North Canterbury Catchment Board
and
Regional Water Board

The Water Resources of the Rakaia Catchment

by G. D. Stephen

THE WATER RESOURCES

OF THE

RAKAIA CATCHMENT

by

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CONTENTS

NORTH CANTERBURY CATCHMENT BOARD

THE WATER RESOURCES OF THE RAKAIA CATCHMENT

A B S T R A C T

The report deals principally with the water resources in the catchment for which quantitative information is available, and hydrological data relating to these resources are presented. In describing the catchment, emphasis has been placed on those features affecting run-off. The distribution of average annual rainfall is examined. Details of daily, monthly and annual mean discharges from 1958 onwards at the principal gauging site at Rakaia Gorge bridge are given, together with flow duration curves derived therefrom. Reference is made to an earlier report on low flows in the Rakaia river. Flow data relating to discharges from Lake Coleridge and Highbank power stations, and from Lake Heron are included, together with some flow measurements made at other sites in the upper catchment. The effect of intermittent discharges from Lake Coleridge power station on flow in the main river is discussed, and results given of an investigation into the reduction in river flow between Rakaia Gorge and State Highway No. 1 bridge. The average annual run-off is compared with the average annual rainfall. The distribution of ground water on the plain adjoining the main river is described. The uses made of water at present are summarised. Reference is made to possible future demands of water for irrigation, and to the views expressed by certain users on future large abstractions. Details of a water quality analysis are also included.

1. INTRODUCTION:

On 17 November 1970, following receipt of the report on the Waimakariri river as a water resource (Dalmer 1970), the Minister of Works wrote to the Board saying that it would be necessary to investigate the Rakaia river as another possible source of water for irrigating areas to its north as well as to its south. The Minister therefore asked the Board "to undertake an investigation of the Rakaia river as a water resource and to continue its studies of the most beneficial uses of natural water, particularly with reference to the sources and availability of water for future irrigation schemes in the central plains."

The Director of Water and Soil Conservation wrote on 1 April 1971, stating that all possible assistance would be given to the Board in the collection and processing of data. Discussions with the District Office of the Ministry of Works were requested so that the investigation and assistance could be planned.

A meeting was held on 21 May 1971 in Christchurch, between staff of the Ministry of Works and the Board, when the position regarding flow records was discussed. Arrangements were made for existing data in possession of the Department to be processed and forwarded to the Board, and future work required for determining infiltration losses was planned.

2. DESCRIPTION OF THE CATCHMENT:

2.1 AREA:

The catchment of the Rakaia river and its tributaries extends from the east coast of the South Island in a north-westerly direction to the Southern Alps. It falls into two distinct regions: the narrow portion across the Canterbury plain consisting of little more than the river-bed itself, and the much larger mountainous part above the Gorge bridge which gradually widens out and drains 40 miles of the main divide, this being the straight line distance from Mt. Isobel in the north to the Lyell glacier in the south. The total catchment area to the mouth of the Rakaia river is

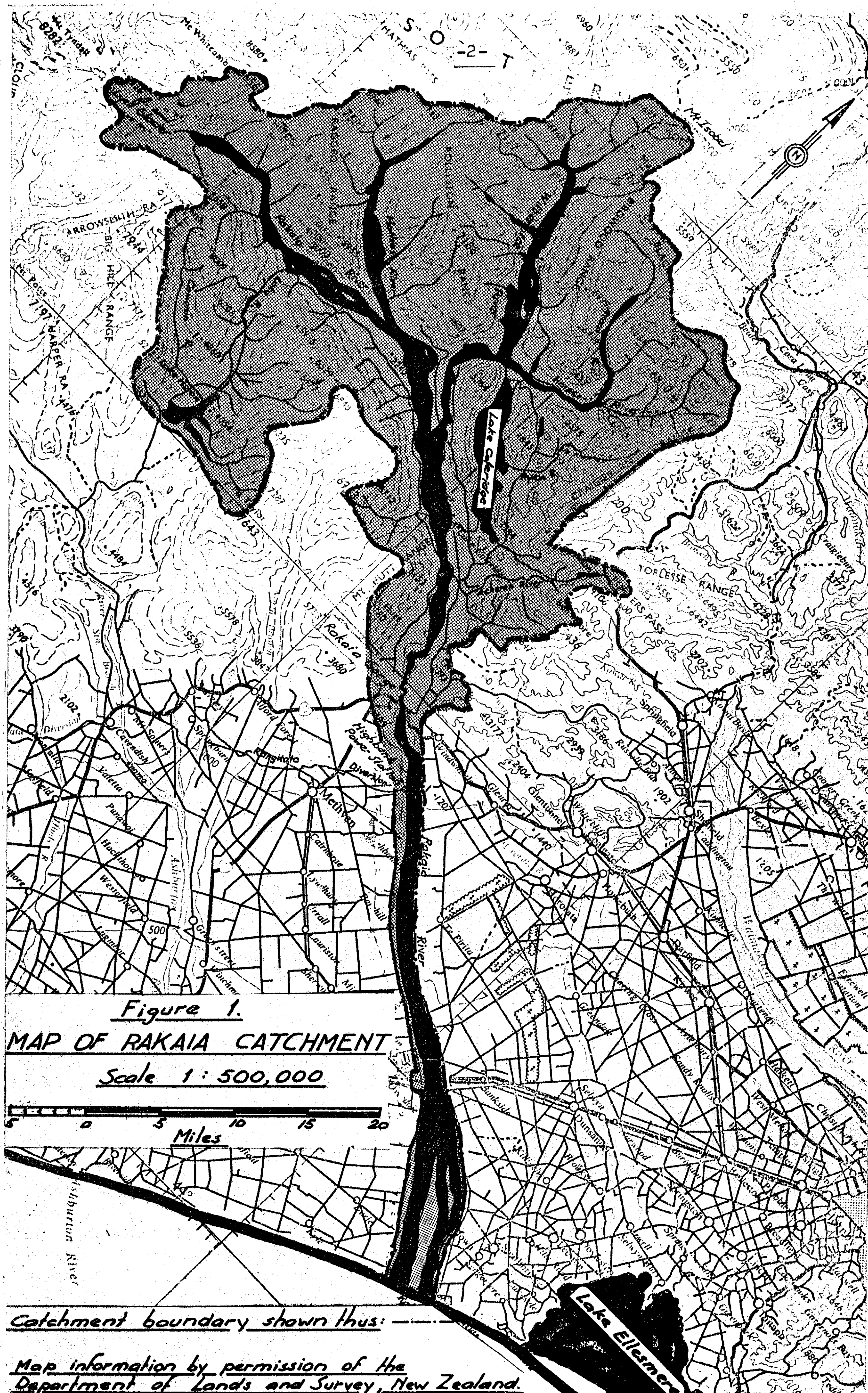

Figure 1.
MAP OF RAKAIA CATCHMENT
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approximately 1,100 square miles, of which 997 square miles lies above the Gorge bridge. The shape and general features of the catchment are shown in Figure 1.

2.2 RELIEF:

The highest point in the upper catchment is Mt. Arrowsmith rising to 9,171 feet, and there are a number of peaks exceeding 7,000 feet. Not only is the major part of the catchment bounded on all sides by high terrain (the principal exception being in the vicinity of Lake Heron), but much of the interior of the catchment between tributaries is of similar elevation. From the contours shown on map NZMS 19 Sheet 15, 1:500,000 scale, it has been estimated that 28% of the area above the Gorge bridge lies above 5,000 feet. By comparison, the corresponding figure for the Waimakariri catchment is only 10%.

2.3 COVER:

There appears to be little quantitative information regarding the distribution of various types of vegetation over the catchment as a whole. Packard (1947) investigated changes that had taken place in the condition of 250 square miles of the eastern part of the upper catchment, including the catchments of the Harper and Avoca rivers, and Lake Coleridge. He gave the following percentages of surface cover for this part of the catchment in 1946:

	% Total Area
Beech forest	11.1
Plantation	0.2
Scrub	2.2
Tussock grassland	46.0
English grassland	1.5
Subalpine vegetation	5.7
Shingle and Rock	31.2
Rock Ice and Snow	2.1
	100.0

N.Z. topographical maps, 1 inch to the mile series, now cover most of the catchment and these show the areas of bush, scrub and plantation. By measurement from these maps it has been estimated that these three categories of vegetation together cover about 7.5% of the upper catchment. In general terms, the remainder of the catchment above the Gorge bridge appears to consist mainly of tussock grassland, shingle, and bare rock in proportions not known at present.

2.4 RIVER SYSTEM:

The length of the Rakaia river from its source in the Lyell glacier to the mouth is 87 miles approximately. Over the lower 38 miles the river crosses the Canterbury plain in a wide braided shingle channel between terraces 500 feet high near the Gorge, gradually diminishing in height towards the coast. Over this length the river has an even grade of some 24 feet to the mile, and the shingle phase extends to the sea. Unlike the Waimakariri, there is no evidence that the Rakaia has undergone any major changes in its course in recent times. It flows within its confining terraces in a remarkably straight line from the Gorge to the sea. As far as is known, no comparative bed surveys have been undertaken to show whether the channel is aggrading or degrading, although Speight (1933) observed that the railway bridge did not have the clearance that it had when it was first erected.

The larger tributaries - the Wilberforce, Harper, Mathias and Lake Stream - all join the main river in the upper catchment. Below the Gorge bridge there is only one small natural tributary, namely Camping Gully on the north side, and the only addition of any magnitude to the main river flow is the discharge from Highbank power station situated on the south bank some 6 miles below the Gorge. This hydro-electric station uses water diverted from the Rangitata and Ashburton rivers when it is not required for irrigation. The discharge into the Rakaia has at times exceeded ~~900 cusecs~~, but the higher flows normally only occur during the winter months.

2.5 GEOLOGY:

The predominant basement rock in the upper Rakaia catchment is greywacke. Measurements taken from N.Z. Geological Survey maps 1:250,000 scale, Sheets 17, 18 and 21, show that about three-quarters of the area above the Gorge bridge consist of surface exposures described in the legend as "indurated poorly fossiliferous uniform greywacke and argillite, commonly showing graded bedding; scattered interbedded volcanics(mostly spilitic) commonly with associated limestone and chert." Tertiary rocks are confined to relatively small areas, examples being in Redcliffe Gully opposite Lake Coleridge power station, in the valley of the Harper river, and in the valley of the Smite river near Lake Heron. Rhyolite is found just above the Gorge bridge. Apart from the predominant greywacke, and the other above-mentioned rocks, the balance of the upper catchment consists of river gravels, glacial outwash gravels and morainic deposits.

Below the Gorge, tertiary beds are exposed on the north bank of the Rakaia some ~~three miles~~ downstream of the bridge, but otherwise the deposits consist of gravels which are overlain in part by loess on the south bank.

2.6 GLACIATION:

In common with most mountainous areas of the South Island, the upper catchment of the Rakaia and tributaries was subjected to successive glacial advances during the Pleistocene period. Speight (1933) gave the following description of the general conditions at the height of the glaciation:- "The great mountain basin was full of ice, fed chiefly by three great streams coming from the main divide down the valleys of the Rakaia, Mathias and Wilberforce, with a subordinate flow down the Avoca. These streams coalesced and covered the whole country now occupied by the main Rakaia valley, Lake Coleridge and the country east of it." Soons (1963) traced four main glacial advances in the Rakaia valley, and concluded that during the earliest and greatest of these the ice extended out on to the plain as far as Woolshed Hill, about ~~6 miles~~ from the lower end of the Gorge.

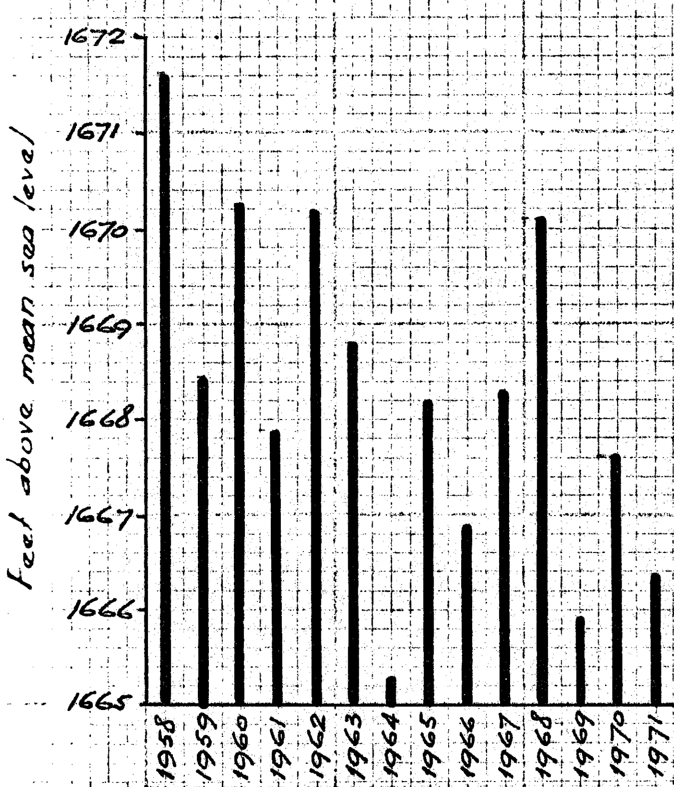
The ice caused modifications in the drainage pattern in the upper catchment. These are of considerable interest and have been referred to by Speight (1933), but of more importance to the present investigation are the remnants of these old glaciations. The headwaters of the Rakaia are fed by the Lyell and Ramsay glaciers referred to by Gage (1951) as the northernmost of any magnitude in the Southern Alps. The Cameron river, which joins the Lake Stream just below Lake Heron, also has its source in a glacier, and there are small glaciers at the heads of some tributaries of the Wilberforce. The presence and extent of these glaciers, and the meltwater from them, are probably the main reasons why the dry weather flow in the lower reaches of the Rakaia is considerably higher than it is in the Waimakariri, although the upper catchments of both rivers have very nearly the same area.

2.7 LAKES:

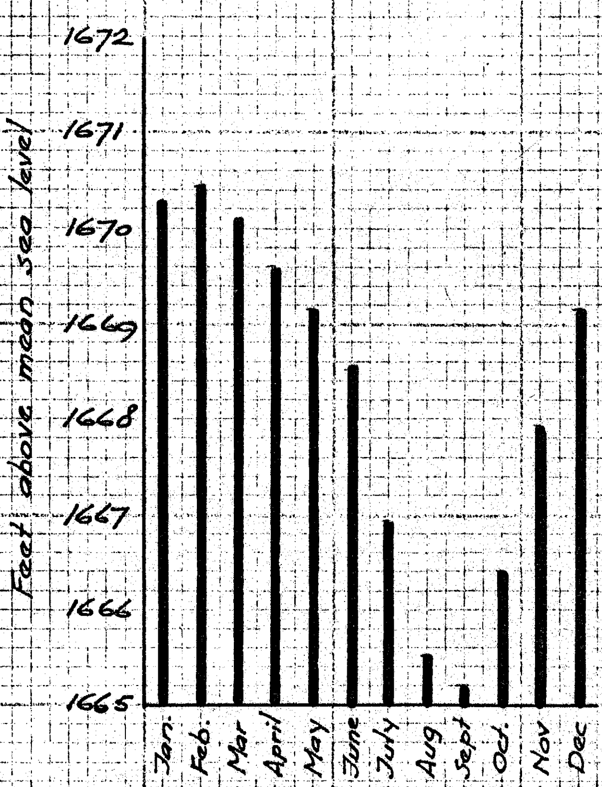
Lakes have an important bearing on the water resources of a catchment. Not only do they exert a regulating effect on river flows downstream, but they store water where it is readily available for use. The two largest lakes in the Rakaia catchment are Lake Coleridge and Lake Heron. These are followed in size by Lake Lyndon, and a number of smaller lakes and tarns chiefly in the eastern part of the upper catchment.

