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THE RELATIONSHIP BETWEEN SUMMER LOW FLOWS AND GEOLOGY IN NORTHLAND, NEW ZEALAND

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SUMMARY

Flow data from catchments with uniform geology are used to show that in Northland the geology of the catchment area is the most important influence on the low flows occurring during a drought. For each major hydrological region the base-flow recessions form a distinct group recognisable by the slope of the recession curves, as shown by the recession constant *K* and/or the minimum flows.

Antecedent rainfall is shown to be the most important factor in accounting for the difference in minimum flows observed at the end of various droughts.

INTRODUCTION

Cross (1949), studying the lower end of flow-duration curves for several streams in Ohio, was able to show that differences among the various curves could be related to ground-water geology; he concluded that it was very risky, in the absence of discharge data, to predict stream flow from the geology. The results of the present study indicate that in Northland it is feasible to predict probable minimum flow from the geology, largely because of the major differences in lithology.

Knisel (1963) and Troxell (1953) make brief comments on the importance and use of the recession constant *K*. The present study shows that in each region the *K* values are relatively homogeneous but are different from the *K* values for other regions. The recession constant *K* is therefore a useful index of the ground-water conditions for each catchment region, and rock type.

The various geological papers by Hay (1952), Kear (1959), Waterhouse (1961, 1966), and Kear and Waterhouse (1967) provide valuable confirmation of the stream-flow gauging results presented in this paper. The information on bore-hole yields is particularly useful.

BACKGROUND

In Northland, low-flow gaugings have been carried out during droughts at least as far back as 1946. One reason for the large number of gauging sites is that rivers in Northland are quite small and their flows are highly variable.

A system of hydrological regions has been evolved which covers the whole of New Zealand (Toebes and Neef 1962; Toebes and Palmer 1969). In 1962 a series of low-flow gaugings was carried out at a number of sites in Northland selected on the basis of this system. This organised gauging provided data for a water-resources survey of Northland and led to the publication of a minimum-flow map (N.Z. Ministry of Works 1964, p.52). Data from several sites gauged in 1962 are used in the present study to compare the droughts of 1962 and 1968. (Northland is defined for the purposes of this paper as being the entire peninsula north of the Auckland urban area. It therefore includes a larger area than the 1962 water-resources survey.)

As part of New Zealand's IHD programme, a number of representative basins have been established in Northland, the basic idea being to have one basin representing each of the major hydrological regions. Four of the seven representative basins in Northland have 90° V-notch weirs as the flow-measuring device, thus providing very accurate low-flow data.

OBJECTIVES AND FIELD TECHNIQUES

Further systematic low-flow gaugings were carried out during the drought which developed in January – March 1968. The aim of the low-flow gauging programme was to provide:

(a) Detailed information suitable for use in future investigations of water supply for both town and rural areas.

(b) A check on how representative the low-flow data from the representative basins are.

(c) An opportunity to check on the accuracy of the mapping of hydrological regions in Northland.

(d) Data for the preparation of a new water-resources map similar to the one prepared from the 1962 data.

Fifteen catchments, each on a single rock type, were selected for gauging. (One further site on the Awanui River was gauged, but its catchment contains sedimentary and volcanic rocks. The plotted data from this site do not fit into any one of the major regions.) Later, towards the end of the drought, individual gaugings were carried out at other similar sites to extend the data for mapping purposes.

At the original 15 sites a gauging was carried out every fourth day. The field staff used the same cross section, the same verticals, the same number of points in each vertical (where possible), and also attempted to use the same current meter at any one site. This field procedure appears to be essential, particularly on the smaller streams with catchments of less than 10 square miles where the measured differences between consecutive gaugings are very small. As well as the data collected by this gauging programme there were the chart and punched-tape records from five representative basins and one experimental basin.

DEFINITIONS AND BASIC NOTIONS

1. For the purposes of this paper a drought is defined as "a lack of rainfall so great and long continued as to affect injuriously the plant and animal life of a place and to deplete water supplies . . . for domestic purposes . . ., especially in those regions where rainfall is normally sufficient for such purposes" (Havens 1954). The word is also used to mean a period of abnormally low river flow which would occur in these conditions.

2. Throughout this paper all discharge data used in plotting recession curves have been reduced to cusecs per square mile to "eliminate the effect of size of drainage area" (Searcy 1959, p.12) on the analysis. A plot of minimum discharge in cusecs per square mile against catchment area showed no obvious trend, and it appears that this basic notion is a reasonable one to use. (Some overseas results reported by Chow [1964] indicate that discharges per unit drainage area are smaller from smaller areas when compared with like unit discharges from larger areas.) It should be noted that the catchment areas planimetered from NZMS 1 maps are one of the largest sources of error in the data.

3. The other basic notion of importance used in this paper is that during a drought in Northland the geology of the catchment is the only major influence on base flow. Field observation has shown that once the dry weather continues beyond a certain point the upper layers of soil and the forest vegetation are almost completely desiccated. There was no clear relationship between the percentage of catchment in forest and the respective minimum flows (table 1), although some catchments with a high percentage of forest cover have a slightly higher minimum flow. This could be related to increased infiltration opportunity, which may exist under forest, thus leading to a higher level of ground-water storage before the drought. Considerably more detailed data are needed to investigate this possibility. However, as Searcy (1959) points out, other factors such as variations in permeability of the formation, the character of the underlying formation, and the depth of incision of the stream could just as easily account for the slightly higher flows in these cases.

TABLE 1: PERCENTAGE OF CATCHMENT FORESTED AND MINIMUM FLOWS

Region	Catchment	Catchment Area (square miles)	Percentage Forested	Minimum Flow (cusecs per sq. mile)
Hokianga	Waiopakonga	5.3	43,4	0.000
	Waiotehue	8.0	25.0	0.033
	Kaeo	14.3	17.0	0.086
	Waionepu at Weir	3.3	15.0	0.047
	Opahi	4.1	13.7	0.000
	Waiharakeke	91.0	9.7	0.027
	Waionepu	13.7	4.0	0.022
	Tauraroa	14.3	3.7	0.032
	Puketurua	0.96	0.0	0.0016
Waipoua	Mangamuka	9.0	91.0	0.640
	Mangakahia	93.0	28.7	0.382
	Kaihu	45.0	17.7	0.495
Kerikeri	Puketotara	9.1	10.0	0.439
	Maungaparerua	4.0	0.0	0.219
Whangerei	Waipapa	47.0	83.0	0.438
	Waihoihoi	7.1	40.0	0.570
	Tirohanga	22.4	29.0	0.350
	Mangahahuru	10.5	20.0	0.487
Waiotira	Waiwhiu	3.1	55.3	0.278
	Makarau	18.6	14.9	0.162
	Hoteo	82.0	10.3	0.157
Waitakere	Mokoroa	5.2	69.9	0.200
Northland	Selwyn Swamp	0.81	0.0	0.195

*All streams in the same region have the same geology.

Information available from the Puketurua experimental basin gives some indication of the extent to which the upper layers of soil were depleted of moisture. Eleven bore holes were drilled to a depth of 50 feet during the 1968 drought. These bores are at various elevations in the catchment, and the water levels recorded at the end of the drought were, on average, 5.9 feet lower than those recorded 3 months later when prolonged rain had recharged the upper soil layers (table 2).

