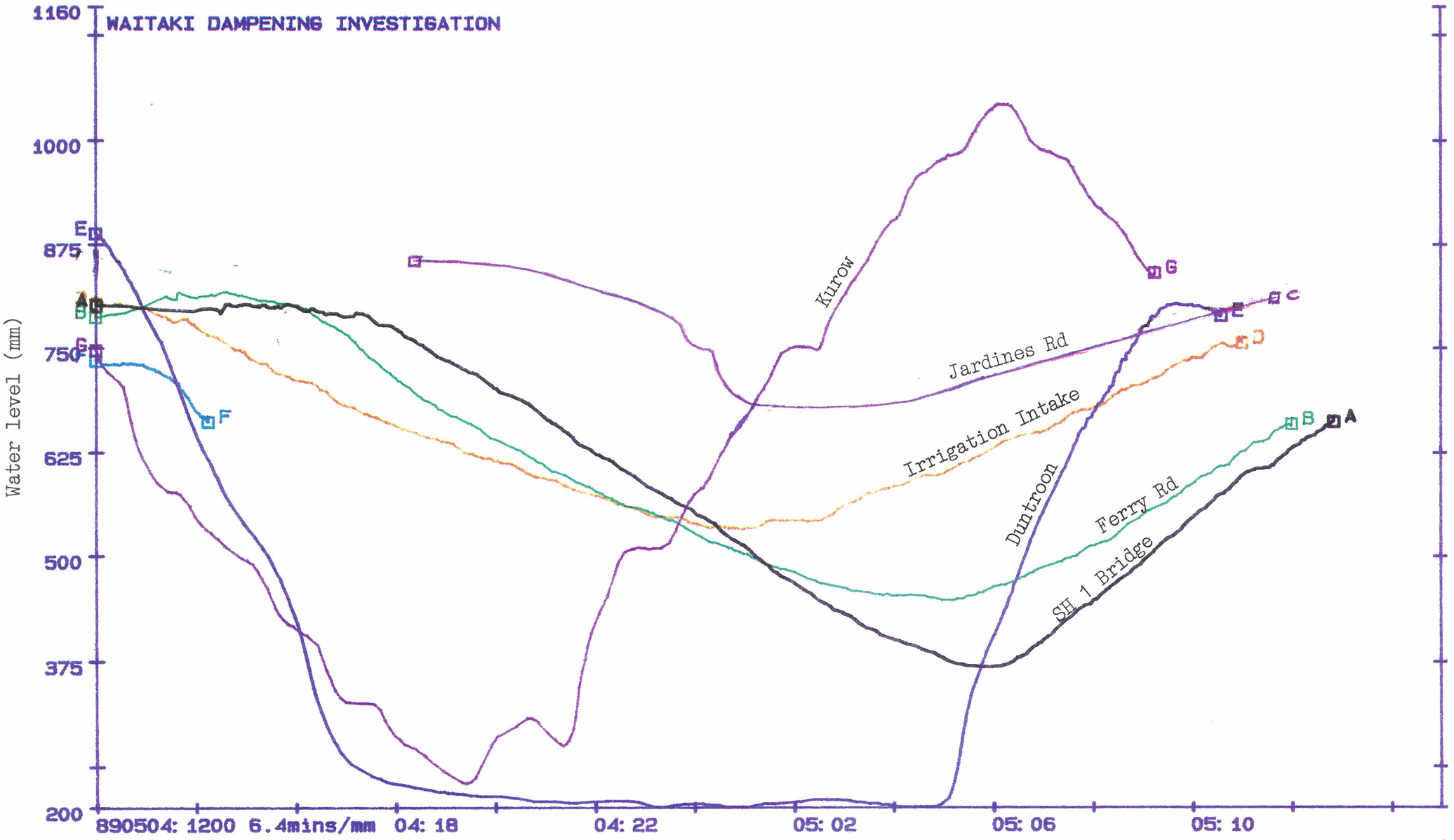


FIGURE 15. Water levels (stage) recorded at six sites on the lower Waitaki River, 1200 4 May - 1200 5 May 1989. Note: Not at same starting point on vertical axis.

TABLE 2. Average time for a crest of water to travel from Waitaki power station to various points downstream. Average rate of travel was 1.7 m/s.

Site	Distance downstream (km)	Travel time (hr:min)
Waitaki power station	0	00:00
Hydrometric station	2	00:20
Kurow bridge	5	00:50
Otiake River	12	01:55
Duntroon	26	04:15
Lower Waitaki irrigation intake	35	05:40
Jardines Road	46	07:30
Ferry Road	55	09:00
SH 1 bridge	60	09:50
Mouth	65	10:40

3.3 Flow/Water Level Relationships

River water levels (stage) normally change with flow according to a relationship of the form

$$Q = k(\text{Stage}-b)^a$$

The exponent a varies between 1 and 2 depending upon the form of hydraulic control and the channel shape. The measurements from the 1983 study were used to derive flow/water level relationships for the Waitaki River above Kurow, at Priests Road, and at Jardines Road (Fig. 16). These relationships are close to linear, at least over the range of flows of interest, and level variations for a 100-m^3/s flow change have been taken from them.

Water level measurements from both the 1983 and 1989 studies were compared to the discharges from the Waitaki power station to estimate the changes in water level for a 100 m^3/s flow change. Table 3 shows that the variation of water level with flow was greatest in the reach above Kurow where the river is confined in a single channel. As the river spreads out into a number of braids between Kurow and Duntroon the water level variation was between 234 and 270 mm per 100 m^3/s flow change. Below Duntroon the variation of water level reduces to between 86 and 136 mm per 100 m^3/s.