The natural catchment area draining to Lake Coleridge is 82 square miles. The lake itself has a surface area of some 9,000 acres; it is nearly ~~11 miles~~ [17km] long with an average width of just under ~~1½ miles~~ [2.4km]. It is over ~~650~~ [198m] feet deep in the deepest part, and contains a very large volume of water. From the isobaths shown on the lake chart based on the work by Flain (1970), it has been calculated that the total volume stored when the surface is 1664.7 feet above mean sea level is 2.908×10^6 acre feet or 1.266×10^{11} cubic feet. Some idea of this large quantity can be formed from the fact that, if it were possible to drain the lake completely at a constant discharge of ~~1,000 cusecs~~ [28.32 cumecs], with no inflow, it would take 4 years to empty it.

From records of the N.Z. Electricity Department, the annual mean levels of the lake have been calculated for the period 1958 to 1971. The results are shown graphically in Figure 2 (a) and these indicate that, although there can be considerable variation in mean level from year to year, there has been no particular trend during the past 14 years. The average annual level over the period was ~~1668.26~~ [508.48 m] feet above mean sea level. Of greater interest is the <u>variation in average monthly levels</u> shown in Figure 2 (b), and it will be noted that on an average the <u>level drops</u> during the <u>winter months</u> to reach a <u>minimum in September</u>, thereafter <u>rising</u> to reach a <u>maximum in February</u>. [Not Now due to Wilbert Diversion]



Annual mean levels of Lake Coleridge Period 1958-71 inclusive
Figure 2 (a)



Average monthly levels of Lake Coleridge Period 1958-71 inclusive
Figure 2 (b)

Water stored in the lake is used to generate electricity at Lake Coleridge power station, situated on the north bank of the Rakaia river some ~~13 miles~~ 20.9 km above the lower end of the Gorge. The water is drawn from the lake through two tunnels leading to surge chambers, whence it flows through pipes down the steep hillside to the station below, afterwards discharging into the Rakaia river.

To augment the run-off to the lake from its natural catchment, the N.Z. Electricity Department has carried out works to enable a maximum of about ~~1,000 cusecs~~ 28.32 cumecs to be diverted from the Harper river into the north-western end of the lake. A smaller quantity is diverted from the catchment of the Acheron into the south-eastern end. By these means the area draining to the lake has been increased from 82 square miles to 229 square miles, but it should be made clear that the run-off from the larger area does not at all times flow into the lake. When the Harper and Acheron are in flood, most if not all of the flows in these two rivers continue on their normal courses to the Rakaia. Moreover, any water that is diverted must all return eventually to the main river above the Gorge, although the actual discharge added to the river may be modified.

The only natural outlet from the lake is at the north-western end through a channel leading to a point near the confluence of the Harper and Wilberforce rivers. The N.Z. Electricity Department can control the flow through this outlet, and hence the level of the lake, by a radial gate 15 feet wide and 8 feet 9 inches high approximately. The top of the gate in the closed position is at a level of ~~1673.5 feet~~ 510 m measured from the staff gauge alongside. According to the Superintendent of the power station, there has been no flow through this outlet for the last ten years, and all discharge from the lake during this time has been through the station into the Rakaia river.

Figure 3, based on the lake isobaths (Flain 1970), shows the relation between the volume of water stored in the lake and the surface elevation.

It is understood that the maximum and minimum levels between which water is used for power generation are ~~1671.5~~ 509.47 m and ~~1658 feet~~ 505.36 m respectively. The graph shows that these two levels correspond to about 2.97×10^6 and 2.85×10^6 acre feet respectively, the difference being 0.12×10^6 acre feet or about 4% of the total volume of water in the lake. This fact does not, of course, imply that the remaining storage is available, under present circumstances, for other consumptive use.

Information about discharges from the lake through the power station into the Rakaia river is given in a later section of the report.

Lake Heron has a surface area of some 1,700 acres, and, although much smaller than Lake Coleridge, it is of special interest because of its position in the south-western part of the catchment, and the fact that it is separated from the adjoining catchment of the Ashburton river by comparatively low ground. The lake, which has a catchment area of about 44 square miles, drains to the Rakaia river via Lake Stream flowing in a direction almost due north. Some flow data relating to this tributary are available and the level of the lake has been recorded since 1938. During this period the level of the lake has varied from a maximum of ~~5.5 feet~~ 1.68 m on the gauge to a minimum of ~~6 inches~~ 0.152 m below zero. The reduced level of the staff gauge zero is not known, but the one mile to the inch map S73 gives the elevation of the lake surface as ~~2,276 feet~~ 693.72 m.

The possibility exists of diverting a controlled quantity of water from the lake at its southern end into a tributary of the South Ashburton river and thence into the Rangitata diversion race. This possibility is recognised by engineers of the Ministry of Works, and it is considered that the diversion could be achieved by relatively minor engineering works. The supply of water from this source could be increased still further by diverting the Cameron river into the lake.

Lake Lyndon having a surface area of 270 acres, and the other smaller lakes are of importance chiefly from a recreational and aesthetic point of view. So far as is known, no hydrologic data exist in respect of them.

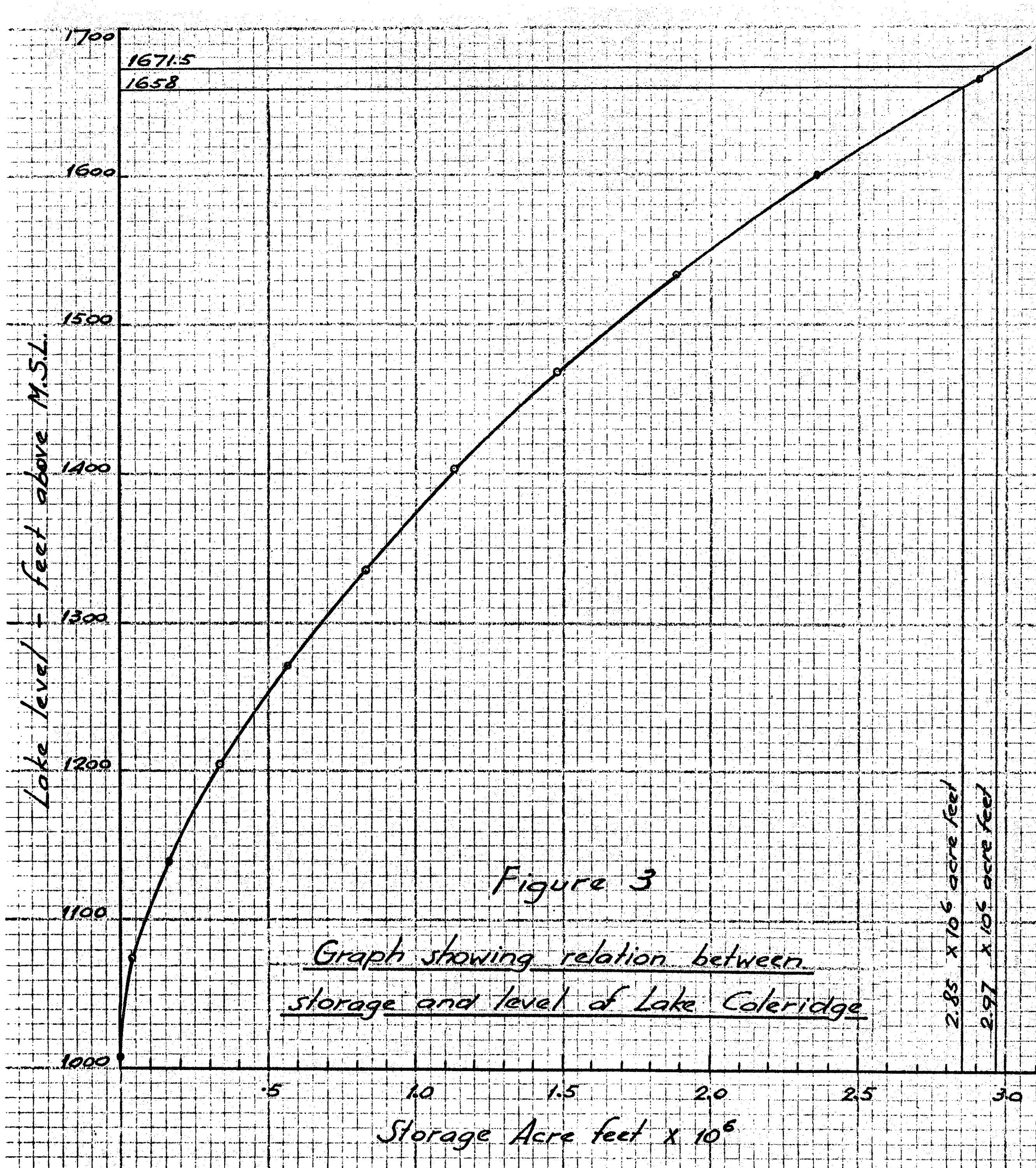


Figure 3

Graph showing relation between storage and level of Lake Coleridge

3. RAINFALL:

Owing to the mountainous nature of the area and the fact that it is sparsely populated, there are comparatively few rainfall stations in the upper catchment. Table 1 gives a list of rainfall stations for which the normal rainfalls (average 1921-50) are given in "Rainfall Observations for 1970", (N.Z. Meteorological Service, 1970). Some stations on the plain lying just outside the catchment boundary have been included.

Station	Met. Service No.	Elevation above sea level - feet	Normal annual rainfall inches (av. 1921-50)
Glenthorne	H.31141	2000	61.0
Double Hill	H.31321	2500	55.2
Harper river	H.31241	1750	46.5
Bayfields	H.31461	1630	42.0
Peak Hill	H.31341	1350	39.3
Highbank Power Station	H.31572	1102	36.7
Lake Coleridge Homestead	H.31351	1685	36.6
Simois Creek	H.31251	1800	36.0
Lake Coleridge Power Station	H.31352	1195	33.0
Creeside	H.31681	740	32.1
Te Pirita	H.31691	500	30.5
Killinchy	H.32722	150	29.9
Somerton	H.31792	500	29.6

TABLE 1

Normal annual rainfalls (average 1921-50)

The locations of the above stations are shown in Figure 4, the stations being identified by the last three figures of the Meteorological Service number.

The Ministry of Works has supplied annual rainfall totals from a gauge at Upper Lake Heron (H.3141A). The average for the standard period is not at present available, but the average for the ten years 1961-70 is 42.30 inches.

In 1962, owing to the lack of rainfall information in the catchment near the main divide, the Board installed a 95-day Casella recording gauge at a site on the Stewart (or Unknown) river in the upper catchment of the Wilberforce. Only three complete years of records were obtained, but in spite of the short period, the records were a valuable confirmation of the much higher rainfall towards the north-western boundary of the catchment. The three annual totals were as follows:-

Year	Total annual rainfall inches
1963	171.85
1964	211.34
1965	193.44

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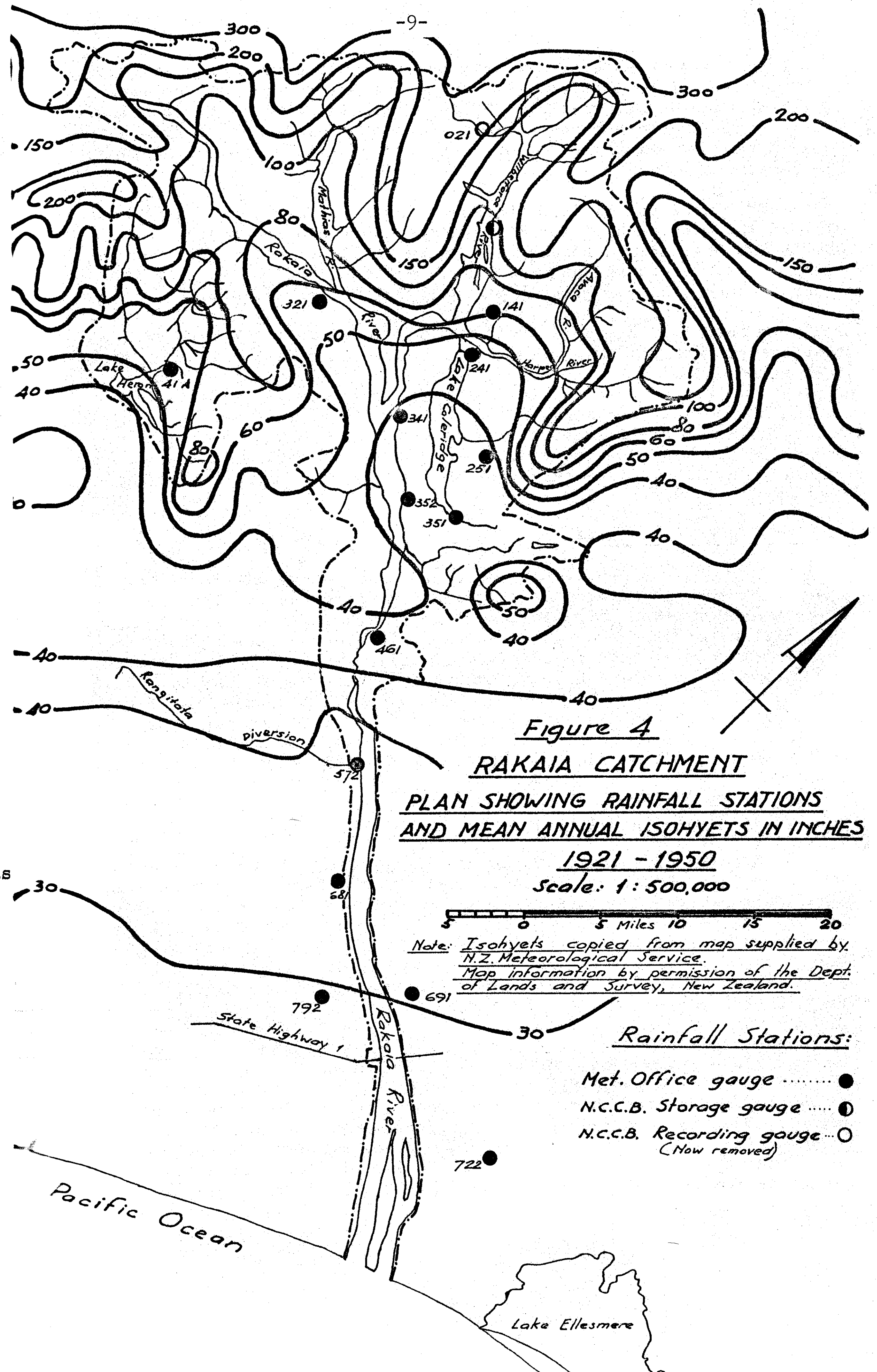


Figure 4

RAKAIA CATCHMENT

PLAN SHOWING RAINFALL STATIONS AND MEAN ANNUAL ISOHYETS IN INCHES

1921 - 1950

Scale: 1 : 500,000

5 0 5 Miles 10 15 20

Note: Isohyets copied from map supplied by N.Z. Meteorological Service.
Map information by permission of the Dept. of Lands and Survey, New Zealand.