TABLE 2: GROUNDWATER LEVELS* IN DEEP BORES AT PUKETURUA

Bore No.	1	2	3	4	5	6	7	8	9	10	11
Location in Catchment	Lower Slope	Lower Slope	Upper Ridge	Lower Slope	Lower Slope	Upper Slope	Ridge Top	Ridge Top	Upper Slope	Upper Slope	Ridge Top
4.3.68	6.3	9.8	18.9	10.3	2.4	12.2	7.5	30.5	13.0	6.2	Dry at 15.5
17.6.68	1.5	5.8	12.1	3.0	1.2	6.5	1.9	14.3	9.1	0.3	12.0
Rise of Water Level	4.8	4.0	6.8	7.3	1.2	5.7	5.6	16.2	3.9	5.9	3.5

*Expressed as depth of water level below ground surface, in feet.

Another event of considerable significance was the drying up of a shallow bore in the valley floor 8 days before the end of the drought (fig. 1). The bore is one of a set of seven located in the swampy floor at Puketurua. This particular bore is 3 feet deep and situated 13 feet from the stream channel, which is only 3.68 feet deep in this part of the catchment. The pattern of swamp ground-water movement shown in fig. 1 is followed by the other shallow bores, with the lowest water levels recorded on 4 March immediately before the drought ended. At this time the stream was rapidly approaching zero flow, as were many other streams in similar country. It seems reasonable to conclude that all streams at this stage of the drought were being fed only from deep-seated ground-water storage.

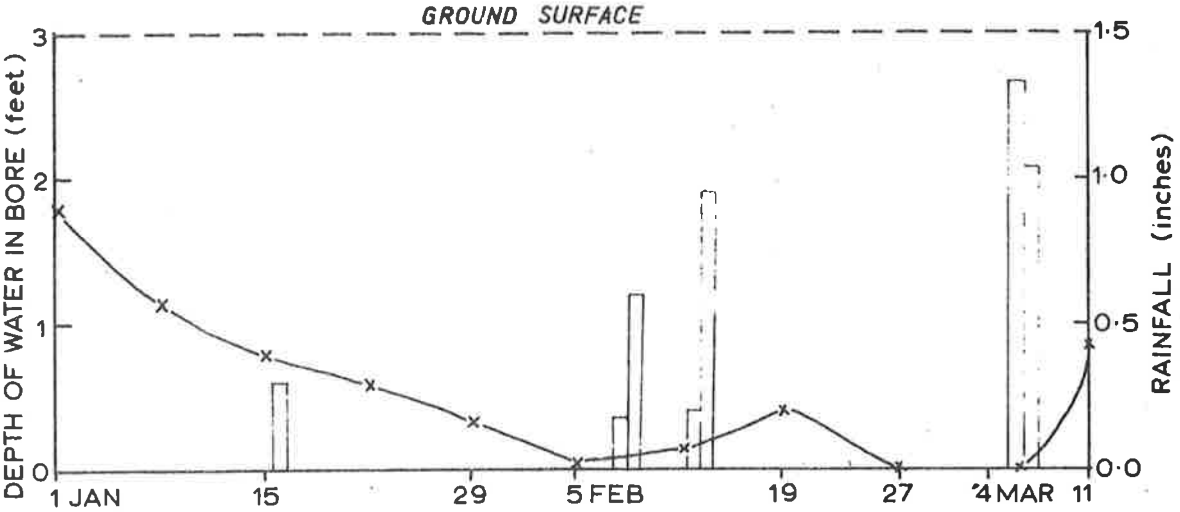


FIG.1 - SWAMP GROUND-WATER MOVEMENT AT PUKETURUA.

THE OCCURRENCE OF DROUGHT IN NORTHLAND

An examination of a world map showing Trewartha's (1954) modified Köppen classification of climate shows that Northland, lying between 34°S and 37°S, is at the same latitude as other areas recognised as having a Mediterranean climate. One of the major features of this climate type is the occurrence of drought in summer, when anticyclonic conditions predominate. The occurrence of drought in Northland appears to be associated with the process of anticyclonic replacement outlined by de Lisle (1964).This sometimes produces 2 to 3 weeks of mostly fine weather, as seen in the later parts of January and Feburary 1968. In this Mediterranean type of climate the bulk of the rainfall comes in winter. In Northland approximately one-third of the yearly total falls in the three winter months and only one-fifth in the summer months (de Lisle 1964, p.41). It appears reasonable, allowing for a certain amount of modification of the basic pattern, to regard Northland as lying within this climatic type. Hence, it is not surprising that droughts of varying severity have been recorded in Northland since the arrival of European settlers.

Rainfall records from seven rainfall stations spread over Northland have been examined for the 1962, 1964, and 1968 droughts. The Whangerei figures are quite representative of the other stations and are used in the subsequent discussion. Examination of 50 years of rainfall records for Whangerei shows that on average a 2-monthly summer rainfall total of less than 2.5 inches (1968: 2.46 inches) occurs once every 5 years. On this basis the 1968 drought appears to be of a 5-year frequency and is the ninth driest summer in the 50 years of record. On the basis of 2-monthly summer rainfall, the 1961–62 summer would occur once every 2 years, and even when its 3-monthly total is considered it would occur once every 4 years. This matter is further investigated later in this paper where it is suggested that the low rainfall total in the preceding spring would account for the low flows gauged in 1962.

The 50 years of records up to and including the summer of 1968 were divided into 10-year periods. Each 10-year period since 1918 has seen at least one summer with a 2-monthly rainfall total under 2 inches. The long-term average for any two summer months is approximately 8 inches for Whangerei. On the same basis each 10-year period has one summer with a 3-monthly rainfall total under 3.7 inches. Using this criterion the 1964 drought would be of 10-year frequency.

The major drought of 1945-46, for which a few flow figures are available, ranks second in the 50 years of record to the summer of 1949-50 for both 2-monthly and 3-monthly rainfall totals (table 3).

TABLE 3: TWO AND THREE–MONTHLY RAINFALL TOTALS FOR MAJOR DROUGHTS

Drought Year	Two-Month Total (inches)	Three-Month Total (inches)
1945-46	1.02	2.41
1949-50	0.89	1.59

However, the severity and duration of the 1945-46 drought, with a 4-month rainfall total of 3.42 inches (long-term average approximately 15 inches) would give it a frequency of at least 50 years. The only other drought of similar duration and severity occurred in the summer of 1912-13, when only 2.82 inches fell in 4 months.

BASE–FLOW RECESSION CURVES

All the available data from 1968 were plotted on semi-log graph paper, using the methods outlined by Toebes and Morrissey (1969). The diagrams show only the portion of each recession line immediately before the end of the drought. A straight line was assumed to exist, except in the few cases where reliable and detailed data showed that a curve existed (e.g., Opahi). As Toebes and Strang (1964, p.12) pointed out "... individual recessions are normally too short to detect anything but a straight line when plotted on semi-log paper". Toebes and Strang (1964) also pointed out that for comparison of recessions in catchments the simple exponential (straight line on semi-log paper) is preferable since is has only one constant (*K* value).

The recessions for the individual rivers were plotted and *K* values calculated for each line. Values obtained from the individual recessions were then used to calculate mean discharge values for each region. This information was used to plot the regional mean base-flow recession curves in fig. 2. The mean *K* values were similarly derived from the individual *K* values.

The means base-flow recessions (fig. 2) highlight the quite considerable differences which exist between the various regions (fig. 3). An examination will now be made of these mean recession curves, together with the base-flow recessions for the individual rivers within each region, to show that the differences can be related to the geology of the catchments.

Field observations and gaugings showed that all rivers in the Waipoua and Whangerei regions had well sustained base flow during the drought of January to 5 March 1968. The position and slope of the mean recession curves for these regions in fig. 2 further illustrate this point.