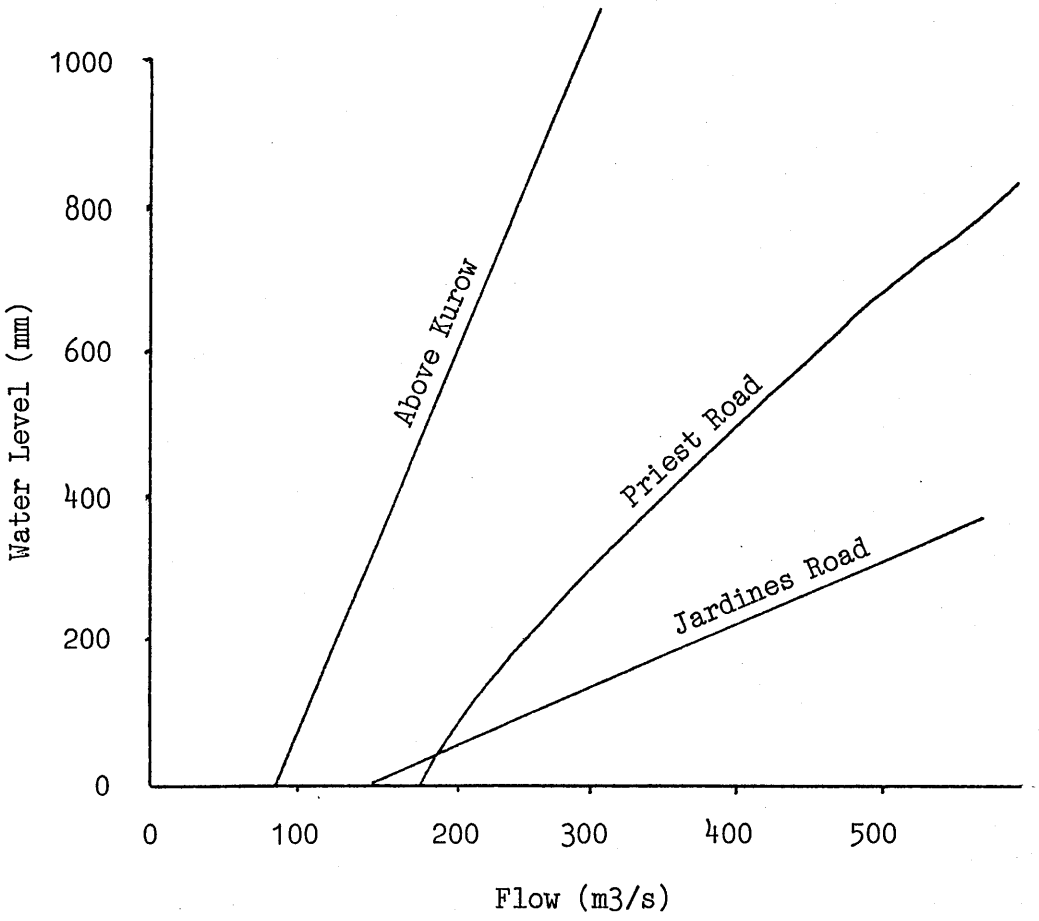


FIGURE 16. Relationship between water level (stage) and flow at 3 sites on the lower Waitaki River.

TABLE 3. Change in water level for a flow change of 100 m^3/s in the Waitaki River downstream of Waitaki Dam.

Location	Distance downstream	Change in water level (mm)	
Hydrometric station	2	500	
Kurow bridge	5	270	
Priest Road (1983)	23	240	
Duntroon	26	234	
Lower Waitaki irrigation intake	35	86	
Jardines Road (1983)	46	100	
Jardines Road	46	56	(recorder suspect)
Ferry Road	55	110	
SH 1 bridge	60	136	

The major differences between these three sections of river are caused by the river channel widening with distance downstream. However within any section local factors, such as the hydraulic control downstream of the braid on which the recorder was sited, have a small effect and there is a certain amount of natural variability.

3.4 Impact on Aquatic Resources

These flow/water level relationships have several implications for aquatic resources in the lower Waitaki River. The potential impacts of water level variation on aquatic resources are greater upstream of Duntroon then downstream. The major upstream resources which would be affected include chinook salmon spawning, brown trout spawning (most if not all rainbow spawning occurs in the tributaries), juvenile salmon and trout rearing, adult trout rearing, trout angling, native fish rearing for species like upland and common bully, and benthic invertebrates. The major affected downstream resources would be the same as above excluding salmon spawning but including salmon angling, rearing for a wider variety of native species, and fisheries for native fish.

3.5 Effect of Flow Reduction on Salmon Spawning Depths

Figure 17 shows the "preferred" spawning depths and velocities for chinook salmon. These curves were developed in North America (none were available for New Zealand) but should be applicable to this study. We shall assume that if the water level falls by 300 mm, the "preferred" salmon spawning depth, a significant number of redds would be exposed.