From these results, presumably by correlation with another station in the area, the Meteorological Service has estimated that the long-period average annual rainfall (1921-50) for the Stewart river site is 208 inches. The Meteorological Service number allocated to this gauge when it was operating was H.31021, and the site is shown on the plan, Figure 4.

Towards the end of 1970 the Board installed a storage gauge at Fang Hill on the east bank of the Wilberforce about 6 miles north-west of Glenthorne Station. A reading was taken on 31 December 1971, and the total for the year was 1673 mm or 65.9 inches. Judging by rainfalls at other stations, this figure is probably well below average.

The best impression of the distribution of rainfall over the catchment can be obtained from mean annual isohyets. These have been copied from a map supplied by the Meteorological Service and are shown on Figure 4. The isohyets indicate very clearly the big variation in rainfall over the catchment, and how the high rainfall decreases rapidly in a south-easterly direction away from the main divide. By measuring the areas between each isohyet, it has been estimated that the mean annual rainfall over the catchment above the Gorge bridge is approximately 102 inches.

4. CONTINUOUS FLOW DATA:

In any study of the water resources of an area, data relating to flow in rivers and streams are of paramount importance. This is particularly so when abstractions of water are under consideration. This section of the report deals with available continuous flow data that has been processed in the form of daily mean discharges from which derivatives such as monthly and annual mean discharges, and flow duration data may be obtained. The data available relate to the Rakaia river at the Gorge bridge, to discharges from Lake Coleridge and Highbank power stations (both of which at times contribute substantial flows to the Rakaia river), and to the Lake Stream which carries the flow from Lake Heron.

4.1 RAKAIA GORGE BRIDGE:

Daily mean discharges of the Rakaia river at the Gorge bridge for the water years 1958 to 1970 inclusive, and for part of 1971 have been made available by the Ministry of Works. These data were revised early in 1972 and supersede earlier figures. The daily mean discharges are reproduced in full as an Appendix to this report, and a summary giving annual mean, monthly mean and average monthly discharges in cusecs is given in Table 2. The annual mean and average monthly discharges are shown graphically in Figures 5 (a) and (b).

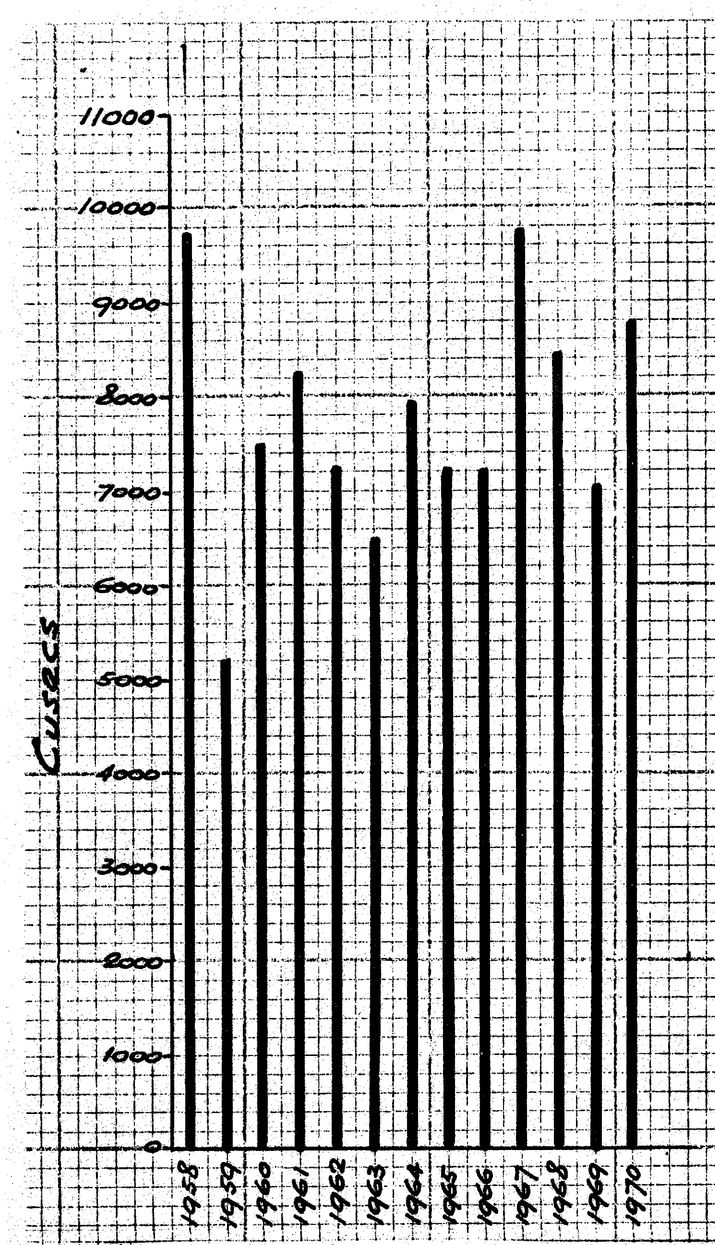
Over the period that the daily mean discharges have been calculated, from 1st January 1958 to 9th May 1971, 128 actual flow gaugings have been carried out at the Gorge bridge, all by Ministry of Works staff. The measurements have been made over the range from 65,200 cusecs on 23rd January 1970, to 3,180 cusecs on 25th June 1969. Subsequent to the above period, a discharge of 2,730 cusecs [77.32 cumecs] was measured on 25th August 1971, and as far as is known this is the lowest flow ever actually gauged in the Rakaia river at the Gorge bridge.

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Mean Discharge
1958	15247	17724	12014	9178	12700	6395	3694	6040	6569	9186	8581	10365	9766
1959	3996	4758	4529	4517	3767	5322	3542	3371	5450	4877	7946	10549	5216
1960	8816	10569	8826	4742	6173	5833	4546	7240	8134	8078	8598	8481	7494
1961	8299	11482	11401	10264	4910	5503	5070	5959	4511	10564	13477	7947	8254
1962	13724	4325	3995	3587	9753	5355	6145	5004	5125	10595	11916	7054	7246
1963	5800	8866	6619	4710	8796	6571	4541	5104	7953	5360	8118	5761	6494
1964	13419	5641	10156	4949	11987	6107	6194	6297	5008	6106	6056	12780	7930
1965	13839	8517	4796	4244	5154	5749	4410	3948	4151	6015	13223	12605	7215
1966	16480	13721	7749	9811	5522	4149	3801	3567	3762	4004	7533	6982	7214
1967	10055	10061	13280	15017	5960	4102	6331	8973	4703	8396	15351	14949	9762
1968	11390	10740	9945	7549	10102	5278	5021	5755	5319	12473	9847	7950	8451
1969	7053	5755	7946	6539	4906	3621	3663	3590	15668	6976	6473	12213	7033
1970	10283	5697	9219	8990	4850	5568	7856	11867	15853	7272	9195	8438	8770
Average Monthly Discharges	10646	9066	8498	7238	7275	5350	4986	5901	7093	7685	9716	9698	7757 *

* Average annual discharge 1958-70.

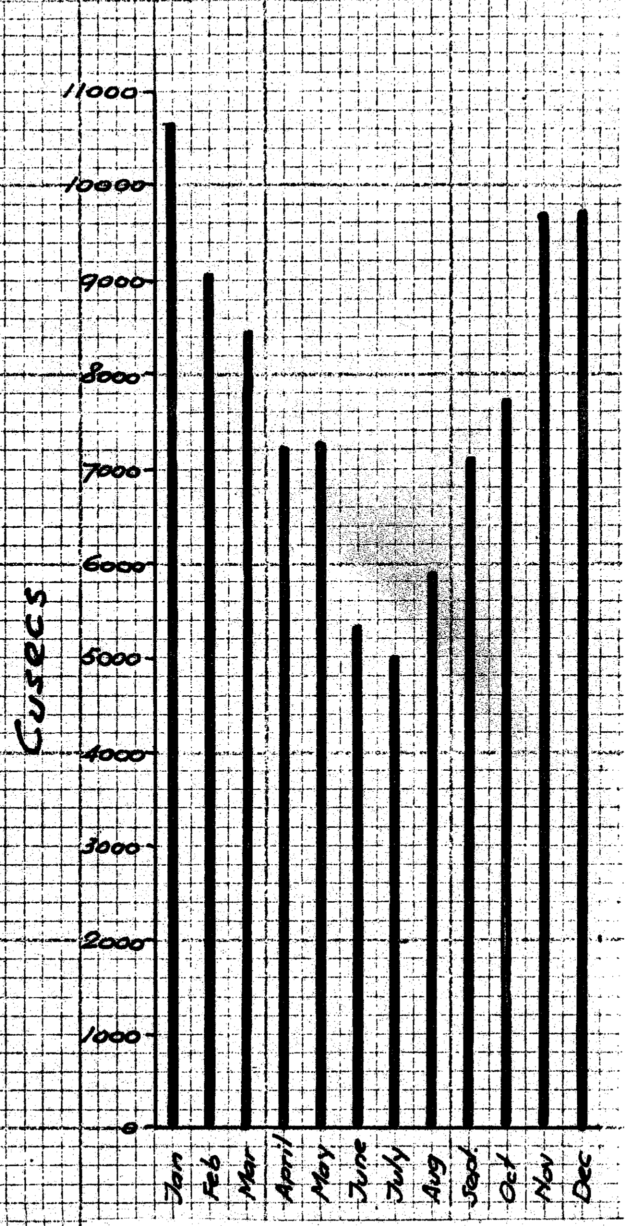
TABLE 2

Annual mean, monthly mean and average monthly discharges in cusecs - Rakaia river - Gorge bridge.



Annual mean discharges in cusecs Rakaia river ~ Gorge Bridge

Figure 5(a)



Annual monthly discharges in cusecs for period 1958-70. Rakaia river ~ Gorge Bridge

Figure 5(b)

In a letter forwarding the revised figures to the Board, the Acting District Commissioner of Works makes the following comment: "Rating of this site is extremely difficult and the ratings so far derived could be incorrect, particularly above 30,000 cusecs. It should be appreciated that all mean flows could be significantly in error and should, therefore be quoted with caution until such time as the ratings are more certain."

Despite the limitations that must be placed on the figures, they are the best available and form an essential part of this investigation.

Table 2 and Figure 5 (a) show that the annual mean discharge of the river can vary considerably from year to year. In the period of 13 years it varied from 5,216 to 9,766 cusecs, and the average annual discharge for the period was 7,757 cusecs. Figure 5 (b) shows that on an average over the period the river flow is greater during the summer than it is during the winter. The average discharge over the 13 periods October to March is 8,813 cusecs. The highest average monthly discharge occurs in

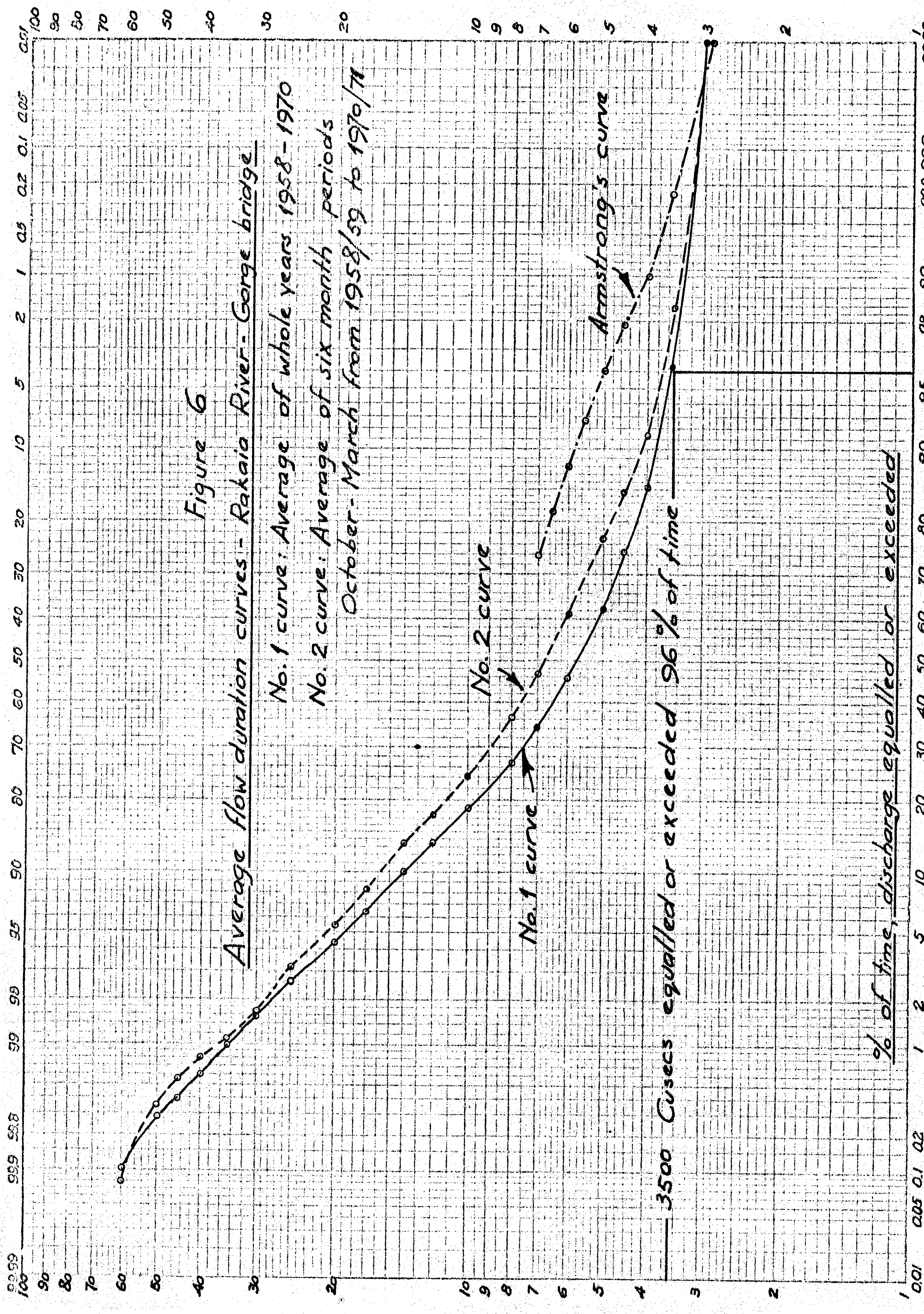
January and it is more than twice the average monthly discharge for July. From the point of view of irrigation this is fortunate, because a demand for water could more readily be met, on an average, during the season it is required.

When daily mean discharges are available they can be processed further to provide what are known as flow duration data which can also be conveniently expressed in graphical form as flow duration curves. The flow in a river is constantly changing and during a period of, say, a year the discharge may only be exactly equal to a certain magnitude for a short period of time. But it is possible to select certain discharges and to find the percentage of the total time that these discharges are equalled or exceeded. This has been done for the Rakaia at the Gorge bridge for each year of complete record and the 13 sets of data have then been combined to give an average flow duration curve for the period 1958 to 1970 inclusive. The result is shown as No. 1 curve in Figure 6, and from this curve it is possible to read off the discharge that is equalled or exceeded for any percentage of time. For example, the discharge that is equalled or exceeded on an average for 96% of the time (or 350 days out of the year) is 3,500 cusecs, and it follows that for the remaining 4% of the time (or 15 days) the discharge would be less than 3,500 cusecs.