WAIPOUA REGION

The rock type in this region is largely volcanic in origin, consisting of Waipoua basalt and the Tangihua volcanics (largely basalt), forming upland masses in the west and across the north of Northland. These fairly recent volcanic rocks (Waipoua basalt is mapped as Pliocene) have been extensively shattered, particularly in the Kaihu area, and have not formed impermeable soils (N.Z. Soil Bureau 1954, p.156). It follows that the fairly permeable volcanic areas provide a greater opportunity for the quite high rainfall – 80 to 90 inches per annum – to enter the ground and recharge the ground-water storage, which is capable of holding very large quantities of water. The same rainfall on adjacent clay hill areas is not stored to the same extent, and in summer droughts the streams cease flowing.

The recession curves for the rivers in this region (fig. 4) give further support to the above argument. The average minimum flow in the Waipoua region was 0.50 cusecs per square mile, and the average *K* value 0.997 (fig. 2). The recessions for the individual rivers in the Waipoua region (fig. 4) all show well sustained base flow.

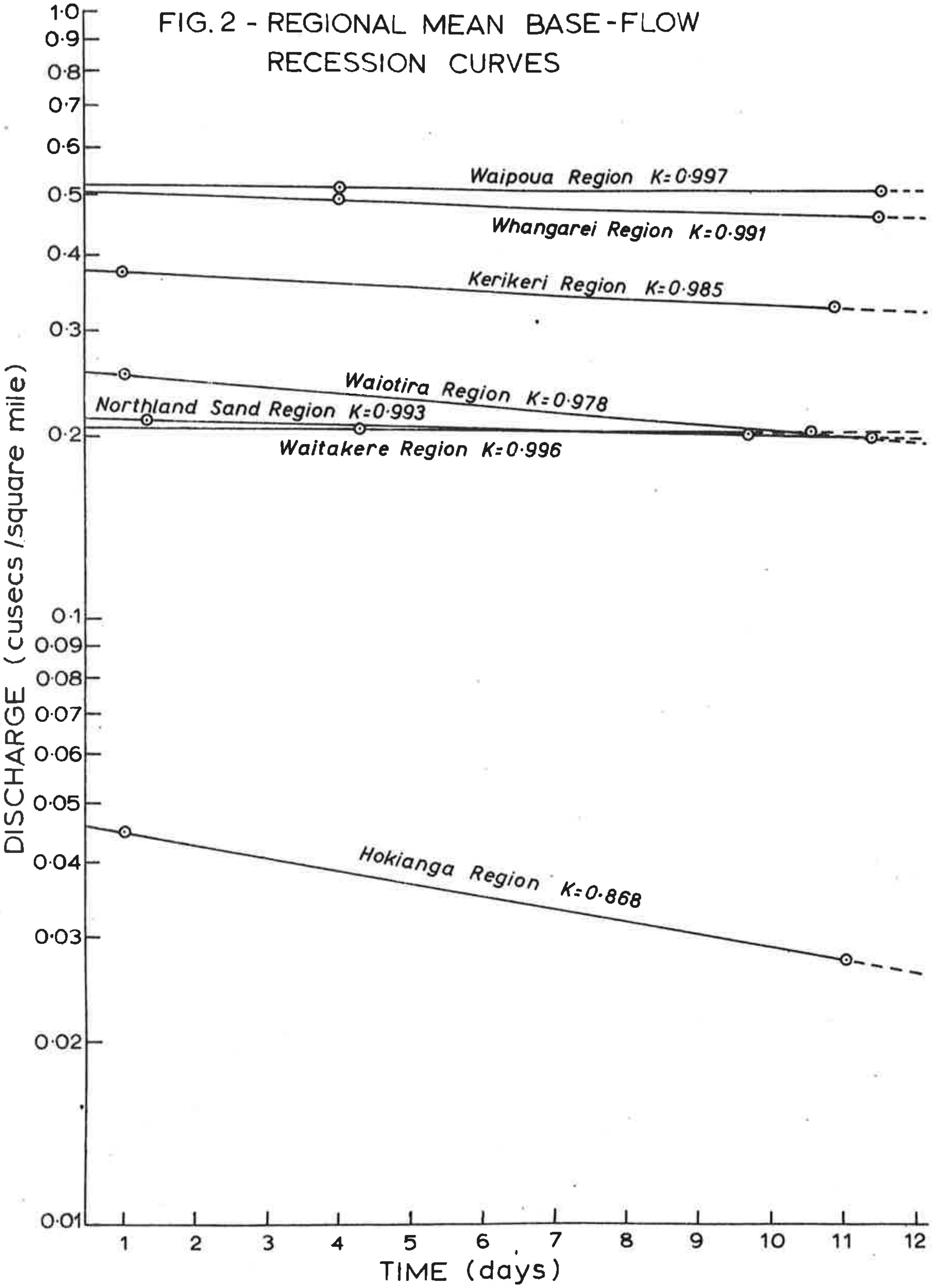
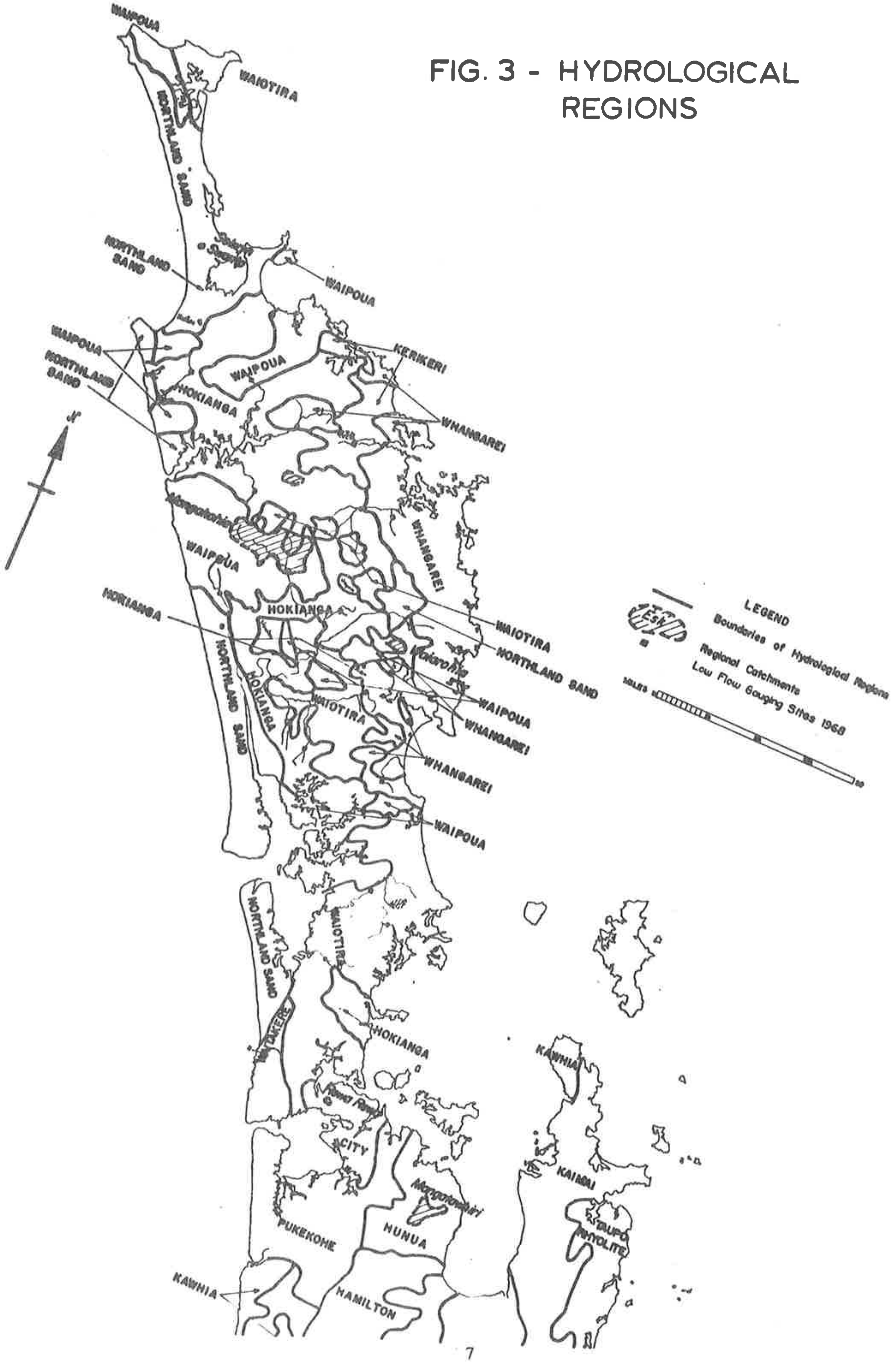