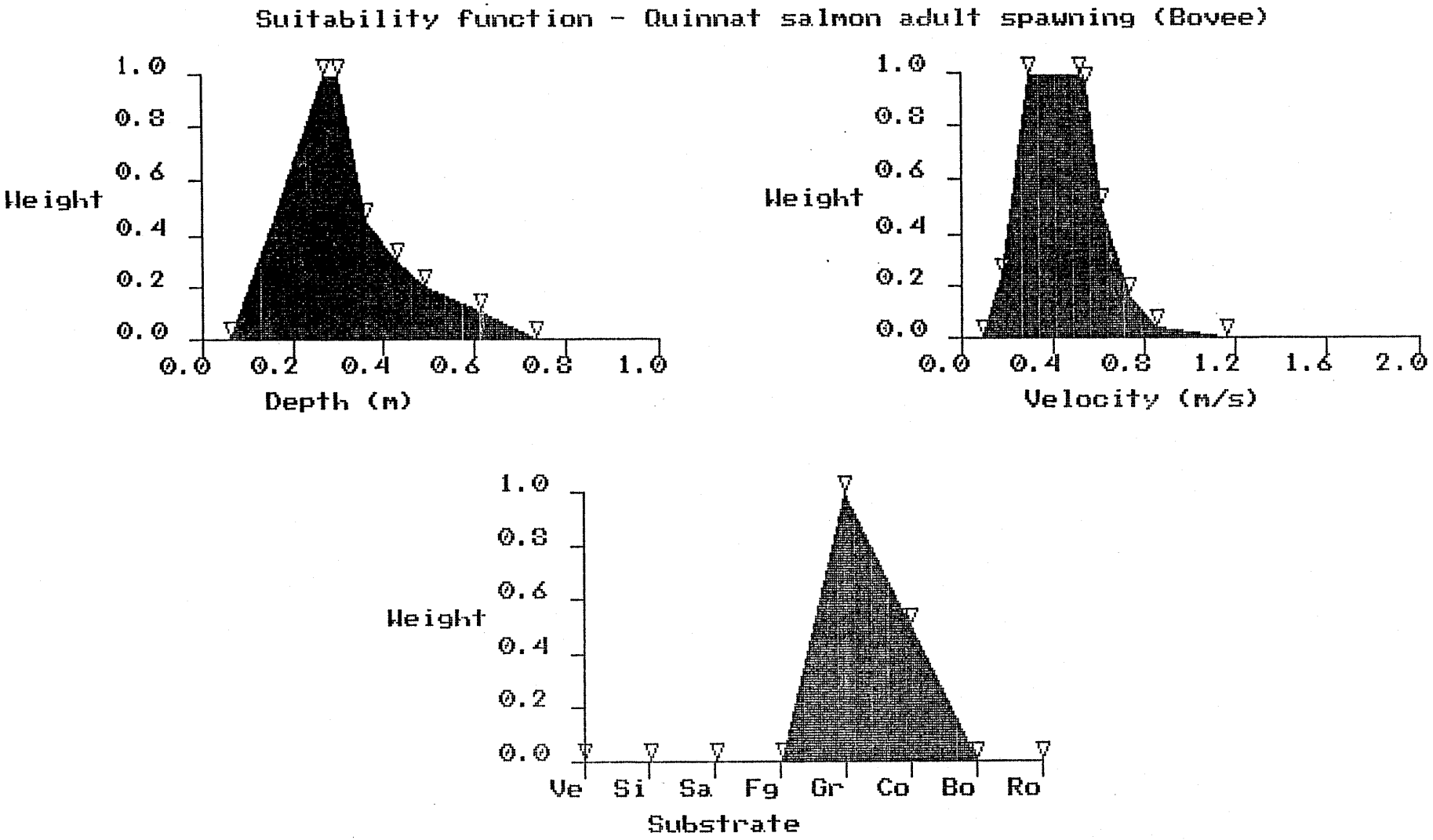


FIGURE 17. Suitability functions for chinook (quinnat) salmon spawning (from Bovee 1978).

Impacts would be greater between Duntroon and Kurow where a 300-mm reduction in water level would be caused by a flow reduction of about 120 m^3/s. Downstream of Duntroon a flow reduction of about 280 m^3/s would cause the water level to fall 300 mm. On average, dewatering of redds would occur if flows were about 200 m^3/s lower than when the salmon spawned.

4. FISH STRANDING

Based on the findings from comparing the historical flow and fisheries records (See Section 2) we believe that there is no need to carry out fish stranding studies. The potential for fish stranding was greatest when the frequency and magnitude of flow fluctuations were high as was the case from the late 1950's to the mid-1970's. The flow fluctuations in more recent times were much less severe and so would have greatly reduced the potential for stranding. If this flow pattern continues then the potential for stranding should remain low.

Limits on the rate of flow reduction (down ramp) would further reduce the potential for stranding. These are largely in place at the moment where flow reductions below 200 m^3/s are limited to 10% of the flow per hour. These ramping rates were shown to be attainable during the stage dampening study carried out in April/May 1989. We recommend that these guidelines continue to be followed.

5. REDD DEWATERING

Based on the findings from comparing the historical flow and fisheries records (See Section 2) we believe that there is no need to carry out redd dewatering studies. Occasions when redds become dewatered would be unpredictable (we can, however, predict flow reductions which cause redds to become dewatered) and appear to be uncommon. To carry out such studies we would have to request low flows to purposely dewater redds. Such a decision would be biologically unwise and from the comparison of historical flow and fisheries records seems unwarranted. Even so there is the potential for redd dewatering and associated mortalities. Further consideration is useful with implications for flow management.

When redds become dewatered mortalities can occur to the eggs and alevins within the redd caused by extremes in temperature, insufficient oxygen or removal of waste products, or desiccation. Overseas studies (Becker et al. 1982 and 1983, Becker and Neitzel 1985, Neitzel and Becker 1985, Reiser and White 1983) have established the periods of development when salmonid eggs and alevins are likely to be most at risk from dewatering. Eggs and embryos which have not hatched are relatively tolerant of dewatering provided moisture levels in the gravel are adequate. By contrast, post-hatching (but pre-emergence) phases are quite intolerant. For chinook salmon, experiments have shown pre-hatching phases can survive quite well up to 12 days at 10° C, while post-hatching phases, particularly alevins, may only survive a few hours at most. Similar conclusions were reached in New Zealand studies by Hawke (1978) and Hardy (1963).

It is important to recognise therefore, that when a redd is exposed to the air it's contents may or may not survive, and this is dependent on species characteristics, phase of egg and alevin development, flow, length of exposure, moisture level, and temperature. It is possible for the surface of a redd to be dewatered but for the eggs and alevins, buried some 10-45 cm under the surface, not to be. Residual water can remain within the redd around the eggs and alevins. This probably occurs to a large extent in the lower Waitaki because with its relatively coarse substrate (Jowett 1982) there is generally good intra-redd flow.

Chapman et al. (1986) reported that the distribution of chinook salmon redds in the Columbia River (having a general flow pattern similar to the lower Waitaki during the 1965 to 1972 period) was correlated strongly with the mean daily flow during the spawning period but not with the minimum daily flow. They concluded that the use of spawning areas in higher river bank locations (which increases the potential for redd dewatering when flows are subsequently dropped) could be reduced by managing the river discharge to provide lower mean daily flows. This practice could be implemented in the lower Waitaki to further reduce the potential for salmon redd dewatering. Additional protection to redd contents would be provided by linking the flows that occur during incubation to those that occur during spawning.