Because of the interest in irrigation, and the fact that the flow in the river is greater during the summer than it is during the winter, the same sort of analysis has been done for each of the six-month periods, October to March. The 13 available sets of data have again been combined to give an average flow duration curve and shown as No. 2 curve in Figure 6. Using this curve and assuming water was abstracted from the river in the vicinity of the Gorge bridge, Table 3 has been prepared showing the average percentage of time and number of days (during the six-month period October to March) that different water demands could be met for various minimum residual flows in the river just downstream of the intake.

Table 3 could of course be extended, but the range of figures given is probably sufficient to cover any likely water requirements on the one hand, and any minimum residual river flow that may ultimately be fixed on the other. It is not within the scope of this report to make recommendations on either of these matters, but once the minimum residual flow in the river is decided, the figures should serve as a useful guide to the supply that is likely, on an average, to be available.

Although a flow duration curve is of considerable value in providing a general picture of the quantity of water flowing in a river, it must be remembered that it is an average curve for the period upon which it is based. It combines the data for years when flows are generally high with those when they are generally low. To illustrate this, the 13 sets of flow duration data for the six-month seasons have been examined to find the seasons having the highest and lowest flows. For the medium and low range of discharge, these turn out to be the 1960/61 and 1958/59 seasons respectively, and curves for these seasons have been plotted in Figure 7, together with the average curve plotted again for comparison. It will be seen that whereas a river flow of 4,000 cusecs was equalled or exceeded for 91.2% of time on an average, it was only equalled or exceeded for 63.7% of time during the season of lowest flow in 1958/59. During the season of highest flow in 1960/61 on the other hand, the same flow was equalled or exceeded for 100% of the time. Attention should be drawn to the fact that there are considerable departures from the average, but at the same time it is felt that any conclusions concerning the discharge of the river should in fact be based upon average conditions as portrayed by the No. 1 and No. 2 curves in Figure 6.



Discharge in 1000 cusecs

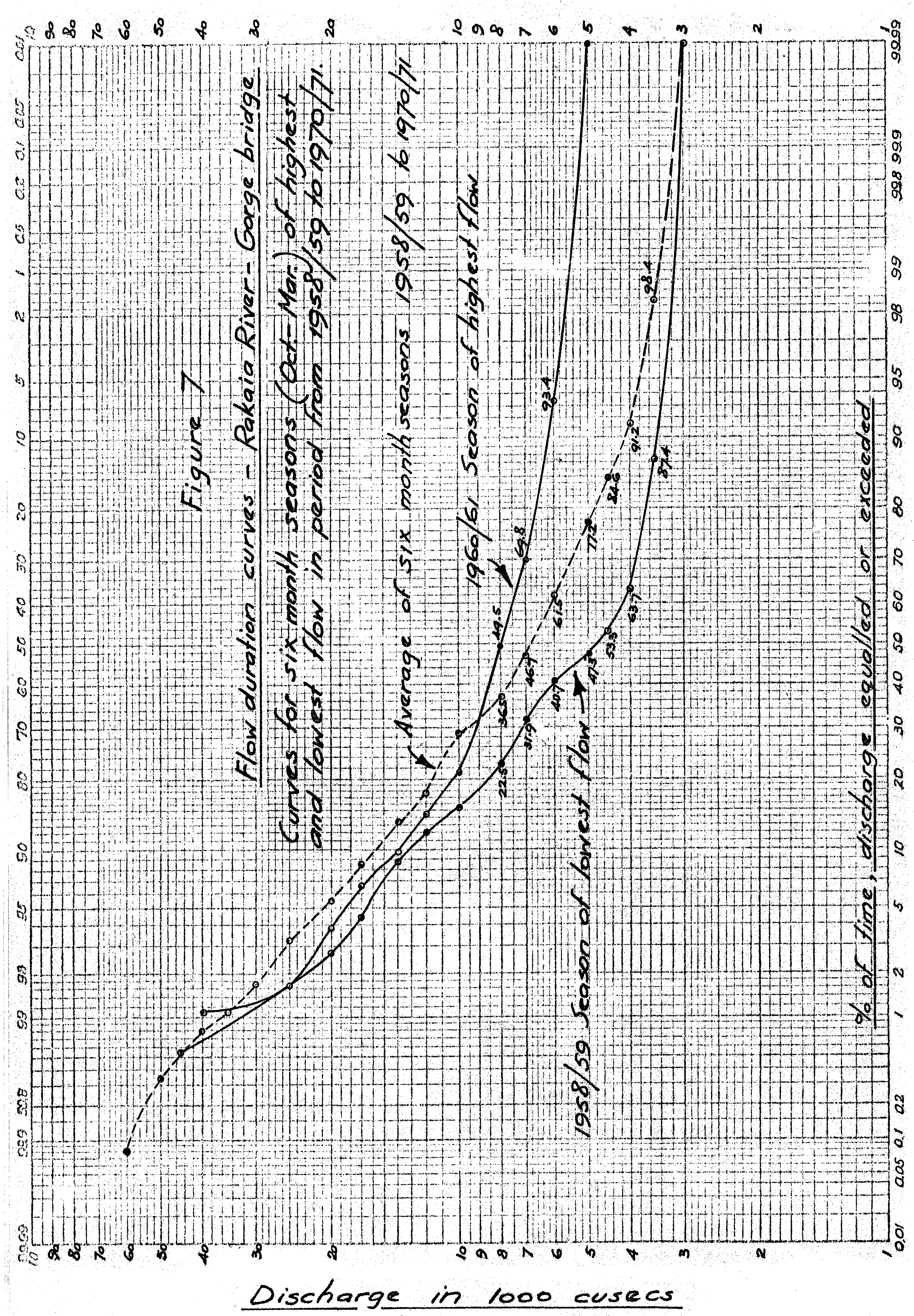
% of time, discharge equalled or exceeded

0.01 0.05 0.1 0.2 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99

Water Demand Cusecs	Minimum residual river discharges - cusecs													
	1000		1500		2000		2500		3000		3500		4000	
	% of time	days	% of time	days	% of time	days	% of time	days	% of time	days	% of time	days	% of time	days
500	100	182	100	182	100	182	100	182	98.4	179	91.2	166	84.6	154
1000	100	182	100	182	100	182	98.4	179	91.2	166	84.6	154	77.2	141
1500	100	182	100	182	98.4	179	91.2	166	84.6	154	77.2	141	69.0	126
2000	100	182	98.4	179	91.2	166	84.6	154	77.2	141	69.0	126	61.5	112
2500	98.4	179	91.2	166	84.6	154	77.2	141	69.0	126	61.5	112	54.0	98
3000	91.2	166	84.6	154	77.2	141	69.0	126	61.5	112	54.0	98	46.7	85
3500	84.6	154	77.2	141	69.0	126	61.5	112	54.0	98	46.7	85	42.0	76
4000	77.2	141	69.0	126	61.5	112	54.0	98	46.7	85	42.0	76	36.5	66

TABLE 3

Percentage of time and number of days in the six month period October to March at Rakaia Gorge bridge that different water demands could be met, on an average, for various minimum residual flows in the river immediately below the intake.



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One further point about flow duration data should be mentioned. Although a flow duration curve gives the percentage of time that a certain discharge is equalled or exceeded, it does not show how the total number of days, represented by that percentage, is distributed throughout the period. In the example given in the last paragraph, it was found that a flow of 4,000 cusecs was equalled or exceeded for 63.7% of the time during the 1958/59 season of six months. In other words it was equalled or exceeded for 116 days out of 182. The discharge was therefore less than 4,000 cusecs for 66 days, but the flow duration curve gives no clue whether these days occurred in one consecutive block or whether they occurred as a number of shorter periods. To anyone wishing to abstract water at a rate that was known could not be met all the time, this point would be of interest. To investigate this particular example, reference must be made to the daily mean flows given in the Appendix. If the figures for the last three months of 1958, and the first three of 1959, are examined, it will be found that the numbers of days in each group of days when the discharge was less than 4,000 cusecs are as follows:-

4, 5, 13, 6, 4, 24, 10 = total of 66 days.

In this case, therefore, the longest consecutive period that the discharge was less than 4,000 cusecs was 24 days.

It would be possible to extend this sort of analysis over other six-month seasons in the period of record and find, for example, the average longest consecutive number of days that the river flow was less than 4,000 cusecs, and same procedure could be applied to other selected river discharges.

Before concluding this section, some reference should be made to earlier records of river flow at Rakaia Gorge. Armstrong (1957) investigated the summer low flows of the Rakaia, Rangitata and Waimakariri rivers, using in the case of the Rakaia, data from the now abandoned recorder site about two miles above the Gorge bridge. This water level recorder operated over the period from 1935 to 1953, but unfortunately there were many gaps in the records. Over the same period, some 30 flow gaugings were carried out from a cableway across the river, and from these an average relation between stage and discharge was established. This rating was then used to convert the record of river level to discharge, and annual flow hydrographs were plotted which were only complete for the same periods as the stage records were complete. Just as the more recent records show, Armstrong found that the river flow was higher during the summer months than during the winter, and he confined his study to the four-month periods November to February inclusive. In all he was able to select 13 such periods of more or less complete record.

As far as is known, the records were never analysed in digital form, and therefore cannot be reproduced as tabulated daily mean discharges like the ones given in the Appendix to this report. The data were, however, analysed for flow duration in the lower range, using a graphical method, and an average flow duration curve for the four-month periods November to February included in Armstrong's report has been re-plotted for comparison in Figure 6. It will be seen that for the same percentage of time, the discharges that are equalled or exceeded according to the Armstrong curve are considerably higher than those given by the No. 2 curve based on the more recent data. It may well be asked why the two sets of data could not be combined to give a more optimistic view of the discharge in the river. There are several reasons against doing this. Armstrong made the best use of the data available at the time. He accepted the annual hydrographs, drawn by applying a single rating for the whole period, as authoritative.

However, an examination of the original gauging cards casts considerable doubt on the reliability of the rating. Although 30 flow measurements were made in all, there were long periods when no observations were taken. In the years between 1935 and 1944, for example, only one gauging was carried out in 1939. It is known from experience on the Waimakariri and on the Rakaia itself at the Gorge bridge, that changes in cross section due to shingle movement mean that a rating will not remain valid for an extended period. Again gauging techniques have improved since the earlier days. Examination of the original gauging cards shows that in many cases surface velocities only were measured and apparently no correction was made when computing discharges. This would produce results on the high side. For these reasons it is considered that it would be unwise to attach any weight to the earlier data when considering the availability of water in the Rakaia river in the vicinity of the Gorge.

4.2 LAKE COLERIDGE POWER STATION:

As mentioned earlier, Lake Coleridge power station discharges water intermittently into the Rakaia river at a point about 13 miles above the Gorge bridge. It is an important contributor because at times the quantity added can amount to about a third of the low flow of the river.

The N.Z. Electricity Department made available to the Board figures of power generated at the station in megawatt hours each day for the period of 14 years from 1958 to 1971. According to the Department, the average relation between the rate that water flows through the turbines and the rate of power generation is that 36 cusecs is required to generate 1 megawatt. Although the level of the lake varies, the variation in total head is small and the adoption of an average figure to derive discharges from the records of power generated appears to be quite justified. On 14th October 1971, by arrangement with the Department, flow measurements were made by Board's staff in the tail-race below the station to test the above relation. Two gaugings were carried out by jet-boat while the power out-put was held as steady as possible. The first gauging gave a discharge of 735 cusecs for an average power out-put of 20.25 megawatts or 36.3 cusecs per megawatt, while the second gave 674 cusecs for an out-put of 20.15 megawatts or 33.45 cusecs per megawatt. The lake level on the day was 1,663.15 feet. As these particular flow gaugings could be subject to observational errors of ±5%, the results are considered to be satisfactory confirmation of the Department's average conversion factor. The daily out-puts of power in megawatt hours have therefore been divided by 24 to give the average rate of generation in megawatts, and multiplied by 36 to give discharges in cusecs. A summary giving annual mean, monthly mean and average monthly discharges from the station for the period is given in Table 4. The annual mean discharges and average monthly discharges are shown graphically in Figures 8 (a) and 8 (b).

In the period of 14 years, the highest daily mean discharge from the power station was 1,451 cusecs on 23rd June 1967, when the daily mean discharge in the Rakaia river at the Gorge bridge was 4,328 cusecs.

There does not appear to be any particular trend in the annual mean discharges, and the main interest lies in Figure 8 (b) which shows that on an average the discharge from the power station is greater during the winter months than it is during the summer. This is not surprising as one would expect the demand for power to be greater during the winter. Figure 2 (b) showed that the lake level falls during the winter months and it appears therefore that the higher rate of power generation, and hence of discharge into the Rakaia river, during the winter is only achieved by drawing on the storage built up in the lake during the summer. It will also be recalled that river flows at Rakaia Gorge bridge (which include the flow added by the power station) are greater during the summer than during the winter. The average monthly flow distribution from the power station, however, is the reverse of this, and it is reasonable to

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Mean Discharge
1958	418	483	591	475	238	420	515	526	623	236	416	642	465
1959	453	338	494	737	751	616	652	696	408	172	251	372	496
1960	233	280	338	659	456	418	446	384	360	371	410	344	391
1961	395	376	380	400	833	853	928	855	578	269	65	222	514
1962	263	329	470	678	357	658	591	585	432	463	494	386	476
1963	364	281	366	677	764	819	1114	1089	515	564	676	1088	697
1964	380	694	601	883	810	964	1004	889	639	680	731	67	694
1965	78	428	436	459	607	820	828	703	621	624	346	382	528
1966	460	335	460	355	655	875	971	654	600	495	316	57	521
1967	19	28	25	142	681	793	1043	609	893	813	490	402	498
1968	554	598	614	908	492	1080	951	512	482	542	928	482	677
1969	525	530	377	517	376	782	736	895	494	787	265	87	531
1970	224	175	222	256	694	581	675	797	704	421	794	570	511
1971	228	362	330	422	516	406	879	812	464	415	388	434	473
Average Monthly Discharges	328	374	407	541	588	720	810	715	558	489	469	395	534*

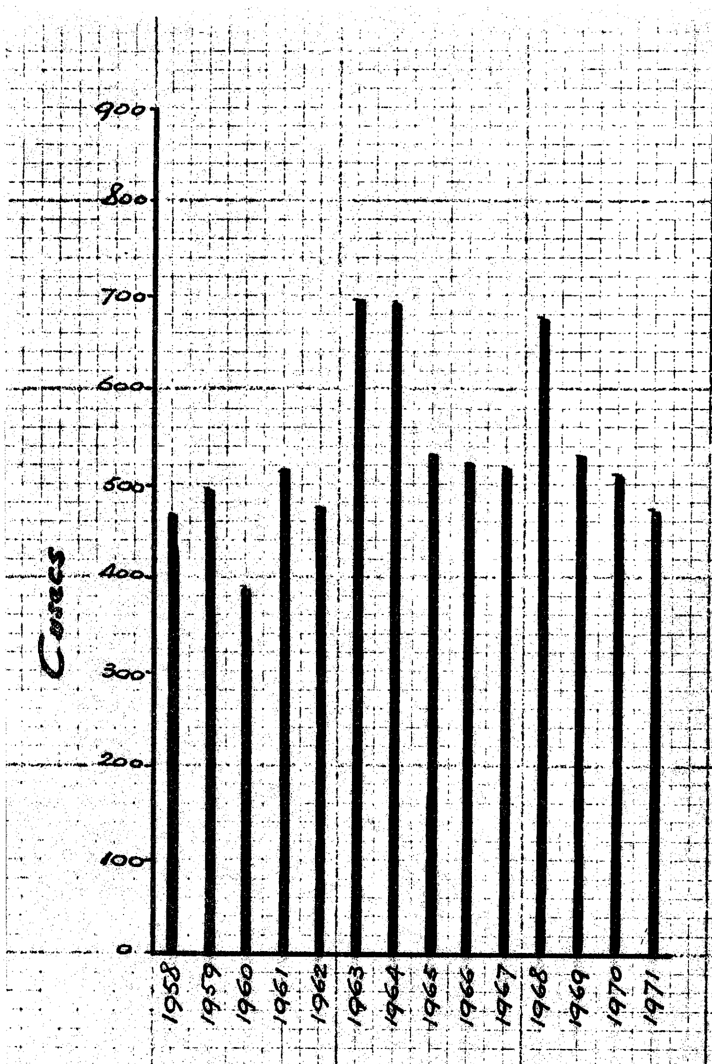
Cumecs ?