FIG. 2 - REGIONAL MEAN BASE-FLOW RECESSION CURVES

FIG. 3 - HYDROLOGICAL REGIONS



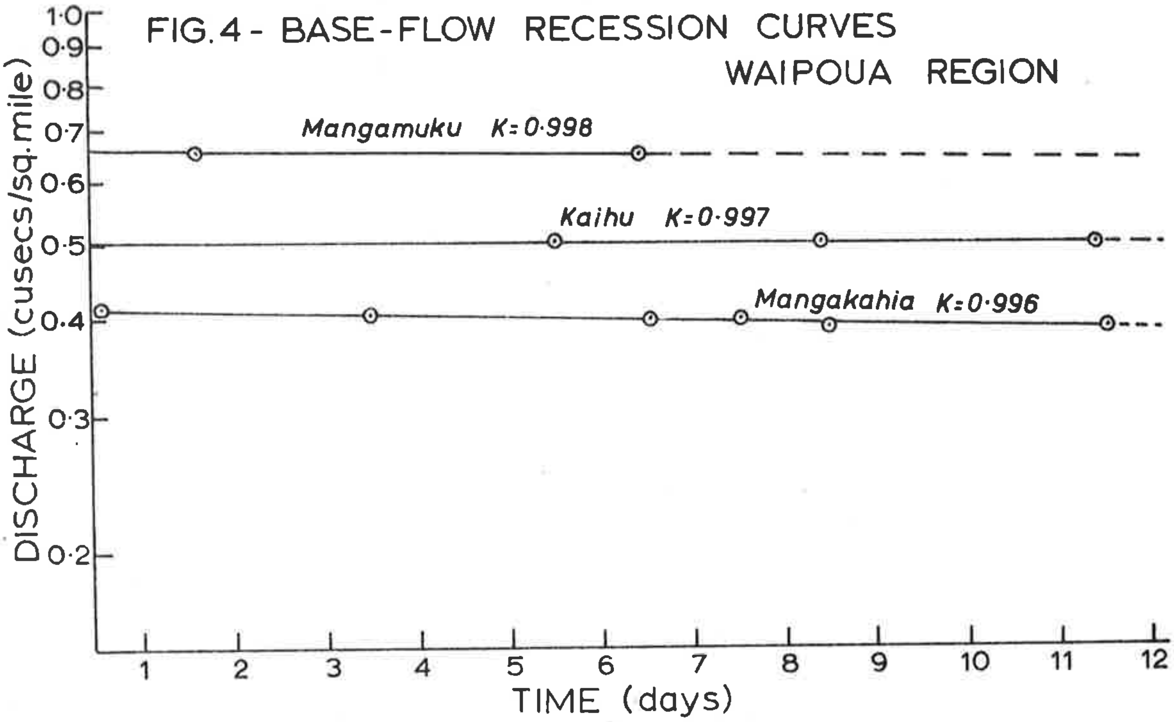


FIG. 4 - BASE-FLOW RECESSION CURVES WAIPOUA REGION

The minimum flows at the end of the drought range from 0.382 cusecs per square mile on the Mangakahia River to 0.64 cusecs per square mile on the Mangamuka River. On the minimum-flows map (fig. 9) this region is mapped as having flows greater than 0.35 cusecs per square mile, but it can be seen that individual minimum flows can be much larger. The minimum discharges (table 4) of the rivers gauged are quite large, and these rivers are some of the most important water resources in Northland. Much the same conclusion is reached, using different methods, in the Northland Catchment Commission (1968) *Preliminary Report on the Water Resources of Northland.*

TABLE 4: MINIMUM DISCHARGES OF RIVERS IN THE WAIPOUA REGION

River	Area (sq. miles)	Discharge (cusecs)
Mangakahia	93.0	35.52
Kaihu	45.0	22.32
Mangamuka	9.0	5.82

The three recessions in fig. 4 group quite closely around the mean recession, which closely approximates to the Kaihu recession, and their slopes are all similar. Hence, from an examination of fig. 4 it appears that the Mangakahia River is reasonably representative of the Waipoua region, at least for low flows. Removal of the Awarua River catchment and its flow (a non-representative tributary area) from the Mangakahia data might improve this result.

WHANGEREI REGION

This region covers the elevated greywacke hills along the east coast of Northland north of Whangerei, as well as several isolated fault blocks (fig. 3). The rocks in this region are predominantly Permian greywacke and argillite, which have been deeply weathered and are intensely deformed, jointed, and sheared—providing considerable potential for ground-water storage, especially in the deep weathered zone (Thompson 1961).

The average minimum flow in the Whangerei region was slightly lower than in the Waipoua region at 0.46

cusecs per square mile. The base flows, although well sustained, were decreasing a little more rapidly than in the Waipoua region, mean $K = 0.991$. As fig. 5 shows, the individual recessions form a reasonably uniform group when compared with the recessions from other regions (figs. 4 to 8).

The minimum flows ranged from 0.35 cusecs per square mile (Tirohanga Stream) to 0.57 cusecs per square mile (Waihoihoi Stream). On fig. 9 this region is also shown as having minimum flows greater than 0.35 cusecs per square mile.