We recommend that EC manage the flows during May, the major portion of the salmon spawning period, at as low a level as possible. Thereafter and through the incubation period (to the end of September) they should attempt to avoid flows more than about 200 m^3/s below the mean daily flow provided

during May. (A reduction of 200 m^3/s would result in a lowering of the water level by about 300 mm). Any routine activities requiring low flows, such as bridge inspections, etc., should be scheduled outside the spawning to incubation period (April through September).

6. POTENTIAL IMPACTS TO OTHER AQUATIC RESOURCES

6.1 Macrophytes, Periphyton, and Benthic Invertebrates

All of these features of the aquatic ecosystem can be affected by flow regulation below hydro-electric facilities (See reviews by Ward and Stanford 1979, Brooker 1981, Milner et al. 1981, Armitage 1984, Cushman 1985, Irvine and Jowett 1987 and references therein).

Macrophyte surveys showed the lower Waitaki to be sparsely vegetated (Graham 1987). Impacts on macrophytes in the lower Waitaki would, therefore, be minimal.

Flow reductions can reduce the abundance and standing crop of periphyton and benthic invertebrates through loss of habitat and desiccation and for invertebrates through reduced food supply. Fluctuating flows also have their effects. Benthic invertebrate and periphyton standing crop typically are higher at the margins of large streams or channels (over 7 m wide) than at the centre due to differences in current velocity and availability of shelter. Under peaking flow regimes this productive area is compressed from both sides. On the shore side this results from the stranding and desiccation of invertebrates as flows are reduced and on the midstream side from excessive velocities when the flows

rise. The result is a reduction of invertebrate standing crop in the margins of large streams compared to that which would normally occur in these areas in the absence of flow fluctuations. Reduced invertebrate abundance in the stream margins could affect the fish that live in the margins such as juvenile salmon and trout.

The effects of flow changes on numbers of invertebrates living on the bottom (benthic) and drifting in the current (drift), has been examined in several New Zealand rivers including the Tekapo (Stancliff et al. 1982) and Hawea (Irvine and Henrigues 1984). Both these studies showed that drift increased with increases in flow, but the effects on benthic invertebrate densities were variable.

The above effects on periphyton and macroinvertebrates are the type that would have occurred commonly during the late 1950's to mid-1970's. Since the severity of flow fluctuations has been greatly reduced in recent times these kinds of effects would also be greatly reduced. The more typical pattern now is one where flows change from one level to another in a short period of time but remain at the general levels for a matter of days or weeks. It is unlikely that the effects of such a pattern on periphyton and invertebrates could be detected from within the natural variability of these populations and even more unlikely that the effects on fish growth or condition could be detected.

6.2 Native Fish

Native fish occurring in upper sections of the lower Waitaki River where flow fluctuations could be of concern are:

Upland Bully	-	widespread and common
Common Bully	-	widespread and moderately common
Longfinned Eel	-	widespread and common
Shortfinned Eel	-	uncommon
Lamprey	-	reportedly moderately common
Torrent Fish	-	occasional

Of these fish it is only the two bully species which potentially could be affected by flow fluctuations, either by stranding of juveniles or adults, or by exposure of the eggs to the air by dewatering.

6.2.1 Stranding

Although the smaller native fish species are perhaps not as mobile as juvenile salmonids, in general it seems likely that if salmonids are protected from stranding by satisfactory ramping rates, then native species are not likely to be much affected.

6.2.2 Reproduction

Two bully species spawn in the upper sections of the lower Waitaki River where flow fluctuations could be significant: upland bully which are the more abundant and common bully. These species lay eggs on the undersides of stones often in relatively shallow water during the spring and summer. The eggs take about 3 to 4 weeks to develop and so could be killed by even brief exposure to the air if dewatered in late spring or summer. The potential impact of flow fluctuations on bully numbers in the

lower Waitaki is unknown. However, both species are widespread and abundant in the upper Waitaki system, in the tributaries of the lower Waitaki, and in the lower Waitaki itself, and spawning in these areas probably has the potential to augment some of the losses that may occur in the upper parts of the lower Waitaki River.

6.3 Salmon and Trout Spawning Behaviour

Chapman et al. (1986) reported that female salmon were not deterred by widely fluctuating daily flows and completed redds in areas that were dewatered for up to 8 hours/day and in other areas that had excessive velocities near 2 m/s for part of each day. Similar findings were reported by Graybill et al. (1979) where salmon were observed to return to complete redds after being "chased off" by low flows. These observations are not directly applicable to the lower Waitaki because of its reduced severity of flow fluctuations. They do serve to show the determination of salmon to complete spawning under adverse conditions. Under the current pattern of flows salmon spawning behaviour in the lower Waitaki is probably little affected.

While we are not aware of similar observations for trout it is likely that they, being closely related to salmon, would show similar determination. Impacts on trout spawning behaviour is also likely to be small. Brown trout in the lower Waitaki were observed to use the more stable side braids for spawning and rainbow trout appear to use the tributaries only (Graybill et al. 1988).

6.4 Adult Salmon Migration

Adult salmon migration is probably little affected by regulated flows because of the large waters available to migrating fish even at the present minimum flow of 120 m^3/s.

6.5 Salmon and Trout Fisheries

The effects of flow regulation on salmon and trout fisheries in the lower Waitaki have been discussed earlier (See Section 2). In general the salmon fishery has benefited from the reduction of floods and it remains a nationally important fishery. The trout fishery of the lower Waitaki has also developed to become nationally important. Even in the 1970's when flow fluctuations were severe, anglers commented on the good trout fishery. The trout fishery has probably become important in large part because of flow regulation. By comparison the Rakaia River has a similar catchment to the Waitaki but is not regulated and the trout fishery there has not become prominent.