* Average annual discharge 1958 - 71.

TABLE 4

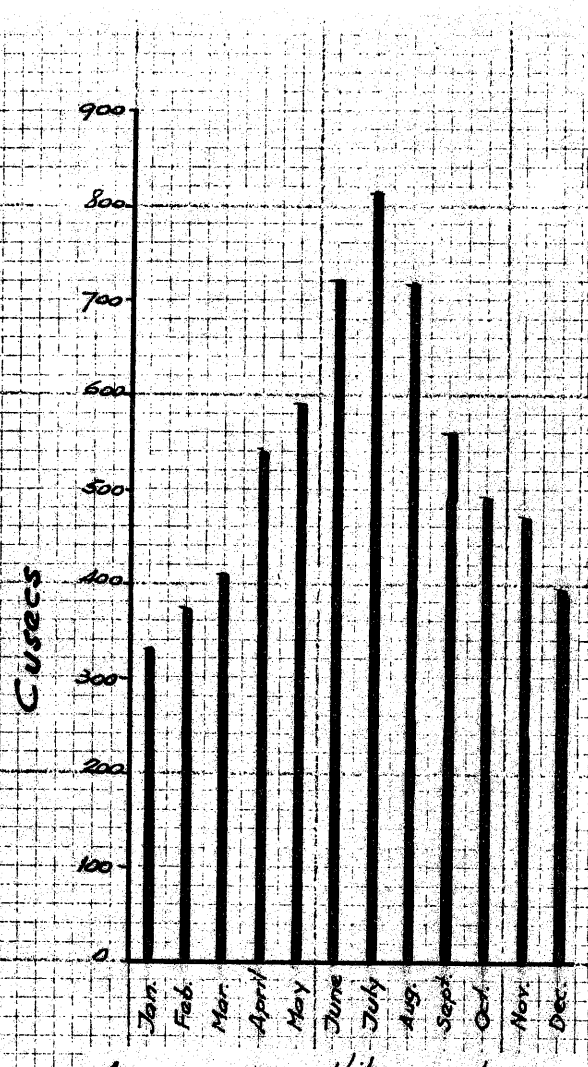
Annual mean and monthly mean discharges in cusecs from Lake Coleridge Power Station; also average monthly discharges and average annual discharge for period 1958 - 71.

conclude that if the flow from the Harper river had not been diverted into Lake Coleridge, then the summer flow in the Rakaia would be even more than it is at present.



Annual mean discharges in cusecs from Lake Coleridge Power Station

Figure 8(a)

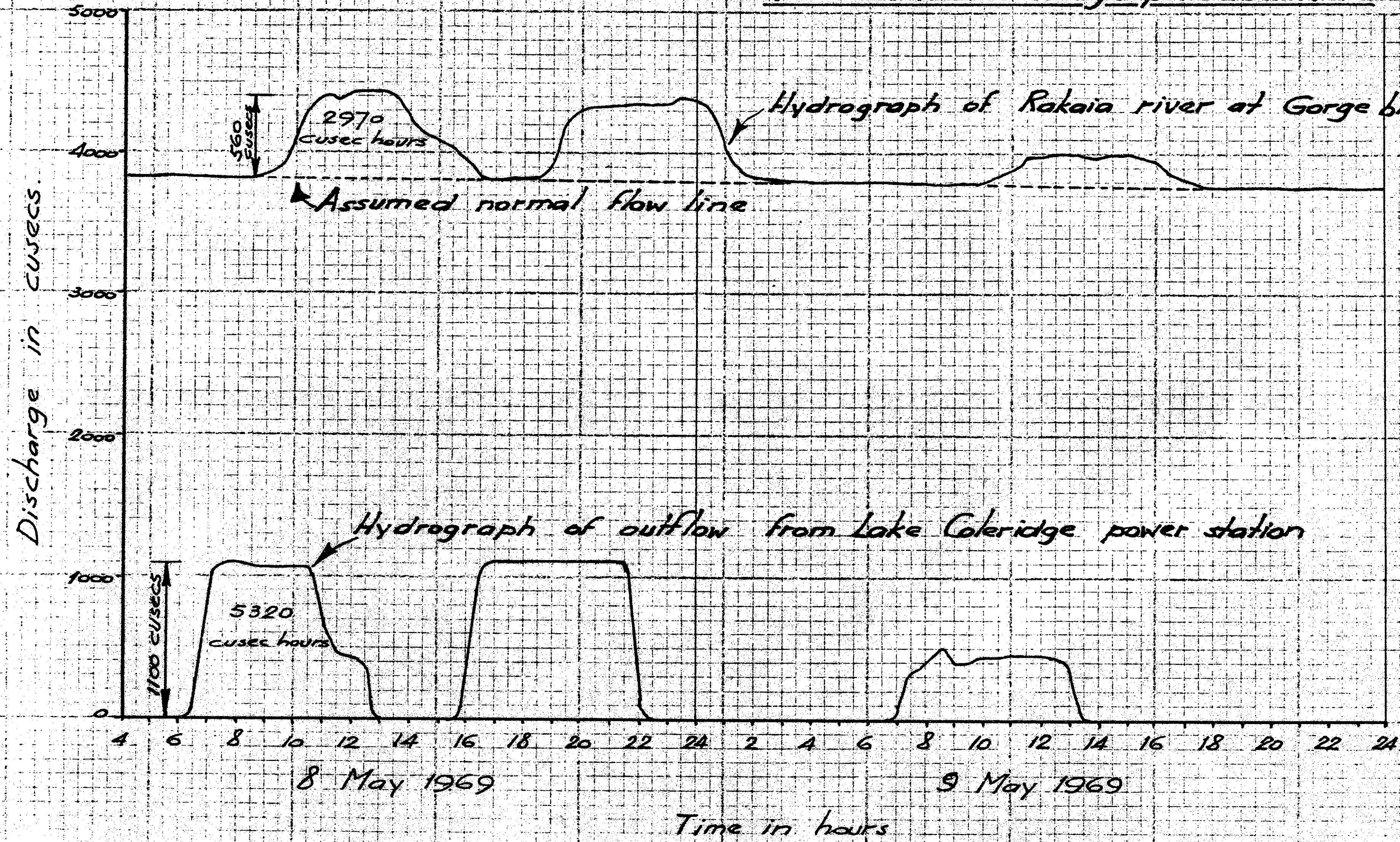


Average monthly discharges in cusecs from Lake Coleridge Power Station
Period 1958-71 inclusive

Figure 8(b)

Figure 9

Hydrographs of Rakaia river at Gorge Bridge and of outflow from Lake Coleridge power station



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In Figure 9 the upper part of the diagram shows a hydrograph of the Rakaia river at the Gorge bridge on 8th and 9th May 1969. The "humps" in the hydrograph are caused by intermittent discharges from Lake Coleridge power station which are shown to the same scale in the lower part of the diagram. The upper hydrograph may be regarded as a typical example of the varying river flow caused by the operation of the power station. Originally this diagram was compiled, together with others like it for different periods, to estimate the time taken for surges induced by the power station to travel down the river so that discharge measurements could be made under steady flow conditions. It will be seen that the surges take about 3 hours to travel the 13.3 miles from the power station to the Gorge bridge. But there are other points of interest about the diagram. In the first period of outflow from the station (between 0600 hours and 1300 hours on 8th May) the discharge into the river rose from zero to about 1100 cusecs. The discharge in the river at the Gorge bridge, however, only rose from 3850 cusecs to a little over 4400 cusecs, that is an increase of about 550 cusecs. The subsequent periods of discharge from the station, shown in the diagram, indicate the same disparity, namely that the increase in discharge in the river at the Gorge bridge is only about half the peak discharge added to the river by the power station. The explanation that springs to mind is that the amplitude of the wave diminishes as it travels downstream: but there is another point that is harder to explain. During the first period of discharge from the power station the total volume added to the river is about 5320 cusec hours (1 cusec hour = 3600 cubic feet). This is obtained by measuring the area under the hydrograph. But the volume represented by the first "hump" on the river hydrograph (measured above what apparently would have been the discharge if the station had not operated) is only about 2970 cusec hours. So somewhere in the 13.3 miles of river nearly half the volume of water added by the power station had been lost, at any rate as far as surface run-off at the Gorge bridge is concerned. Other examples that have been examined have shown similar results. The amount of loss varies but is always considerable. The only tentative explanation that can be put forward at present is that a lot of water is absorbed in the shingle comprising the river-bed downstream of the power station tail-race. The matter has not been examined exhaustively, but attention should be drawn to it. If serious thought were ever given to constructing a dam in the Rakaia, to form a reservoir so that water could be released during periods of low flow to augment supplies downstream, as has been done in Britain on the River Severn, it would be essential to study these losses in more detail.

4.3 HIGHBANK POWER STATION:

Water in the Rangitata diversion race is used to generate electricity at Highbank power station, and is afterwards discharged into the Rakaia river on the south bank 6 miles below the Gorge bridge. In the case of this station, the N.Z. Electricity Department has made available actual daily mean discharges in cusecs which presumably are calculated from a known relation between power generated and quantity of water used. With the co-operation of the Department's staff, two gaugings were carried out on 23rd August 1971 in the diversion race close to the station intake. The first gauging between 1135 and 1215 hours resulted in an observed discharge of 744 cusecs. According to the station records the average rate of generation during the same period was 17.4 megawatts, which was stated to be equivalent to 735 cusecs. The second gauging between 1340 and 1420 hours on the same day gave an observed discharge of 760 cusecs when the rate of generation was 17.55 megawatts, equivalent to 743 cusecs. The close agreement of these observations with the discharges recorded by the power station staff was considered to be very satisfactory.

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Mean Discharge
1958	251	247	183	372	794	736	674	752	286	585	282	249	453
1959	12	164	397	741	889	841	869	877	543	340	0	0	475
1960	0	0	0	56	832	903	829	898	812	777	593	592	527
1961	266	232	19	571	769	880	872	870	838	465	233	250	523
1962	255	221	204	300	265	864	860	864	824	467	227	196	463
1963	163	103	84	240	399	821	818	834	820	451	177	217	429
1964	69	0	0	0	109	844	851	849	722	191	286	163	341
1965	190	270	114	700	806	818	807	824	783	336	620	276	546
1966	99	90	414	632	841	811	816	809	753	525	367	253	534
1967	83	29	0	288	507	812	812	795	703	478	586	330	454
1968	91	6	334	600	762	770	752	756	427	586	208	219	461
1969	145	0	0	20	391	810	805	799	636	44	23	334	336
1970	398	71	391	456	768	791	785	708	580	0	0	0	415
1971	0	0	29	343	591	768	752	738	594	489	376	96	400
Average Monthly Discharge	144	102	155	380	623	819	807	812	666	410	284	227	454*

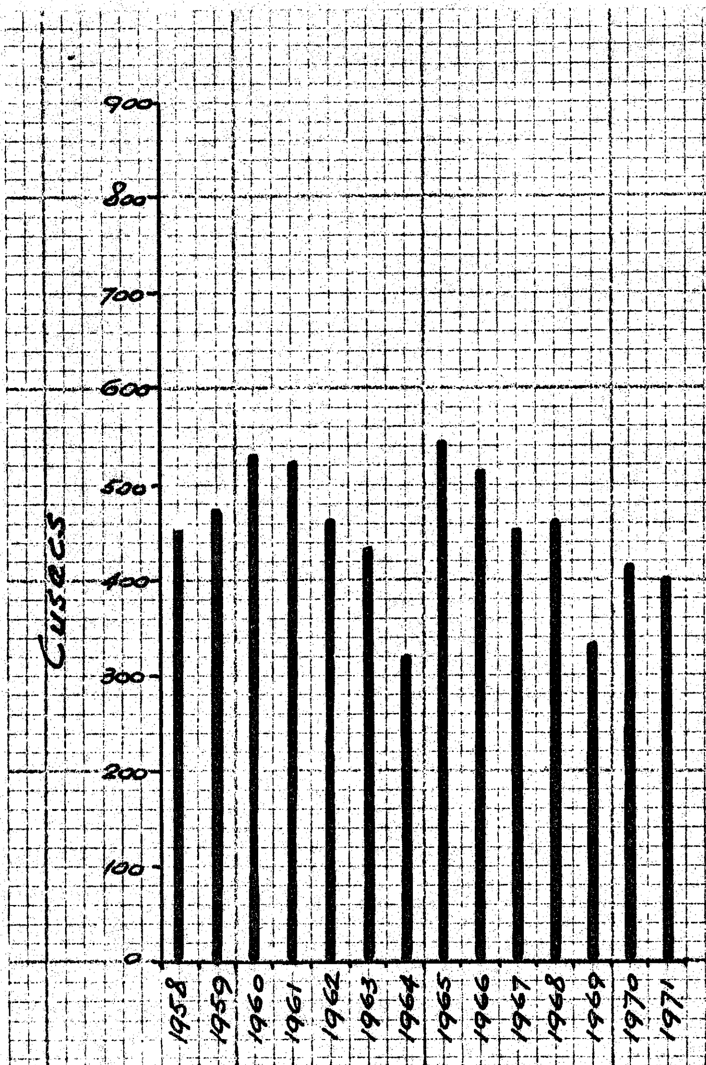
* Average annual discharge.

TABLE 5

Annual mean, monthly mean, and average monthly discharges in cusecs from Highbank power station - period 1958 to 1971.