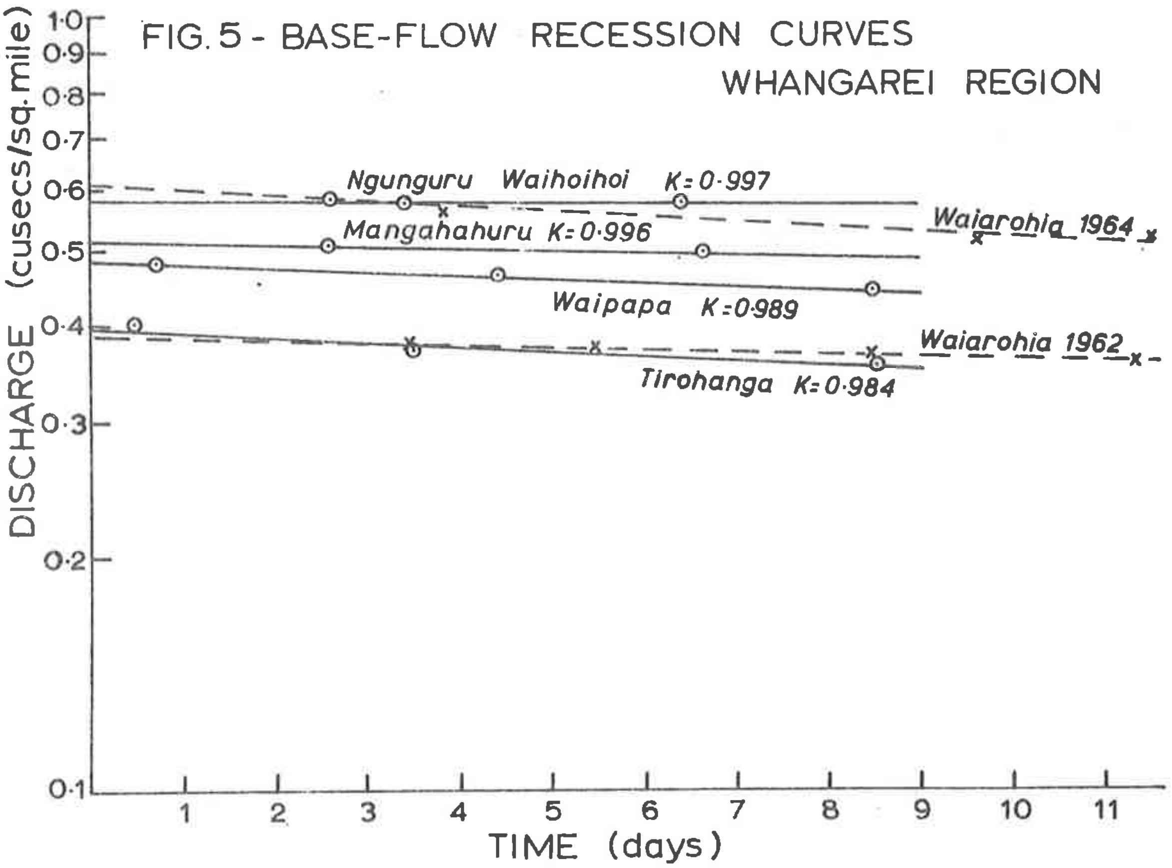


FIG. 5 - BASE-FLOW RECESSION CURVES WHANGAREI REGION

The individual minimum discharges (table 5) of the majority of the streams are fairly small, and this is quite typical of the many small rivers and streams in this region. However, in spite of the fairly small minimum discharges, the rivers in the Whangerei region do have well sustained base flows (K values range from 0.984 to 0.997.)

TABLE 5: MINIMUM DISCHARGE OF RIVERS IN THE WHANGEREI REGION

River	Area (sq. miles)	Discharge (cusecs)
Waipapa	47.0	20.745
Tirohanga	22.4	7.90
Mangahahuru	10.5	5.18
Waihoihoi	7.1	4.09

In the Whangerei region the representative basin was the Waiarohia catchment, which is on a isolated greywacke block near Whangerei. This station has now been closed, as the stream has been dammed for water supply, but data from 1962 and 1964 are available and have been plotted on fig. 5, as has a single gauging made on 26 March 1968 from the new representative basin (Ngunguru River) when river flows were still very low. It can be seen that both these representative basins are quite representative of their region. Future gauging will show the exact relationship of the new representative basin to the other streams in the region.

KERIKERI REGION

The Kerikeri region, like the Waipoua region, consists of areas of basaltic rocks. Most of this small region is a gently sloping lava plateau at fairly low altitude, which, together with the greater depth of soil covering the plateau, would account for the considerable difference in base flow between this region and the Waipoua region, as illustrated by the mean recession curves in fig. 2.

The average minimum flow was 0.32 cusecs per square mile (cf. Waipoua 0.50) and the base flows were not as well sustained (mean *K* = 0.985) as in the Waipoua region. The above mean values were derived from only two streams, Maungaparerua Stream (the representative basin) and the adjacent Puketotara Stream. As fig. 6 shows, the recessions of these two streams are quite different, with minimum flows of 0.219 and 0.44 respectively. Subsequent gauging has shown that the Maungaparerua Stream is quite typical of the region and that Puketotara Stream is the exception. On 6 November 1968 Maungaparerua's discharge was 0.95 cusecs per square mile, four other streams gave discharges of 1.14, 1.04, 0.99, and 1.19 cusecs per square mile, while Puketotara Stream produced 1.41 cusecs per square mile.

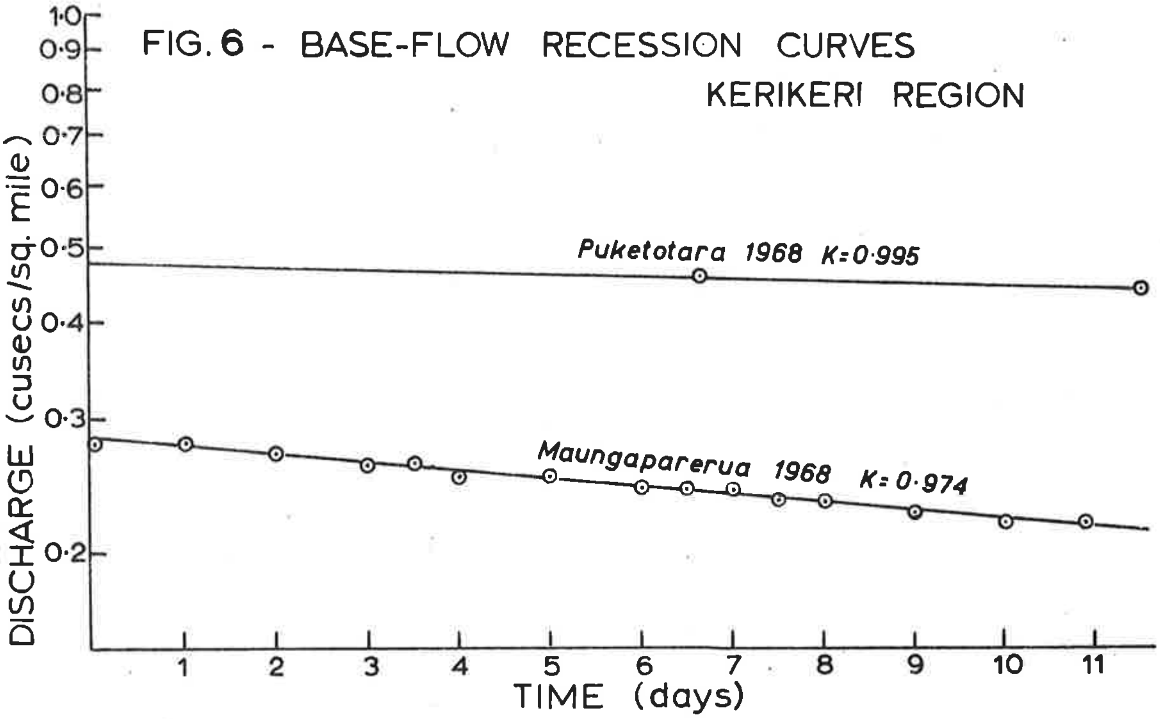


FIG. 6 - BASE-FLOW RECESSION CURVES KERIKERI REGION

The individual minimum discharges were quite small – Puketotara 4 cusecs and Maungaparerua 0.885 cusecs – and as the *K* values indicate, the flows were still decreasing but not too rapidly. It is interesting to note that in the very severe 1946 drought the Kerikeri River (with a catchment area of 19.4 square miles) was still flowing at 0.198 cusecs per square mile (3.85 cusecs), recorded on 1 March 1946. The Puketotara and Maungaparerua Streams are tributaries of the Kerikeri River.