6.6 Non-Salmonid Fisheries

The effects of flow regulation on non-salmonid fisheries appear to be minimal. Fisheries for whitebait, flounder, and mullet occur mainly near the mouth (Pierce 1987) where water level changes are significantly dampened and where most are within tidal influence. A small commercial eel fishery operates throughout the river in summer (Pierce 1987) but is unlikely to be affected by the current level of flow regulation.

7. SUMMARY AND RECOMMENDATIONS

Following a low flow event in 1984, WVAS requested that the lower Waitaki minimum flow be raised from 120 m^3/s to a higher level. Based on the findings of this study there is no evidence to suggest that the fish stocks, fisheries, or other aquatic resources of the lower Waitaki would benefit by raising the minimum flow. Adequate protection from the one-off low flow event can be provided by better communication between the development and resource agencies. This is largely in place from the activities of the lower Waitaki working party.

The flow regime resulting from hydro-electric operations has the potential to adversely affect fish stocks, fisheries, and other aquatic resources. The potential risks were greatest from the mid-1950's to the early 1970's when flows fluctuated widely on a daily basis. Surprisingly, the latter part of this period overlapped with the period when angling was considered at its best. Since the mid-1970's flow fluctuations have become much less severe which would have greatly reduced the potential risk to aquatic resources through such adverse impacts as fish stranding and redd dewatering.

The potential risk from fish stranding could be further reduced by limiting the rate of down ramp when flows go to low levels. Guidelines coming from the lower Waitaki working party suggested that flow reductions below 200 m^3/s be limited to 10% of the flow per hour but that flow increases remain at 30 $m^3/s/hr$. We recommend that these guidelines continue to be followed.

The potential risk from salmon redd dewatering could be further reduced by linking the flows that occur during the spawning and incubation periods. We recommend that the flows during May, the major salmon spawning period, be maintained at as low a level as possible. Thereafter and to the end of September, i.e., through the incubation period, flows should not be reduced more than about 200 m^3/s below the mean daily flow that occurred in May. This will provide protection to eggs and alevins incubating in the redds.

This report presents the findings of the Stage 1 studies of the flow-related effects of the Waitaki power schemes on lower Waitaki aquatic resources. No further studies (Stage 2) are recommended at this time.

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APPENDIX I

Minimum flow each day in 1967 at Waitaki Dam cumecs

DAY	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	
1	44	701	323	416	984	167	44	63	88	104	127	517	
2	44	715	373	149	830	130	45	134	44	111	43	532	
3	87	703	380	131	741	128	42	92	43	130	78	424	
4	88	685	452	152	558	130	87	85	88	128	76	429	
5	75	676	95	88	439	89	40	134	208	89	55	137	
6	88	571	118	133	344	144	96	117	243	90	42	225	
7	102	436	234	123	188	106	107	123	115	127	76	583	
8	84	421	507	121	217	144	108	116	56	88	71	569	
9	86	329	681	64	218	134	93	117	126	90	34	477	
10	85	370	685	311	188	137	56	90	128	98	49	384	
11	86	411	760	677	126	64	54	79	139	124	121	410	
12	86	379	973	739	189	100	69	65	111	126	78	462	
13	86	353	975	736	198	191	70	51	120	126	50	415	
14	41	298	949	777	134	152	69	131	103	125	81	422	
15	43	172	938	682	187	108	75	46	124	68	62	648	
16	41	90	961	525	77	161	50	127	123	87	66	700	
17	42	315	957	462	171	173	69	124	102	101	92	705	
18	92	520	978	419	80	172	91	61	47	42	103	562	
19	71	573	905	446	144	124	113	116	124	90	89	675	
20	92	460	966	436	211	185	104	104	123	52	123	664	
21	78	357	963	431	47	134	88	54	127	89	107	658	
22	84	225	926	296	196	149	173	42	127	86	178	643	
23	105	161	746	316	172	126	124	90	126	51	165	642	
24	127	81	794	324	78	121	110	88	98	86	190	673	
25	160	185	640	443	43	85	153	96	125	128	99	670	
26	577	138	576	588	113	115	128	116	126	57	361	706	
27	608	290	553	800	104	132	103	104	127	127	229	684	
28	676	252	595	939	52	125	128	106	127	105	132	651	
29	703		487	980	89	115	125	54	133	71	601	665	
30	652		479	968	120	41	112	62	90	62	686	652	
31	713		404		150		62	71		54		629	
MIN	41	81	95	64	43	41	40	42	43	42	34	137	34
MEAN	192	388	657	456	238	129	90	92	115	94	142	555	262
MAX	713	715	978	980	984	191	173	134	243	130	686	706	984

APPENDIX I

Maximum flow each day in 1967 at Waitaki Dam cumecs

DAY	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	
1	266	788	507	560	1047	608	534	566	654	519	566	685	
2	250	813	494	461	941	557	486	617	415	553	497	618	
3	218	788	582	449	798	479	612	572	593	563	495	517	
4	257	781	540	425	673	468	651	582	562	571	362	568	
5	292	727	376	420	566	523	633	630	562	567	403	520	
6	372	724	514	408	487	561	626	507	575	475	565	622	
7	317	520	569	450	442	545	635	613	556	462	434	695	
8	303	539	718	560	572	551	574	575	550	361	560	660	
9	326	512	771	565	534	555	648	642	566	525	525	709	
10	310	502	822	668	554	418	656	644	527	494	562	562	
11	324	505	1019	777	558	430	643	647	576	501	446	559	
12	304	501	1075	815	547	497	624	484	564	441	400	575	
13	316	438	1067	804	425	507	641	424	556	469	430	462	
14	295	441	1077	823	430	463	653	648	559	448	460	603	
15	341	417	1052	759	567	532	662	658	547	358	470	755	
16	350	427	1056	667	559	671	608	633	492	521	415	779	
17	316	517	1067	573	549	481	666	655	467	557	535	775	
18	264	703	1083	509	529	303	667	632	500	551	481	711	
19	270	740	1089	535	555	533	663	646	499	565	465	699	
20	237	655	1074	513	526	550	635	546	503	561	448	700	
21	215	405	1076	548	457	565	641	651	542	406	468	694	
22	194	542	1051	504	548	612	638	566	557	435	499	688	
23	343	427	994	551	510	512	592	562	558	333	544	709	
24	553	440	978	511	495	429	666	560	544	459	548	741	
25	690	456	715	582	552	431	652	557	536	450	523	725	
26	796	369	679	759	562	609	632	560	502	437	554	767	
27	786	500	672	1038	566	483	606	543	551	443	556	735	
28	788	525	684	1167	529	564	648	513	561	353	630	713	
29	819		644	1082	563	570	620	562	528	364	805	719	
30	829		617	1047	555	563	547	534	537	451	1055	711	
31	790		541		614		596	556		451		674	
MIN	194	369	376	408	425	303	486	424	415	333	362	462	194
MEAN	411	561	813	651	574	519	624	583	541	472	523	666	579
MAX	829	813	1089	1167	1047	671	667	658	654	571	1055	779	1167