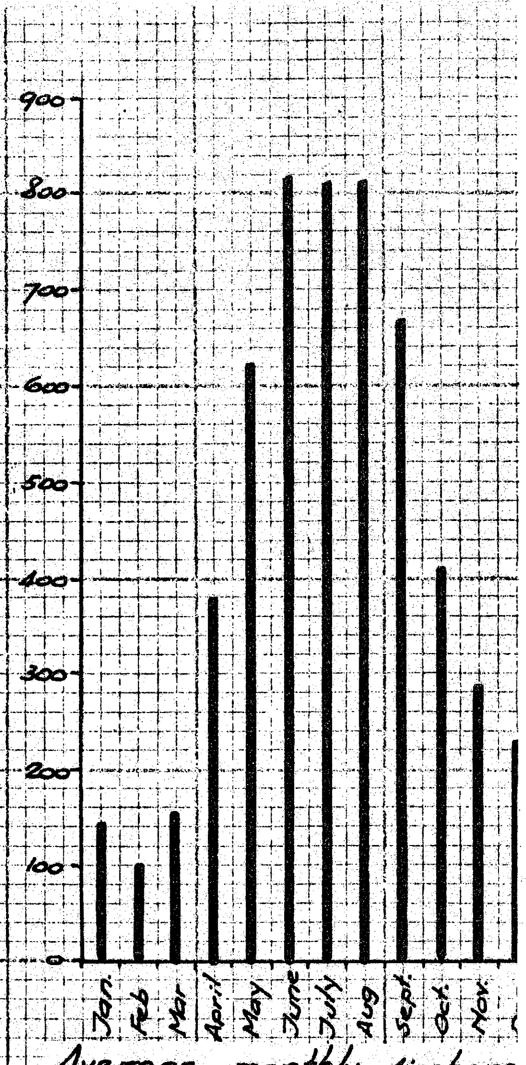
The daily mean discharges in cusecs from the power station for the period 1958 to 1971 are summarised in Table 5 which gives the annual mean, monthly mean and average monthly discharges. The annual mean and average monthly discharges are also shown graphically in Figures 10 (a) and 10 (b)

The highest daily mean discharge in the period was 960 cusecs on 26th May 1960, and the average annual discharge over the 14 years was 454 cusecs, only 80 cusecs less than the corresponding figure for Lake Coleridge. Highbank therefore contributes substantial amounts of water to the river from outside the Rakaia catchment, but as Figure 10 (b) shows the greatest contribution is made during the winter months. During the summer when irrigation demands on the Rangitata diversion race are at their peak, there are often periods of a month or more when no discharge at all is added to the river. From the point of view of any future abstraction during the summer from the Rakaia river, it appears that the contribution made by Highbank power station must be discounted.



Annual mean discharges in cusecs from Highbank Power Station

Figure 10(a)



Average monthly discharg in cusecs from Highbank Power Station Period 1958-71 inclusive.

Figure 10 (b)

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Mean Discharge	Max. Instant Discharge	Min. Instant Discharge
1961	-	-	-	72	73	73	75	102	96	93	90	73	-	130	59
1962	77	57	47	39	61	91	94	82	95	88	110	81	77	141	36
1963	55	46	47	65	98	133	-	105	142	99	103	72	-	171	42
1964	68	56	59	56	71	75	71	72	111	90	73	84	74	-	49
1965	95	109	79	73	64	61	54	58	60	68	96	86	75	151	43
1966	66	57	64	61	65	62	58	70	72	76	78	67	66	92	47
1967	66	68	67	79	76	61	63	80	72	64	133	212	87	680	45
Average Monthly Discharge	71	66	61	64	73	79	69	81	93	83	98	96			

TABLE 6

Annual mean, monthly mean and average monthly discharges in cusecs from Lake Heron. Also maximum and minimum instantaneous discharge in each year.

4.4 LAKE HERON:

The potential of Lake Heron as a water resource has already been referred to, and some data relating to discharges from the lake via Lake Stream to the Rakaia river are available. The Ministry of Works has recorded the level of the lake near the southern end since 1938, and gaugings have been carried out in the Lake Stream outlet at the northern end to establish a rating. Daily mean discharges in cusecs from the lake have been computed for the years 1961 to 1967, although there are some gaps in the record at the beginning of the period. The data are summarised in Table 6 which gives the annual mean, monthly mean and average monthly discharges. The maximum and minimum instantaneous discharges for each year have been added to the table. The area draining to the lake is approximately 44 square miles.

The discharges given in Table 6 are probably subject to error because Ministry of Works staff do not regard the relation between discharge and lake level, on which the figures are based, as very reliable. It might be thought that the level of the lake would be subject to fluctuations due to wind, but the recorder charts do not show obvious signs of this occurring to any great extent. The figures at least give a general idea of the magnitude of flows out of the lake, and also show that the average monthly discharges are fairly uniform. This is no doubt due to the regulating effect of the lake. There is a tendency for the discharges on an average to be greater during the spring and early summer months, and this may be due to increased run-off from melting snow.

The large fan built up by the Cameron river forms most of the western shore of the lake. Normally the flow of this river is not directed into the lake, but joins Lake Stream some distance below the outlet. On occasions, however, the Cameron breaks across the fan and part of the flow goes into the lake. The last time this happened was after heavy snow in November 1967, and the road to Upper Lake Heron station was cut. On this occasion the lake level rose from 2 feet on the gauge to 4.7 feet in a period of 14 days.

5. DISCHARGE MEASUREMENTS AT TEMPORARY SITES:

In addition to the continuous flow data given in the preceding section, certain discharge measurements are available for other temporary sites in the catchment. These isolated measurements do not have the same value as the data derived from permanent gauging sites, but they are of some interest and will be referred to briefly.

5.1 UPPER RAKAIA AND TRIBUTARIES:

On 4th and 5th August 1971 Board's staff, using the jet-boat, carried out the following low flow measurements at sites in the upper catchment:

RAKAIA RIVER:

Meas. No. NC 528
Date: 4th August 1971, 1310 to 1535 hours.
Site: Above confluence with Mathias river at Manuka Point crossing.
Catchment area: 282 square miles.

	Map Ref.	Width ft.	Max. depth ft.	Mean vel. f.p.s.	Q cusecs
Three Streams (a)	S 73:769874	58	3.1	2.20	219.73
(b)	S 73:769868	21.5	1.1	1.13	18.36
(c)	S 73:767860	87	1.5	2.40	244.92
				Total	483.01

Recorded as 483 cusecs

RAKAIA RIVER:

Meas. No.: NC530
Date: 5th August 1971, 1345 to 1610 hours.
Site: Above confluence with Wilberforce river, opposite Glenrock Station.
Catchment area: 455 square miles.

		Map Ref.	Width ft.	Max. depth ft.	Mean vel. f.p.s.	Q cusecs
Three Streams	(a)	S73:915838	79	2.5	4.48	607.30
	(b)	S73:911835	83	2.1	2.10	243.42
	(c)	S73:903829	110	3.2	1.93	523.63
					Total	1374.35

Recorded as 1370 cusecs

WILBERFORCE RIVER:

Meas. No.: NC529
Date: 5th August 1971, 1125 to 1145 hours.
Site: Above confluence with Rakaia river, at "The Point".
Catchment area: 179 square miles (excluding Harper river and tributaries).

	Map Ref.	Width ft.	Max. depth ft.	Mean vel. f.p.s.	Q cusecs
One Stream	S73:929852	133	2.9	2.94	782.99

Recorded as 783 cusecs

MATHIAS RIVER:

Date: 4th August 1971, 1130 hours.
Site: Above confluence with Rakaia river, near Manuka Point.
Map Ref: S73:775890.
Catchment area: 102 square miles.

No surface flow

The considerable increase in surface flow between the two sites on the Rakaia, separated by a distance of only 9 miles, is of interest particularly as there was no visible flow in the intervening tributary of the Mathias at the time the measurements were made.

5.2 CAMERON RIVER:

Table 7 gives a list of gaugings carried out by Ministry of Works staff on the Cameron river at map reference S73:666669, this being a point on the river at the upper end of the fan some 3 miles above the junction with Lake Stream.

The Cameron has its source in a glacier and as might be expected the figures reflect the trend for discharges to be higher during the warmer summer months. The catchment area above the gauging site is 25.6 square miles and, as all the measurements were obtained by wading, the figures cannot include any of the higher discharges that must occur on occasions from a catchment of this size.

Date	Discharge Cusecs	Date	Discharge Cusecs	Date	Discharge Cusecs
15.2.35	151	7.3.67	236	19.7.68	50.2
15.6.44	40.7	5.4.67	98.5	21.8.68	83.0
6.1.44	121	4.4.67	113	24.9.68	114
4.3.56	193	5.4.67	104	27.9.68	113
19.2.59	130	8.9.67	78.4	15.10.68	108
25.3.65	107	21.9.67	80.6	22.11.68	171
28.9.65	81.6	31.1.68	148	12.2.69	123
18.10.66	102	23.2.68	166	5.3.69	124
19.10.66	106	5.4.68	113	15.4.69	165
29.11.66	252	3.5.68	187	29.5.69	95.3
17.1.67	148	29.5.68	155	17.6.69	52.8
18.1.67	165	7.6.68	104	1.10.69	100
7.3.67	238	26.6.68	58.7	10.3.70	295

TABLE 7

Low flow gaugings of the Cameron river.

5.3 HARPER INTAKE:

Over the past two years, the Ministry of Works hydrological staff has carried out a series of gaugings in the channel through which water is diverted from the Harper river into Lake Coleridge. Table 8 gives a list of the dates and flows measured since March 1970.

Date	Discharge Cusecs	Date	Discharge Cusecs
10.3.70	434	27.5.71	74.5
30.6.70	273	27.5.71	110
30.6.70	261	2.6.71	460
26.5.71	178	5.10.71	894
27.5.71	167	5.10.71	899
27.5.71	136	12.10.71	617
27.5.71	103	12.10.71	387
27.5.71	78.6		

TABLE 8

Flow gaugings in the Harper intake channel to Lake Coleridge.

The figures give some idea of the flows diverted from the Harper river. They do not necessarily represent the whole flow of the Harper because when the river is in flood most, if not all, of the flow continues on its normal course to the Rakaia; nor do they give the total inflow to the lake because the Ryton river and other streams in the natural catchment also make their contribution. It is understood that the maximum flow diverted from the Harper is about 1,000 cusecs.

.4 ACHERON RIVER:

This tributary has its source in Lake Lyndon and flows in a south-westerly direction to join the Rakaia on the left bank about 10 miles above the Gorge bridge. There are only two known flow measurements, both carried out by Ministry of Works staff at the road bridge just above the junction with the Rakaia at map reference S74:079728.

Date	Discharge - cusecs
11/11/71	65
3/12/71	38.5

It is believed that both these flows are higher than normal low flow, probably of the order of 1½ times the annual mean discharge in the case of the second gauging.

At a point approximately ~~7~~ 11.3 km miles above the Rakaia junction, the low flow of the Acheron is normally diverted to Lake Coleridge by means of a dam and intake structure. When the above gaugings were done, the quantity being diverted is not known, but a gauging in the diversion channel on 2nd September 1971 gave a discharge of ~~27 cusecs~~ 0.76 cumecs. On this occasion the whole flow of the river at the intake point was being diverted.

. REDUCTION IN RIVER FLOW DOWNSTREAM OF THE GORGE BRIDGE:

In the report dealing with the water resource of the Waimakariri river, Dalmer (1970) gives details of observed reductions in river flow that occur downstream of the Gorge bridge. It was therefore decided to carry out an investigation to see if any reduction in flow occurred in the Rakaia river between the Gorge bridge and the State Highway No. 1 bridge, ~~25.3~~ .8 km miles downstream.

At the Gorge bridge, the river is confined at medium and low flow to one channel, and gauging the flow, either from the bridge or by jet-boat, is a straight forward operation. Downstream, however, the river becomes braided and the total flow can only be obtained by measuring the discharge in a number of separate channels - an operation that may take 3 or 4 hours to complete. Again, when attempting to detect differences in discharge between two points on a river, it is essential that the flow remain steady over the period of the two measurements. Because of the operations of Lake Coleridge and Highbank power stations, referred to earlier, this is rarely the case in the Rakaia. It became necessary, therefore, to ask the N.Z. Electricity Department to hold the discharge from these two stations steady for certain periods while the comparative gaugings were carried out. Arrangements were made accordingly with Systems Control at Islington, and the ready co-operation at all times of the Superintendent and his staff there is gratefully acknowledged.

As Highbank can add an appreciable flow to the river between the two observation points, it was also necessary to know the discharge from this station during the period it remained steady. This information was supplied by Systems Control after the gaugings were completed. The only abstraction of any magnitude at all between the two bridges is that at the Ellesmere County Council's stock race intake at Te Pirita. The flow in the race has been gauged on several occasions and has not been found to exceed ~~20 cusecs~~ 0.566 cumecs. This is so small compared with the flow in the river that it can be neglected in this particular investigation. The gaugings at the lower bridge included the flow in the channels leading to the

Ashburton County Council's Acton race on the south side, and the Ellesmere County Council's lower intake on the north bank.

In all 6 pairs of gaugings at the two bridge sites were carried out and the results, including the flow from Highbank power station when operating, are given in Table 9.

	(1)	(2)	(3)	(4)	(5)
Date	Discharge at Gorge bridge cusecs	Outflow from Highbank P.S. cusecs	Total Discharge Gorge + Highbank cusecs	Discharge at S.H. No. 1 bridge cusecs	Reduction in flow cusecs
25 Aug. 1971	2730	735	3465	3290	175
22 Sept 1971	5660	705	6365	5440	925
9 Nov. 1971	6500	0	6500	5980	520
7 Dec. 1971	4970	0	4970	4280	690
11 Jan. 1972	4600	0	4600	4010	590
1 Mar. 1972	3740	295	4035	3780	255

TABLE 9

Observed discharges at Gorge bridge and State Highway No. 1 bridge, together with outflow from Highbank power station when operating.

The comparative gaugings made at the two sites all indicate that the discharge at the State Highway No. 1 bridge is less than that at the Gorge bridge, when allowance is made for flows added to the river by Highbank power station. Figure 11 shows the discharges in column 4 of Table 9 plotted against those in column 3. Over the range that the measurements were made, the results indicate that there is a linear relationship between the two variables, and that the reduction in discharge gets greater as the flow in the river increases.

Some further observations regarding variation in river flow below the Gorge bridge will be given in Section 8 dealing with groundwater. (P.T.O)

7. COMPARISON OF RUN-OFF AND RAINFALL:

When sufficient data are available, a water balance for a catchment can be attempted. Toebes (1972) gives a simple form of the water balance equation as:

$$P = E + Q \pm \Delta S$$

where P is the precipitation
E the evapo-transpiration
Q the run-off
and ΔS is the change in storage (in snow pack, glaciers, lakes, soil moisture or groundwater)

The terms in the equation are in units of volume, but they can also be expressed as depths of water over the whole catchment. It is not proposed to attempt a complete water balance for the Rakaia catchment, but it is of some interest to examine briefly the relation of two of the terms in the equation, namely run-off and rainfall.