WAIOTIRA REGION

The Waiotira region, lying largely to the south of Whangerei and predominating in the area south of Wellsford, is chiefly higher hill country eroded from Tertiary sandstone and mudstone rocks (Miocene age). It is thought that these younger sediments are less indurated than the older hard shale and sandstone rocks found in the Hokianga region, thus allowing more water to be held in ground-water storage. Another factor of some importance is that because the hills are higher and steeper, especially when compared with the Hokianga region, they have been subject to more active erosion and the soils in general are quite shallow.

Hence, the rainfall can infiltrate down to become ground-water much more readily than in areas where soils with deep clay subsoils mantle the underlying rock (N.Z. Soil Bureau 1954, pp. 100–116).

The average minimum flow in the Waiotira region is considerably less than in the first three regions, being 0.195 cusecs per square mile. The mean recession curve also illustrates the tendancy for base flow in this region to diminish more rapidly during drought periods ($K = 0.979$) than in the regions already discussed.

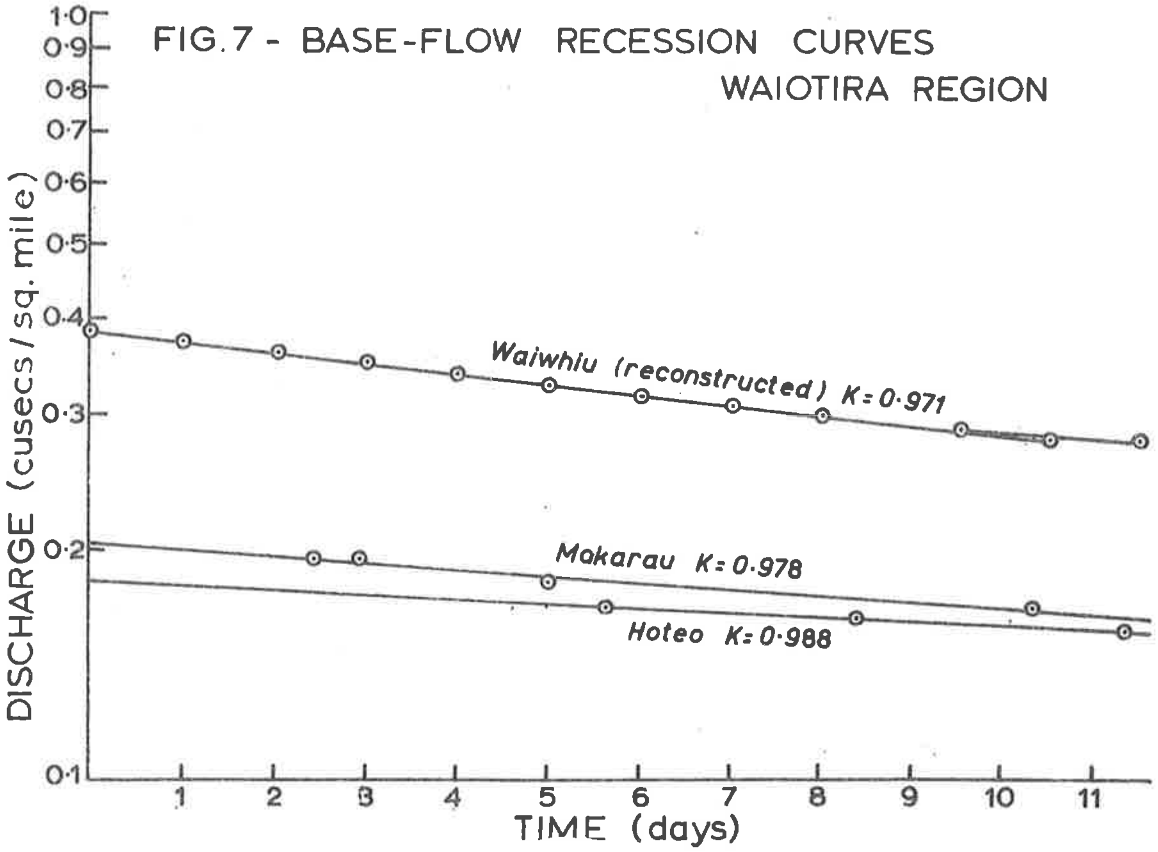


FIG.7 - BASE-FLOW RECESSION CURVES WAIOTIRA REGION

As fig. 7 shows, the representative basin for this region (Waiwhiu) produces quite different results from those of the other two rivers where data were available.

TABLE 6: MINIMUM DISCHARGE OF RIVERS IN THE WAIOTIRA REGION

River	Area (sq. miles)	Discharge (cusecs)
Hoteo	82.00	12.9
Makarau	18.6	3.1
Waiwhiu	3.1	0.852

Table 6 shows the range of catchment area and minimum discharge for the three catchments. As the Hoteo and Makarau Rivers have quite similar recession curves, the apparent difference between these curves and the Waiwhiu recession will have to be further investigated. The minimum flows ranged from 0.157 to 0.278 cusecs per square mile; however, the 0.157 and 0.162 cusecs per square mile for the Hoteo and Makarau Rivers appear to be more typical of this region. The conclusion drawn from the 1968 data is that Waiwhiu does not provide very representative low-flow data.

WAITAKERE REGION

The Waitakere region is another hilly region where volcanic rocks (andesitic breccia) predominate, but there are also sandstones and conglomerate. Only the Mokoroa Stream was gauged in this region, so the mean line on fig. 2 is the actual recession from this stream. The recession curve shows a very steady base flow ($K = 0.996$) with a minimum flow of 0.20 cusecs per square mile.

NORTHLAND SAND REGION

In fig. 2 the Northland Sand region is shown as being very similar to the Waitakere region. The data for this region are also from one site – Selwyn Swamp, the representative basin. Field observations in the other major portion of this region near Dargaville revealed that the small streams among the sand hills and in areas on consolidated sand had no flow during the drought. It therefore appears that the base flow being measured at Selwyn Swamp is from a much larger area than the immediate 0.81 square miles of catchment. Movement of ground water over large distances is quite feasible in this extremely porous sandhill country. The conclusion reached is that in reality this region should appear much lower on the scale in fig. 2, and the data from Selwyn Swamp will have to be used with some caution. The results are likely to be quite typical of the surface outflow from regional ground-water storage areas in the sand country. Subseqent topographic surveys have located several semi-permanent lakes in the sandhills around the catchment. Because of their elevation in relation to the Selwyn Swamp stream it is quite likely that water from the lakes seeps through narrow ridges of unconsolidated sand to add to the stream flow measured at the weir.

HOKIANGA REGION

The final region, the Hokianga region, covers large areas of low hill country in central Northland where the rocks are old hard shale and sandstone (Cretaceous age). These rocks are commonly overlain by a considerable depth of almost impervious clay soils (N.Z. Soil Bureau, 1954). The drilling of bore holes at Puketurua where the soils are classed as Waikare brown sandy clay, clay loam, Waikare clay and silt loam, and Wharekohe silt loam with pan (the last of these being widespread in the Hokianga region) showed that 15 to 18 feet of heavy clay lies between the soil and the parent rock. This mantle of clay appears to be capable of absorbing a certain amount of water, much of it down cracks which open up in summer. However, once the clay is saturated it becomes an almost impervious layer and prevents water reaching the underlying parent rock.