APPENDIX I

Range of flows each day in 1967 at Waitaki Dam cumecs

DAY	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	
1	222	87	184	144	64	441	490	503	565	414	439	168	
2	206	98	121	311	112	427	441	483	371	443	454	86	
3	132	85	202	318	57	351	570	479	549	433	417	93	
4	169	95	88	273	115	338	564	497	474	442	285	139	
5	218	51	281	332	127	434	592	496	355	478	348	384	
6	284	152	397	276	143	418	531	390	331	385	523	397	
7	215	84	335	327	254	439	528	490	441	336	357	112	
8	219	118	211	438	355	407	465	460	494	273	490	90	
9	240	183	90	501	316	420	555	525	440	435	491	231	
10	226	131	137	357	366	281	599	554	399	397	513	178	
11	238	93	259	100	432	366	589	568	437	377	325	149	
12	219	121	102	77	358	397	555	419	453	315	321	114	
13	230	85	92	68	226	316	572	372	436	343	380	47	
14	254	143	127	46	295	312	585	517	456	323	378	180	
15	298	245	114	77	380	424	587	612	423	290	408	107	
16	309	336	95	142	482	510	558	506	369	433	349	78	
17	274	203	110	111	378	308	597	531	365	455	443	70	
18	173	183	105	90	449	132	575	571	453	509	378	149	
19	198	167	184	88	411	409	550	530	375	475	377	25	
20	145	195	108	77	315	365	531	443	380	510	324	35	
21	137	47	112	117	409	431	553	597	415	317	361	36	
22	109	317	125	208	352	462	465	524	430	349	321	45	
23	239	266	248	235	337	386	468	472	432	283	379	67	
24	426	359	184	188	417	308	556	472	446	374	358	68	
25	530	271	76	139	509	346	499	461	411	322	424	55	
26	219	231	103	172	448	494	503	444	376	380	193	61	
27	178	210	119	238	462	351	503	440	424	316	327	51	
28	112	274	89	228	477	439	520	408	434	248	499	62	
29	116		157	102	474	455	495	508	395	293	203	54	
30	177		138	79	435	522	435	472	447	390	368	59	
31	77		137		465		534	486		398		45	
MIN	77	47	76	46	57	132	435	372	331	248	193	25	25
MEAN	219	172	156	195	336	390	534	491	426	378	381	111	317
MAX	530	359	397	501	509	522	599	612	565	510	523	397	612

APPENDIX I

Minimum flow each day in 1974 at Waitaki Dam cumecs

DAY	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	
1	198	321	380	339	380	180	143	309	233	234	121	327	
2	174	216	388	211	262	163	122	305	231	316	121	359	
3	221	216	329	173	279	168	123	257	229	241	83	402	
4	321	304	385	174	276	228	128	211	283	123	142	404	
5	298	367	393	181	194	356	151	310	278	122	138	466	
6	336	246	406	116	229	280	128	293	236	124	140	379	
7	306	288	376	359	266	269	123	318	214	124	174	209	
8	294	217	417	368	187	216	121	326	192	180	127	191	
9	315	170	294	524	210	190	141	326	214	215	126	260	
10	374	160	264	532	189	269	123	217	236	287	126	417	
11	464	213	215	485	188	339	125	238	277	238	143	340	
12	230	232	325	433	190	328	123	236	272	209	126	275	
13	271	310	366	409	189	392	122	248	187	120	125	194	
14	373	255	428	394	205	441	124	278	122	124	147	188	
15	464	195	395	390	206	218	129	251	125	189	184	124	
16	470	178	308	548	280	257	166	217	211	232	167	125	
17	487	164	211	659	190	312	133	140	236	268	128	189	
18	492	173	293	504	169	464	121	142	264	192	149	277	
19	392	213	356	458	177	456	121	214	283	149	305	234	
20	390	329	352	457	196	465	125	335	341	172	295	236	
21	392	353	299	531	246	164	117	297	128	191	276	191	
22	491	396	194	516	301	150	123	302	126	194	288	186	
23	560	392	191	522	268	149	144	322	228	211	130	260	
24	434	442	228	501	177	199	170	262	246	214	175	375	
25	355	434	216	497	172	152	162	192	261	209	345	192	
26	279	373	323	471	166	148	208	167	269	205	420	205	
27	195	363	382	486	257	145	173	297	265	149	395	228	
28	196	359	396	475	167	123	129	305	146	139	389	329	
29	344		389	440	176	123	169	319	212	183	388	297	
30	353		266	409	176	125	214	294	266	232	348	309	
31	394		184		205		230	250		164		265	
MIN	174	160	184	116	166	123	117	140	122	120	83	124	83
MEAN	350	281	321	419	218	249	143	264	227	192	207	272	262
MAX	560	442	428	659	380	465	230	335	341	316	420	466	659