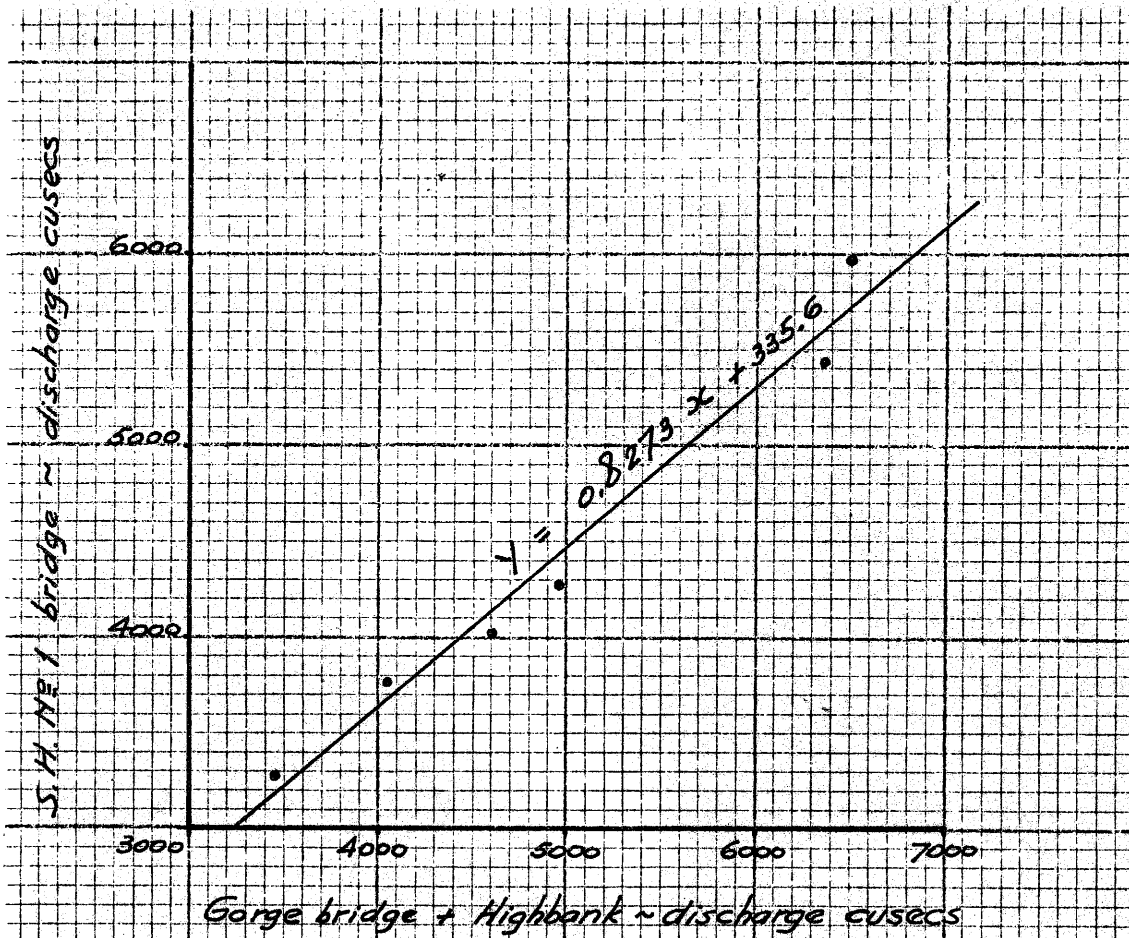


Figure 11

The average annual discharge of the Rakaia for the period 1958 to 1970 at the Gorge bridge has already been given as 7757 cusecs. So in any year on an average the total volume of water in cubic feet that passes this site is 7757 multiplied by 3.1536×10^7 (the number of seconds in a year). This enormous volume can be represented more conveniently as a depth of water in feet over the catchment above the Gorge bridge by dividing it by the area of the catchment in square feet. The result of this computation is 8.8 feet or 106 inches.

An estimate of the average annual rainfall over the above catchment was made by planimetering the areas between the isohyets shown in Figure -. This gave about 102 inches which obviously is not enough to account for a run-off of 106 inches. One would have expected a "loss" of some 20 to 30 inches based on results from other catchments, or in other words an average annual rainfall of some 130 inches. It is true that the figures of rainfall and run-off apply to two quite difference periods, but both periods are quite long and seasonal variations could be expected to balance out. The explanation of the discrepancy probably is that the isohyets shown in Figure 4 under-estimate the total precipitation in the form of snow and rain in the higher part of the catchment. One might wonder for a moment if the recession of glaciers over the period could produce the extra volume of water, but a few trial calculations regarding the amount of ice that would have to melt do not support this theory.

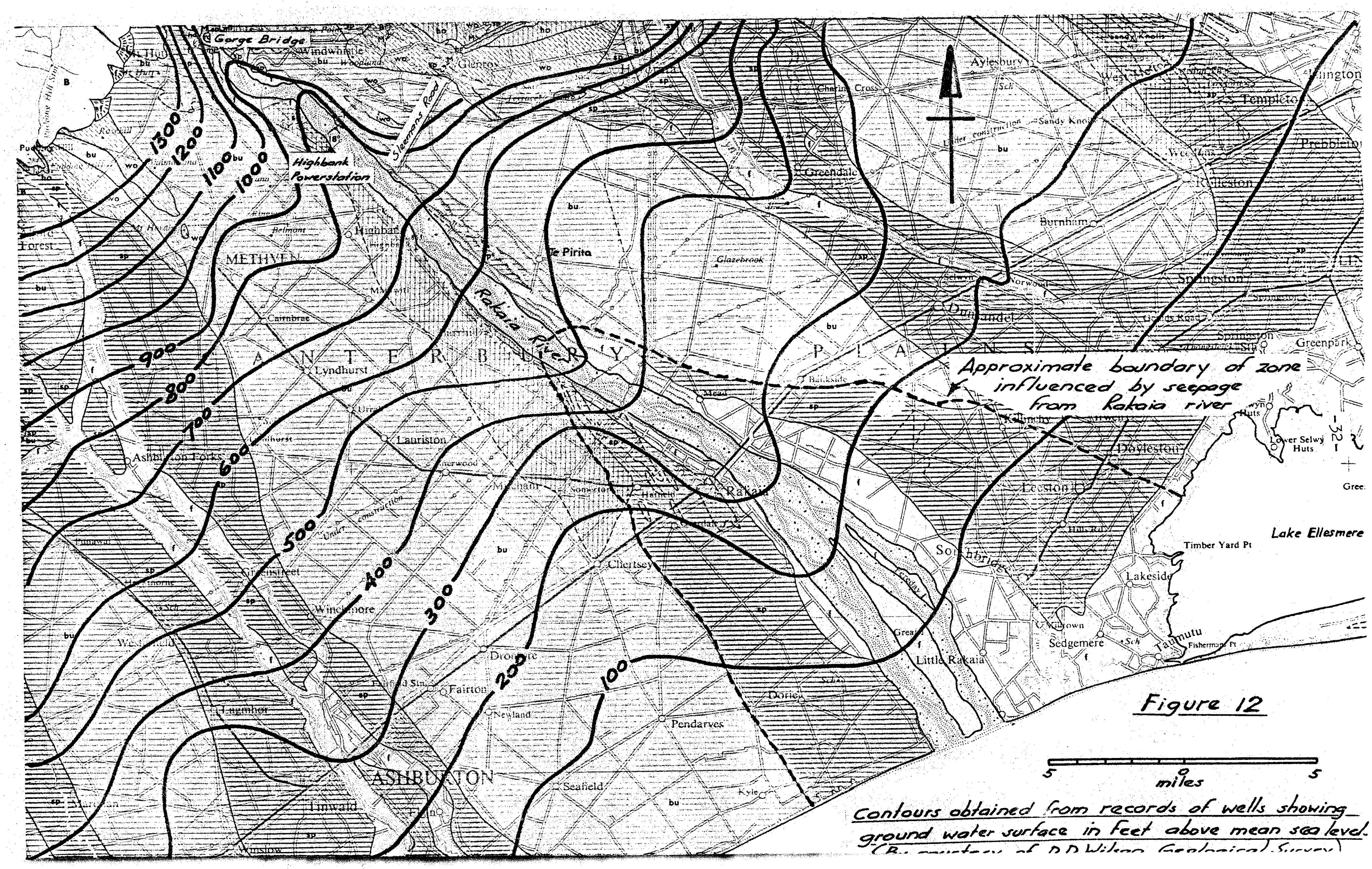


Figure 12

Contours obtained from records of wells showing ground water surface in feet above mean sea level.
(By courtesy of D.D. Wilson, Geological Survey)

8. GROUNDWATER:

There is little information about groundwater in the area above Rakaia Gorge bridge. The Geological Survey has no records of wells in this part of the catchment but springs are known to exist on the sides of valleys and these are tapped for domestic supplies of water.

Much more is known about the extent and level of groundwater on the plain. Mr. D.D. Wilson of Geological Survey, Christchurch, in a personal communication, has kindly made available a map, based on data obtained from wells, showing contours giving the height of groundwater surface above mean sea level. Part of this map has been reproduced in Figure 12. The point of special interest, as far as this report is concerned, lies in the shape of the contours where they cross the river. It will be seen that they curve upstream in the part of the river near the Gorge bridge, and curve downstream in the lower part. The significance of this will be clear from the following two diagrams:

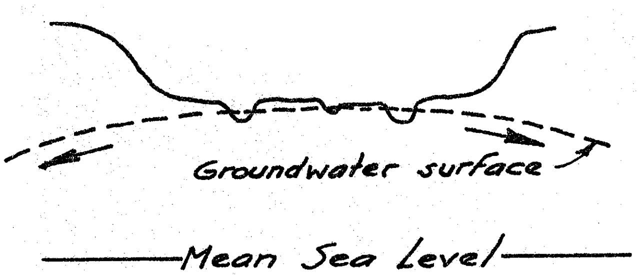


Figure 13 (a)

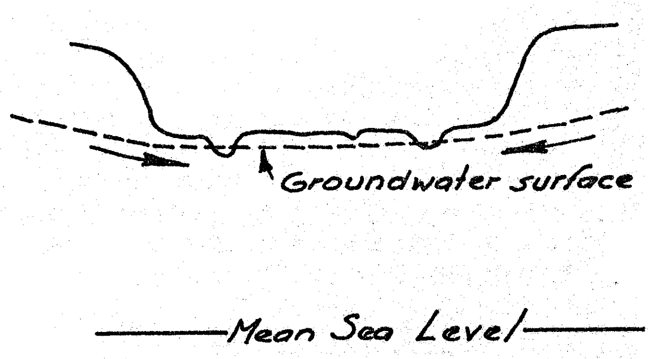


Figure 13 (b)

Figure 13 (a) shows diagrammatically the river in cross-section somewhere downstream of Te Pirita. The groundwater surface line bends down away from the river indicating seepage into the adjoining ground and a reduction in surface flow. The approximate boundary of the area that Wilson suggests is influenced by this seepage is shown in Figure 12. The cross-section shown in Figure 13 (b) is representative of the river above Highbank and here the groundwater line bends up indicating seepage into the river and a gain in surface flow.

The comparative gaugings referred to earlier showed an overall reduction in surface flow between the State Highway No. 1 bridge and the Gorge bridge. When Wilson's map of groundwater contours was received, the obvious step was to investigate the difference in discharge between the Gorge bridge and a point on the river a little above Te Pirita because if anything there should be a gain in river flow between these two sites. The first pair of gaugings on 14th December 1971 gave 5470 cusecs at the Gorge bridge and 5560 cusecs at a point just below Sleemans Road. The increase in river flow was therefore 90 cusecs which was in conformity with Wilson's map. Highbank power station was not discharging any water on this occasion and the usual arrangements were made with the Electricity Department to hold the outflow from Lake Coleridge steady while the measurements were carried out.

The next pair of gaugings on 18th January 1971, however, gave a different result. The discharge at the Gorge bridge was 5850 cusecs and that at Sleemans Road 5600 cusecs, giving a reduction in flow of 250 cusecs. There was again no outflow from Highbank power station. This result, therefore, is contrary to what one would expect from the shape of the groundwater contours and is inconsistent with the previous measurement when the river conditions were much the same. It is, however, expecting rather a lot to try to detect a relatively small loss or gain by comparing two large flow measurements, both of which must be subject to some observational error. At present, therefore, the hydrological evidence regarding the point on the river where reduction in surface flow starts is inconclusive.

Geological Survey, Christchurch, has records of a large number of wells on the plains, including information regarding depths and yields. As a general statement, it can be said that the availability of water increases in an easterly direction away from the foothills, and that in the lower part of the plain good supplies from below ground can be obtaine

On the subject of the possible effect that abstraction of surface water from the Rakaia might have on groundwater in areas adjoining the lower part of the river, Wilson makes the following comment: "If recharge channels from the river to the aquifers are numerous and highly permeable, it is possible that sufficient recharge can be generated by periodic flood if they are not, it is possible that total groundwater discharge will eventually be limited, not by water-availability at the intake ends of the "pipe-line", but by the capacity of the "pipe-lines" themselves. Only continuous effort to monitor water-table fluctuations and their relationsh to total discharges and to river flows, can determine the mechanics of recharge."

9. PRESENT WATER USE:

The uses made of water in the catchment have been dealt with by Ayre (1971), in a comprehensive report, and have also been referred to by Dalme (1971). It is not proposed to do more in this report than summarise the principal uses, and give more detailed information concerning abstractions from the river. The following list of surface and groundwater uses is not in order of importance:

(a) Generation of electricity.

(b) Stock water.

(c) Irrigation.

(d) Domestic supplies.

(e) As a habitat for fish and other wild life.

(f) Recreational - fishing, boating, camping, etc.

(g) The fundamental use of surface water in creating and maintaining a channel for the river.

To the above should be added one known case of use for the dilution of waste. This relates to the discharge of effluent from an Imhoff tank at Lake Coleridge power station, and an application for a right in respect of this is currently being considered by the Water Resource Council, and by the Board.

Table 10 gives some details of abstractions of surface water from the Rakaia river downstream of the Gorge bridge, and the locations of the intakes are shown in Figure 14. The list has been compiled from applications for rights that have been granted by the Board, and also

Site No	Name	Map Reference of intake	Method of Abstraction	Purpose	Quantity Abstracted Gallons/Day	Cusecs
1.	T. Abbott	S82:236508	Pumping from river	Stock water and spray irrigation	1,164,000	2.2
2.	Ellesmere County Council	S82:295444	By gravity from river	Stock water	13,480,000	25.0
3.	W.G. Inch	S82:310425	Pumping from partial diversion of side stream of river	Spray irrigation	576,000	1.1
4.	Creeside Water Supply	S82:292423	Pumping from shallow well in river bed	Domestic water	12,000	-
5.	O.E. Hooper	S82:325391	By gravity from river to pond, then pumping	Spray irrigation	864,000	1.6
6.*	Ashburton County Council	S93:475292	By gravity from river	Stock water	13,750,000	25.5
7.	Ellesmere County Council	S83:512300	By gravity from river	Stock water	10,770,000	20.0
8.	Smith Bros.	S83:512300	By damming side stream of river	Irrigation	7,800,000	14.5
9.	C.L. Searle	S93:567257	Pumping from river	Spray irrigation	400,000	0.7
10.	R.C. Thompson	S93:542204	Pumping from river	Spray and gravity irrigation	600,000	1.1
					Total	91.7 cusecs

* This notification has not yet been formally recorded. Quantity based on average of three flow measurements.

TABLE 10

Abstractions of surface water from the Rakaia river downstream of the Gorge bridge based on applications for rights granted by the Board, or on notifications of existing use.