As the mean base-flow recession curve on fig. 2 shows, this region is quite different from the regions already discussed. The average minimum flow was only 0.027 cusecs per square mile at the end of the drought. Many of the streams in this region had quite steep recessions, average K value 0.868, which were rapidly approaching, or had reached, zero flow. The base-flow recessions for the individual streams in the Hokianga region (fig. 8) have several features which distinguish them from the recessions in the other regions:

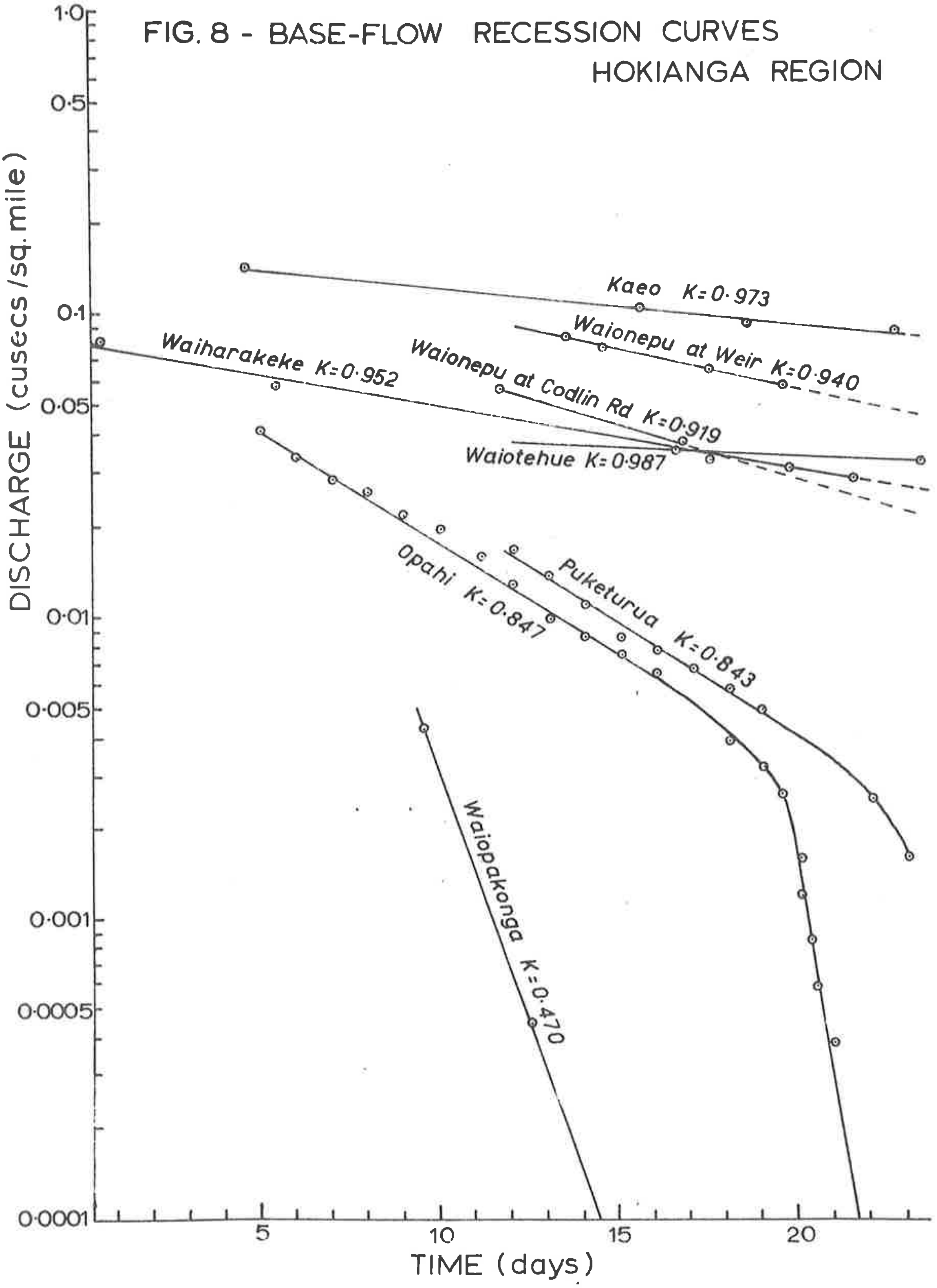
(1) All the minimum flows at the end of the drought are less than 0.10 cusecs per square mile and range from zero to 0.086 cusecs per square mile.

(2) The recessions are all quite steep, with the main range of K values lying between 0.84 and 0.95.

(3) The zero flow recorded at Opahi representative basin and on the Waiopakonga Stream (fig. 8) is quite common in this region. Towards the end of the drought several other catchments in this region were examined and found to have zero flow.

(4) The curves in fig. 8 for Opahi and Puketurua are both drawn from very accurate data. The marked change of slope in the Opahi curve and the suggestion that the same feature would occur at Puketurua, seems to deserve some comment. At Opahi this change of slope occurs at a stage height of 0.11 feet and at Puketurua at a stage height of 0.06 feet, the respective discharges being 0.0105 cusecs and 0.0024 cusecs. At this time temperatures were quite high for Northland, daily maxima over 80°F being recorded at Puketurua, and evaporation from an open pan evaporimeter frequently exceeded 0.3 inch. It is suggested that at this point on the recession, with inflow from ground-water storage almost at zero and with these minute flows, evaporation from the surface of the weir ponds became a much more important factor in lowering the water level at the weir. Comments by Singh (1968) tend to confirm these observations.

FIG. 8 - BASE-FLOW RECESSION CURVES HOKIANGA REGION



(5) The final feature that the streams of the Hokianga region had in common were the very small minimum discharges gauged at the end of the drought. The largest minimum discharge was 2.64 cusecs gauged on the Waiharakeke River (area 91 square miles). Most of the other rivers had minimum discharges of half a cusec or less (table 7).

TABLE 7: MINIMUM DISCHARGE OF RIVERS IN THE HOKIANGA REGION

River	Area (sq. miles)	Discharge (cusecs)
Waiharakeke	91.0	2.64
Kaeo	14.3	1.25
Waionepu	13.7	.51
Waiotehue	8.0	.262
Waiopakonga	5.3	0.0
Opahi	4.1	0.0
Waionepu at Weir	3.3	.194
Puketurua	.96	.0024

The recessions in fig. 8 are not grouped together as closely as those for the Waipoua and Whangerei regions, but they do form a group quite separate from the recessions of the other regions. Because of the generally steep slopes of the recessions and the fact that several other catchments in the region were observed to have zero flow, the Opahi Stream is considered representative of the streams in the Hokianga region.

DISCUSSION

The data examined up to this point have been presented on a regional basis and are from catchments which are each on a single rock type. With a few exceptions the recessions for each rock type (region) form distinct groups recognisable by their slope and/or minimum flow. The broad differences between the recessions for the various regions are shown by the mean recession curves in fig. 2. The conclusion reached from a consideration of all the data presented so far is that the geology of the catchment area is the most important influence on the low flows occurring during a drought.

MINIMUM FLOWS MAP

The data presented in this paper have been used to compile a new minimum flows map (fig. 9). The minimum flows are mapped as being likely to occur once every 5 years (on average). This information should be quite useful to organisations planning future developments of farming in Northland, as a drought of this frequency is common enough to be an economic problem. In 1968 the drought broke before conditions became really serious for the farming community but, even so, milk production had decreased and in the worst affected areas dairy herds had to be dried off early, thus affecting the farmers' income.