APPENDIX I

Maximum flow each day in 1974 at Waitaki Dam cumecs

DAY	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	
1	265	470	544	493	462	261	305	337	328	454	194	374	
2	261	309	467	326	355	212	186	349	492	437	165	563	
3	351	286	422	286	362	230	128	329	518	358	129	469	
4	367	566	494	191	343	564	296	306	384	256	233	500	
5	334	506	461	421	279	554	268	420	422	129	214	510	
6	425	381	467	444	450	513	222	395	318	128	209	482	
7	497	553	445	396	371	499	126	391	310	192	179	289	
8	345	431	476	596	259	384	248	520	217	377	177	216	
9	379	213	355	641	232	242	259	450	324	372	170	548	
10	533	178	337	562	374	451	185	312	444	357	175	449	
11	537	454	450	591	192	460	167	272	370	307	225	448	
12	510	461	636	466	194	456	210	527	312	264	186	493	
13	395	342	546	447	211	454	185	458	287	210	211	255	
14	558	353	520	468	218	540	145	361	217	248	209	299	
15	546	353	501	575	355	425	228	346	190	306	211	155	
16	532	270	393	655	442	353	233	343	277	288	207	270	
17	598	193	299	674	374	661	210	180	295	360	177	431	
18	606	288	542	658	191	570	202	221	373	232	373	428	
19	614	369	531	573	226	530	124	382	436	218	349	424	
20	443	455	466	671	465	518	145	389	467	198	478	327	
21	573	528	417	602	465	452	129	416	309	308	336	240	
22	628	484	400	663	468	205	195	356	248	338	421	214	
23	619	522	346	602	434	180	196	493	380	287	270	320	
24	631	490	307	601	320	378	255	312	332	279	297	409	
25	587	482	404	537	179	248	228	277	373	308	482	429	
26	375	561	413	553	234	247	262	509	360	240	470	267	
27	314	552	525	606	661	153	254	505	414	213	431	327	
28	442	466	454	525	418	173	210	487	282	198	477	370	
29	557		498	530	238	146	223	522	278	416	456	329	
30	573		403	460	252	140	264	467	408	334	428	415	
31	492		291		240		478	412		247		364	
MIN	261	178	291	191	179	140	124	180	190	128	129	155	124
MEAN	480	411	445	527	331	373	218	388	345	286	285	375	372
MAX	631	566	636	674	661	661	478	527	518	454	482	563	674

APPENDIX I

Range of flows each day in 1974 at Waitaki Dam cumecs

DAY	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	
1	67	148	164	154	81	81	162	28	95	220	73	47	
2	87	93	78	114	92	49	64	44	261	121	44	204	
3	130	71	94	113	83	62	6	71	289	117	46	67	
4	46	262	110	18	67	337	168	95	101	133	91	96	
5	36	139	68	240	85	198	117	110	144	6	76	44	
6	89	135	61	328	221	232	93	102	82	3	68	103	
7	192	265	68	37	106	231	3	73	96	68	6	80	
8	51	214	59	227	72	168	128	194	25	196	50	25	
9	64	42	60	116	22	52	118	124	110	157	44	287	
10	159	17	73	29	185	182	62	96	208	71	49	31	
11	73	241	236	105	4	121	43	33	93	69	82	108	
12	280	229	311	33	4	128	87	291	41	55	60	218	
13	124	32	181	38	22	62	62	210	100	90	86	61	
14	185	98	92	74	13	99	21	82	95	124	62	111	
15	82	158	107	185	149	207	99	95	65	117	27	32	
16	61	93	85	107	162	96	66	126	66	56	40	145	
17	111	29	88	15	184	348	78	41	59	92	50	243	
18	114	115	249	154	23	106	80	78	109	39	224	151	
19	223	156	175	114	48	74	3	169	154	69	43	189	
20	53	126	115	214	269	53	21	54	126	26	183	91	
21	181	176	118	71	218	288	12	118	180	117	60	49	
22	137	88	205	147	167	55	72	54	122	144	133	28	
23	60	130	155	80	166	31	52	171	152	77	139	60	
24	197	48	79	100	143	179	85	49	86	65	122	35	
25	232	47	188	40	7	96	65	85	112	99	136	237	
26	96	188	89	82	68	100	54	342	92	35	50	62	
27	119	189	143	119	403	8	81	208	149	64	36	100	
28	245	108	58	51	251	50	81	182	135	59	88	40	
29	213		109	90	62	24	54	202	66	233	67	32	
30	220		137	52	76	15	51	173	142	101	81	105	
31	97		107		35		248	162		83		99	
MIN	36	17	58	15	4	8	3	28	25	3	6	25	3
MEAN	130	130	125	108	113	124	75	125	118	94	77	103	110
MAX	280	265	311	328	403	348	248	342	289	233	224	287	403