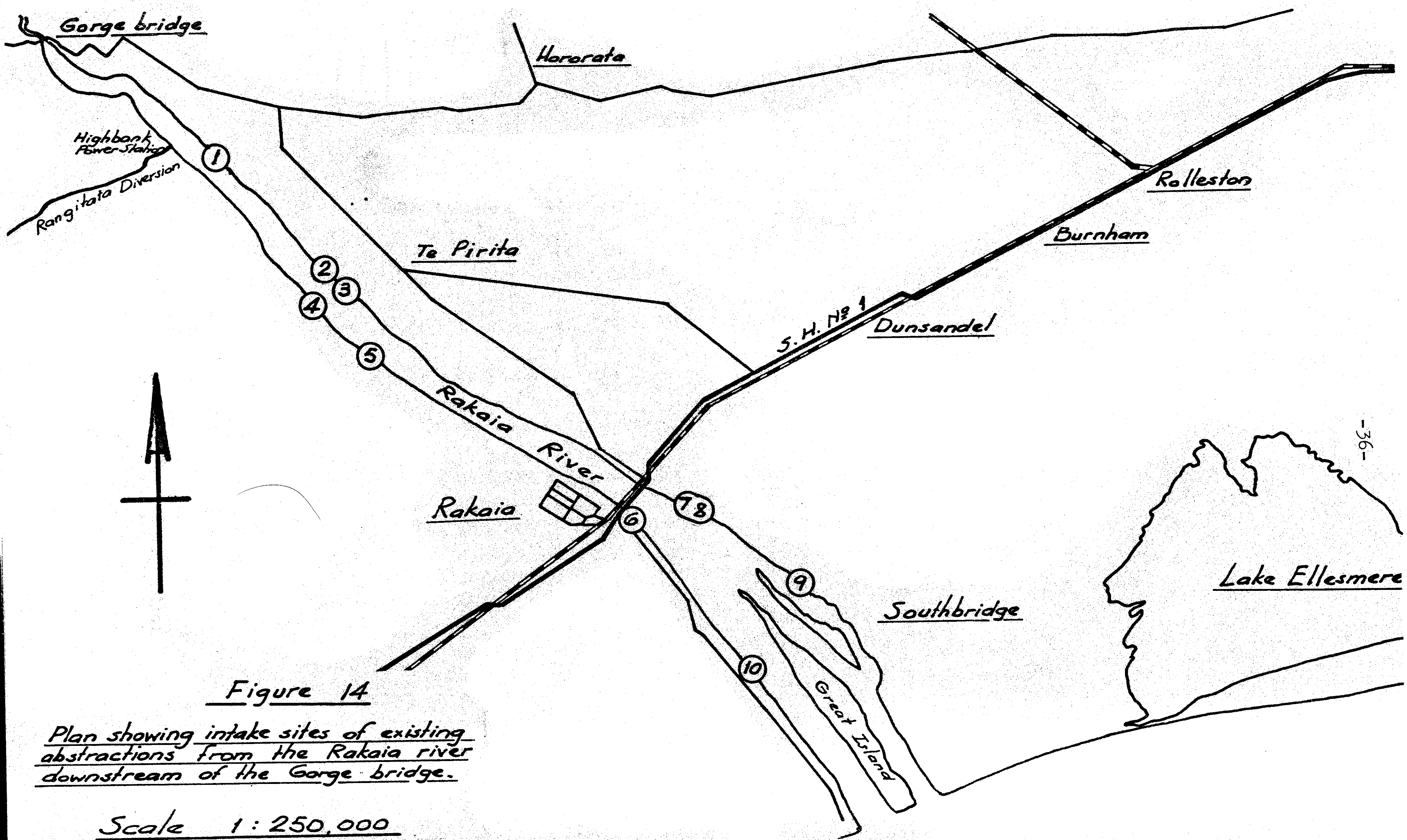


Figure 14

Plan showing intake sites of existing abstractions from the Rakaia river downstream of the Gorge bridge.

Scale 1 : 250,000

Map information by permission of the Department of Lands and Survey, New Zealand notifications of existing use. All except one of the quantities are daily average rates given by applicants and not all have been checked by actual measurements. Subject to this, the total present theoretical abstraction is a little under 100 cusecs which is about 3% of the low flow of the river at the Gorge bridge. The three County stock races, which between them account for over 75% of the total abstraction, have been gauged on several occasions with the following results:

No. 2 Ellesmere County Council, North Bank, Te Pirita		No. 6 Ashburton County Council, South Bank, Acton race		No. 8 Ellesmere County Council, North Bank, below S.H. No. 1 bridge	
Date	Cusecs	Date	Cusecs	Date	Cusecs
[illegible]/11/71	18.7	16/9/71	22.8	4/8/70	12.4
[illegible]/12/71	17.0	24/9/71	24.0	23/3/71	15.5
[illegible]1/3/72	19.5	21/3/72	29.8	24/9/71	14.3
				21/3/72	15.2
				17/4/72	15.1

10. FUTURE USE OF WATER:

10.1 IRRIGATION PROPOSALS:

The most likely major requirement for water in the future is for irrigation on the Canterbury plain to the north and south of the Rakaia river. It is not proposed to comment in any detail on the various proposals in this connection, but brief mention should be made of the demands for surface water from the Rakaia river, envisaged in the several schemes known to the writer.

The submissions by the Northern Central Plains Irrigation Committee to the Irrigation Committee of the Water Allocation Council, dated 10th March 1970, refer to an area of 200,000 acres between the Waimakariri and Selwyn rivers requiring a total of 2,000 cusecs. The Committee's proposal is that 300 cusecs would be taken from the Waimakariri and the balance of 1,700 cusecs from the Waimakariri or Rakaia with an intake in the case of the latter river, possibly situated at the Gorge bridge.

The Rakaia irrigation scheme to the south covers roughly 160,000 acres between the Rakaia and Ashburton rivers mainly to the east of the main railway line. The Irrigation Committee in this area is thinking in terms of a total water requirement of about 850 to 900 cusecs mainly for sprinkler irrigation. It is envisaged that the greater part of this flow would be abstracted just below State Highway No. 1 bridge with an intake possibly combined with the Ashburton County Acton stock race. Another intake for a smaller abstraction would be required about six miles upstream.

It is understood that farmers in an area of some 25,000 acres between the Rakaia and Selwyn rivers and east of Te Pirita are also interested in irrigation with a requirement of about 125 cusecs.

The publication by the Winchmore Irrigation Research Station: "Irrigation on the Canterbury Plains", edited by P.D. Fitzgerald, also refers to future irrigation schemes. These include the areas mentioned above, but have a somewhat wider scope.

The above information has been included merely to give some idea of recent thinking regarding demands for water for irrigation. It is clear that the requirements in mind from both sides of the river amount to a substantial total, in fact to a figure that could approach the low flow of the Rakaia at the Gorge bridge.

10.2 VIEWS OF PRESENT USERS ON FUTURE ABSTRACTIONS:

In response to enquiries made by the Board, several users of water from the Rakaia river have replied giving their views on the effect that future substantial abstractions would have on their interests, and in some cases their comments on minimum acceptable river flows. The following is a summary of the replies received:

(a) Ashburton Acclimatisation Society:

The Society stresses that fish are a product of the whole river and not just water. The minimum river flow requirement is given as 3,822 cusecs, based on a conclusion put forward by Baxter (1961) that the most suitable flows for summer angling are generally 20 - 35% of the average daily flow. (Note - the figure of 3,822 cusecs was obtained by applying the higher of the two percentages to the average annual discharge of 10,921 cusecs, taken from a report by Dalmer (1971). The revised average annual discharge for the period 1958 - 70 is 7,757 cusecs and 35% of this is 2,715 cusecs).

(b) North Canterbury Acclimatisation Society:

The Society comments that not only the minimal quantity of flow in the Rakaia river, but also the quality, has to be considered. The minimum flow requirement put forward by the Ashburton Society is accepted, provided this does not include discharges from Lake Coleridge or Highbank, and that it is maintained at all times between the Gorge and the sea; also that the water temperature does not rise above 22°C with an oxygen content of not less than 70% saturation. The Society expresses concern about the effect of abstraction upon the ecology of the river and considers research should be done on this aspect. Representation of recreational water users on Irrigation Committees is suggested, and it is recommended that the installation of fish barriers on intakes should be mandatory.

(c) Ellesmere County Council:

The Council is not opposed to irrigation, but feels the position must be watched very closely as substantial abstractions could have a detrimental effect on its water race systems, which draw water at present from two intakes on the Rakaia river, and also on underground water resources.

(d) Ashburton County Council:

The County Engineer anticipates that abstraction of further water from the river will increase the cost of works involved in diverting water into the Acton Main race. The possibility of combining the intake for this race with an irrigation intake, should such a scheme eventuate, is mentioned. Another alternative for future consideration is the replacement of the Acton race by a piped water supply.

(e) Canterbury Branch, N.Z. Jet Boat Association:

The Secretary of the Canterbury Branch of the Association states that the Rakaia river offers exceptionally good conditions for jet boating, and that jet-boats are used extensively from the river mouth up past the Gorge o Lake Stream. The activity includes annual competitive events, recreational boating and fishing. There are no problems in boating during low iver flows of about 3,000 cusecs as recorded at the Gorge bridge during pril 1971. The possibility of large abstractions for irrigation from the akaia river is viewed with concern.

f) <u>Little Rakaia Boating Club (Inc)</u>:

he Club has about 80 members of whom 15 use jet-boats and the remainder utboards, the latter operating mainly near the river mouth. An estimate f over 200 fishermen in the river area on the same day is given. Difficulty in obtaining access to the river mouth along the lagoon due to ecreased flow in the north branch of the river is mentioned. The point s made that the popularity of the area is dependent on water.

1. <u>WATER QUALITY</u>:

On 27th October 1971, samples of river water were taken at Rakaia orge bridge, and the results of the analysis carried out by the Chemical ivision of the Department of Scientific and Industrial Research are given elow:

pH	7.6
Colour (A.P.H.A.) (Hazen units)	Nil
Turbidity (silica scale)	Trace
	milligrams per litre
Nitrate nitrogen	0.13
Nitrite nitrogen	$<$ 0.001
Ammonical nitrogen	$<$ 0.005
Albuminoid nitrogen	$<$ 0.005
Total organic nitrogen	0.05
Alkalinity, phenolphthalein	Nil
Alkalinity total	23
Hardness, total (EDTA)	24
Hardness due to calcium	22
Hardness due to magnesium	2
Free carbon dioxide (as CO_2) (Calculated)	1
Total dissolved solids	55
Total suspended solids	Small amount
Chloride (as Cl)	$<$ 1
Sulphate (as SO_4)	6
Iron, total (as Fe)	0.04
Iron in solution (as Fe)	Test not done
Silica in solution (as SiO_2)	6
Manganese (as Mn)	Test not done
Total Phosphorus (as P)	$<$ 0.01
Soluble phosphorus (as P)	$<$ 0.01
Dissolved oxygen	10.5
B.O.D. 5 days 20°C	1.6
Oxygen absorbed 4 hr 20°C	$<$ 0.05

A flow gauging carried out at the time of sampling gave the discharge of the river as 5,510 cusecs and the temperature of the water was 8°C. The chemical analysis shows that the water contained no injurious substances either in suspension or in solution. It was only slightly alkaline and contained a normal amount of oxygen. No bacteriological analysis was done but the present use of the catchment above the Gorge, together with the above analysis, would indicate a water of high quality.

12. CONCLUSION:

A water resource might be defined as natural water that is contained in any source of supply. If this definition is accepted, then the water resources of the Rakaia catchment are widespread and varied: they extend from the glaciers and snows of the mountain ranges, through all the tributaries and lakes to the mouth of the main river; they extend under the river gravels of the upland valleys, and in the opinion of geologists under a large part of the Canterbury plain itself. Several of these resources have been referred to, and where possible hydrological data relating to them have been given.

The particular resource towards which many thoughts are turned at the present time is the water flowing in the lower reaches of the Rakaia river. The basic data in respect of this source of supply have been given in the form of daily mean discharges from 1st January 1958 to 9th May 1972 in the Appendix, and some analysis of these data has been attempted.

The Rakaia river at the Gorge bridge carries a considerable quantity of high quality water. The data available so far show that during the six-month period October to March, on an average, the daily mean discharge is equal to or greater than 3,000 cusecs all the time; and it is equal to or greater than 5,600 cusecs for two-thirds of the time. The average annual discharge of 7,757 cusecs is nearly twice that of the Waimakariri, although the hill catchments of both rivers have much the same area. During the dry period at the beginning of 1971, the low flow of the Rakaia was $2\frac{1}{2}$ to 3 times greater than that of the Waimakariri. The Rakaia also has that important characteristic, not apparently shared by the Waimakariri according to the evidence available so far, of the discharge being much greater on an average during the summer than during the winter.

Water from the Rakaia catchment serves man in many ways. It provides an essential requirement for himself, his stock and his crops; it releases energy to generate electricity; and it provides a medium for recreation and pleasure. Water created a course for the river, and maintains the channel in which the river flows. Without water the river would not exist.

13. ACKNOWLEDGEMENTS:

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New Zealand Meteorological Service.

Department of Scientific and Industrial Research
Geological Survey and Chemistry Division.

The Lands and Survey Department is thanked for permission to use copyright material in the preparation of maps.

Many persons in different professions have been consulted during the investigation. They are too numerous to mention all by name, but their assistance freely given to a civil engineer attempting to deal with a subject somewhat outside his normal field of experience has been greatly appreciated. The writer would also like to thank his colleagues on the staff of the Board for suggestions and advice: Mr. L.A. van Schooten has prepared all the maps and figures in the report, and Mr. D.N. Duffield has been responsible for the flow gaugings carried out by the Board's hydrological staff.

REFERENCES

Armstrong, P.G. 1957: The low flows of the Rakaia, Waimakariri and Rangitata rivers. A Ministry of Works departmental report.

Ayrey, R.B. 1971: Water usage report No. 4 - Rakaia catchment. A report to the North Canterbury Catchment Board, 10 June 1971.

Baxter, G. 1961: River utilization and preservation of migratory fish life. Proc. Inst. Civ. Engrs. 18:225-44.

Dalmer, E.B. 1970: The Waimakariri river as a water resource. A report to the North Canterbury Catchment Board, 2 October 1970. Published by the Board 1971. 54 pp.

——— 1971: Water rights and usage in relation to quinnat salmon fishing waters. Paper presented at the Quinnat Salmon Fishery Symposium, Ashburton, N.Z. 2-3 October 1971.

Flain, M. 1970: Lake Coleridge. Provisional bathymetry, 1:23760. N.Z. Oceanogr. Inst. Chart Lake series.

Gage, M. 1951: The dwindling glaciers of the Upper Rakaia Valley, Canterbury, New Zealand. J. Glaciol. 1:504-7 and 494.

Packard, W.P. 1947: Lake Coleridge catchment: a geographic survey of its problems. N.Z. Geographer 3:19-40.

New Zealand Meteorological Service 1970: Rainfall observations for 1970. Misc. Pub. 110, (1970).

Soons, J.M. 1963: The glacial sequence in part of the Rakaia valley, Canterbury, New Zealand. N.Z. J. Geol. Geophys. 6:735-56.

Speight, R. 1933: The Rakaia valley. Trans. N.Z. Inst. 63:457-96.

Toebes, C. 1972: The surface water resources of New Zealand. A paper presented at the XII th. New Zealand Science Congress, Palmerston North, 1972.