APPENDIX I

Minimum flow each day in 1985 at Waitaki Dam cumecs

DAY	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	
1	650	435	349	281	306	197	394	347	235	373	329	153	
2	649	366	333	358	375	191	428	355	256	460	307	213	
3	597	368	325	249	230	190	398	391	369	465	269	268	
4	639	466	331	166	209	215	395	317	378	476	271	371	
5	672	553	393	165	208	387	365	347	333	483	257	452	
6	604	504	372	173	236	309	262	374	401	384	256	278	
7	691	374	390	170	301	279	262	375	283	391	242	235	
8	719	363	372	169	405	260	306	366	240	361	169	238	
9	818	304	363	171	423	257	455	299	280	396	146	266	
10	893	332	364	188	207	269	462	259	357	398	145	297	
11	926	352	349	191	176	293	402	263	355	279	207	300	
12	919	372	400	187	150	300	62	309	389	323	309	308	
13	1099	363	383	186	214	300	367	433	323	329	301	283	
14	1107	397	364	170	334	275	367	459	249	356	306	219	
15	1040	365	309	166	258	267	360	453	234	339	236	213	
16	911	309	287	299	256	227	363	426	239	390	212	202	
17	836	279	278	270	263	262	360	362	396	447	178	209	
18	785	296	295	172	196	257	365	331	453	412	181	208	
19	760	326	348	148	197	275	389	329	453	363	267	204	
20	725	305	394	196	236	282	393	422	457	349	332	175	
21	656	312	336	272	306	211	375	455	449	352	425	193	
22	577	329	334	327	309	163	378	431	452	331	424	221	
23	563	299	379	242	312	168	372	330	359	334	401	233	
24	559	304	365	200	256	232	182	305	350	328	309	255	
25	543	334	372	145	184	306	383	294	365	314	303	266	
26	566	335	371	165	194	329	390	362	352	315	324	258	
27	596	338	366	124	218	327	360	308	396	333	274	258	
28	581	343	362	123	303	329	358	309	401	331	194	328	
29	506		307	238	328	243	377	353	373	320	189	360	
30	420		300	303	332	236	373	363	368	306	143	335	
31	441		280		365		359	265		300		307	
MIN	420	279	278	123	150	163	62	259	234	279	143	153	62
MEAN	711	358	347	207	267	261	357	355	351	366	264	261	343
MAX	1107	553	400	358	423	387	462	459	457	483	425	452	1107

APPENDIX I

Maximum flow each day in 1985 at Waitaki Dam cumecs

DAY	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	
1	715	520	377	376	383	365	442	380	270	452	345	201	
2	686	408	375	376	400	201	443	462	405	468	333	252	
3	651	460	337	386	399	213	437	440	417	477	326	353	
4	672	562	396	241	217	385	449	358	406	484	358	449	
5	681	563	412	180	243	463	428	410	428	485	308	537	
6	720	561	401	181	322	397	344	410	447	490	291	528	
7	759	461	408	178	406	332	304	417	407	415	285	278	
8	849	381	410	176	429	274	450	438	280	388	226	271	
9	955	366	403	195	443	298	495	379	413	411	173	315	
10	922	355	413	198	434	319	524	284	418	415	212	321	
11	959	457	408	275	198	317	473	284	372	396	335	378	
12	1053	451	411	276	215	343	373	449	424	353	331	376	
13	1119	425	432	197	336	315	381	457	388	445	326	314	
14	1120	431	453	194	463	323	378	471	301	467	333	284	
15	1131	403	453	297	409	302	376	467	251	379	346	216	
16	1039	369	321	330	325	281	372	444	408	476	251	240	
17	926	317	323	369	383	292	372	426	463	469	220	245	
18	914	328	387	254	237	307	398	368	468	467	348	270	
19	780	408	421	199	236	284	421	425	459	397	334	220	
20	783	366	442	271	376	307	442	476	480	373	423	200	
21	743	358	383	352	359	319	432	480	467	455	447	220	
22	661	366	431	343	334	191	443	479	469	410	440	248	
23	590	337	475	315	352	214	461	425	453	407	426	291	
24	594	334	412	240	317	329	366	343	425	372	392	275	
25	587	353	385	201	258	372	469	366	428	332	360	272	
26	605	348	395	215	215	366	470	420	425	394	363	267	
27	609	354	429	182	315	370	464	371	469	397	326	381	
28	603	365	415	223	332	404	456	363	466	348	290	365	
29	571		368	303	344	306	475	421	427	377	236	370	
30	500		349	335	373	374	455	405	462	326	219	368	
31	498		342		375		458	362		346		335	
MIN	498	317	321	176	198	191	304	284	251	326	173	200	173
MEAN	774	407	399	262	336	319	427	409	413	415	320	311	400
MAX	1131	563	475	386	463	463	524	480	480	490	447	537	1131

APPENDIX I

Range of flows each day in 1985 at Waitaki Dam cumecs

DAY	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC
1	65	85	28	95	78	168	48	34	35	79	17	47
2	37	41	42	18	25	10	14	107	149	8	26	39
3	54	92	12	137	169	23	39	50	48	12	57	86
4	33	96	65	76	9	171	54	42	29	8	87	78
5	10	10	18	15	35	76	63	63	95	3	52	84
6	116	58	29	8	86	88	83	36	46	105	35	250
7	68	87	18	8	105	52	42	42	123	24	43	42
8	130	17	39	8	24	13	144	72	40	27	57	34
9	137	62	40	23	20	41	40	80	133	15	27	49
10	30	24	49	10	227	50	62	25	62	17	67	24
11	33	105	60	84	23	24	71	21	18	117	128	78
12	134	79	12	89	65	42	312	139	35	30	22	68
13	20	62	50	10	121	15	14	24	65	116	26	31
14	13	34	89	24	129	48	11	12	52	111	27	65
15	91	38	144	131	150	34	16	14	17	39	109	4
16	128	60	34	30	69	54	9	18	169	86	39	38
17	89	38	45	99	121	30	12	63	67	22	42	37
18	129	32	91	82	41	51	33	37	16	54	166	62
19	21	82	73	51	39	9	32	97	5	34	66	16
20	57	62	48	75	140	26	49	54	22	24	91	25
21	87	46	48	80	53	108	57	25	18	103	22	27
22	84	37	97	16	26	28	64	48	18	79	16	27
23	27	37	96	72	40	46	89	95	94	74	26	58
24	35	30	47	40	61	97	184	38	75	43	82	20
25	44	20	13	57	74	66	85	72	64	18	56	6
26	38	13	24	50	21	37	80	58	73	78	40	9
27	13	16	62	59	97	43	103	63	72	63	52	123
28	22	22	54	100	29	75	98	54	65	16	96	37
29	65		61	64	16	62	98	68	53	57	47	9
30	80		49	33	41	138	82	42	94	19	76	33
31	57		62		10		99	96		45		28
MIN	10	10	12	8	9	9	9	12	5	3	16	4	3
MEAN	63	49	52	55	69	57	71	54	62	49	57	49	57
MAX	137	105	144	137	227	171	312	139	169	117	166	250	312