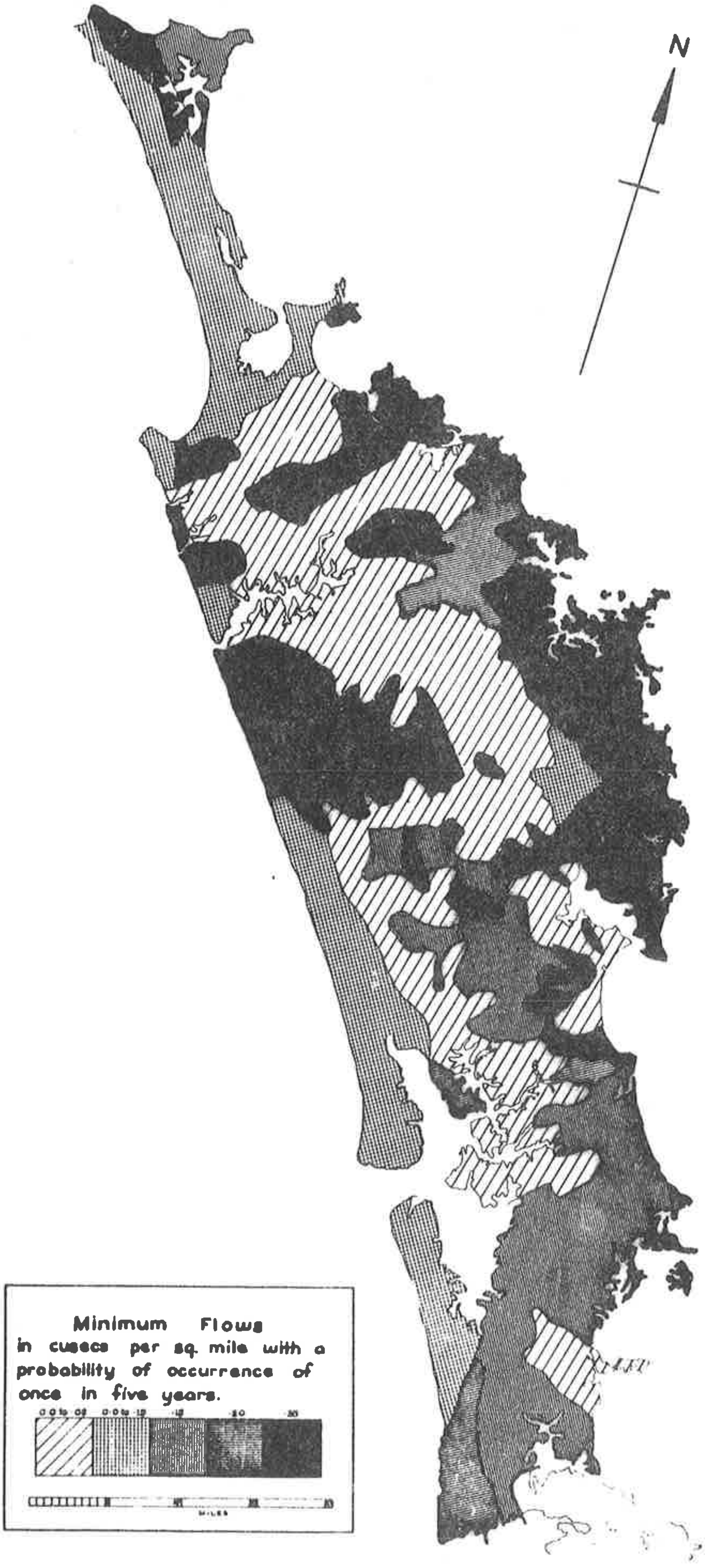
The map was drawn by using a simplified map of the hydrological regions in Northland. With this as a base, the flows gauged at the end of the 1968 drought were used to prepare the final map. Individual gaugings and field observations made at the end of the drought were also used in this mapping.

COMPARISON OF DROUGHTS

In the introduction brief mention was made of the fact that at several sites in Northland comparable data are available for the droughts of 1962 and 1968. A considerable amount of rainfall data are also available from the N.Z. Meteorological Service and these are used to present one possible explanation of the differences between droughts. As in the section on the occurrence of droughts, rainfall data for Whangerei are used, since they appear to be quite representative of the conditions in other parts of Northland.

The base-flow recession curves for Selwyn Swamp, Puketotara, and Waipapa (fig. 10-12) clearly show that at the end of the 1962 drought the streams had smaller minimum flows than in 1968. These three sites are each in a different hydrological region, so the same general pattern probably existed in the other regions where no data are available. The corresponding information for the Tirohanga Stream (fig. 13) does not show

FIG. 9 NORTHLAND MINIMUM FLOWS.



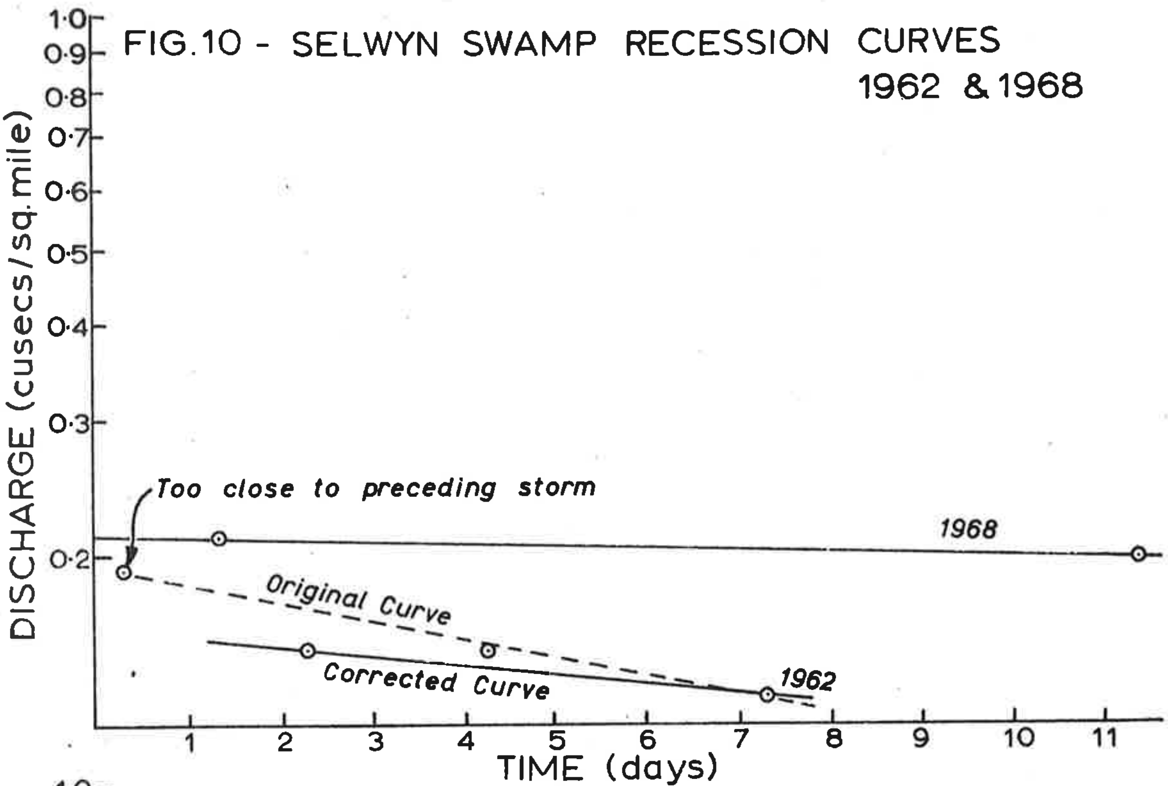


FIG. 10 - SELWYN SWAMP RECESSION CURVES 1962 & 1968

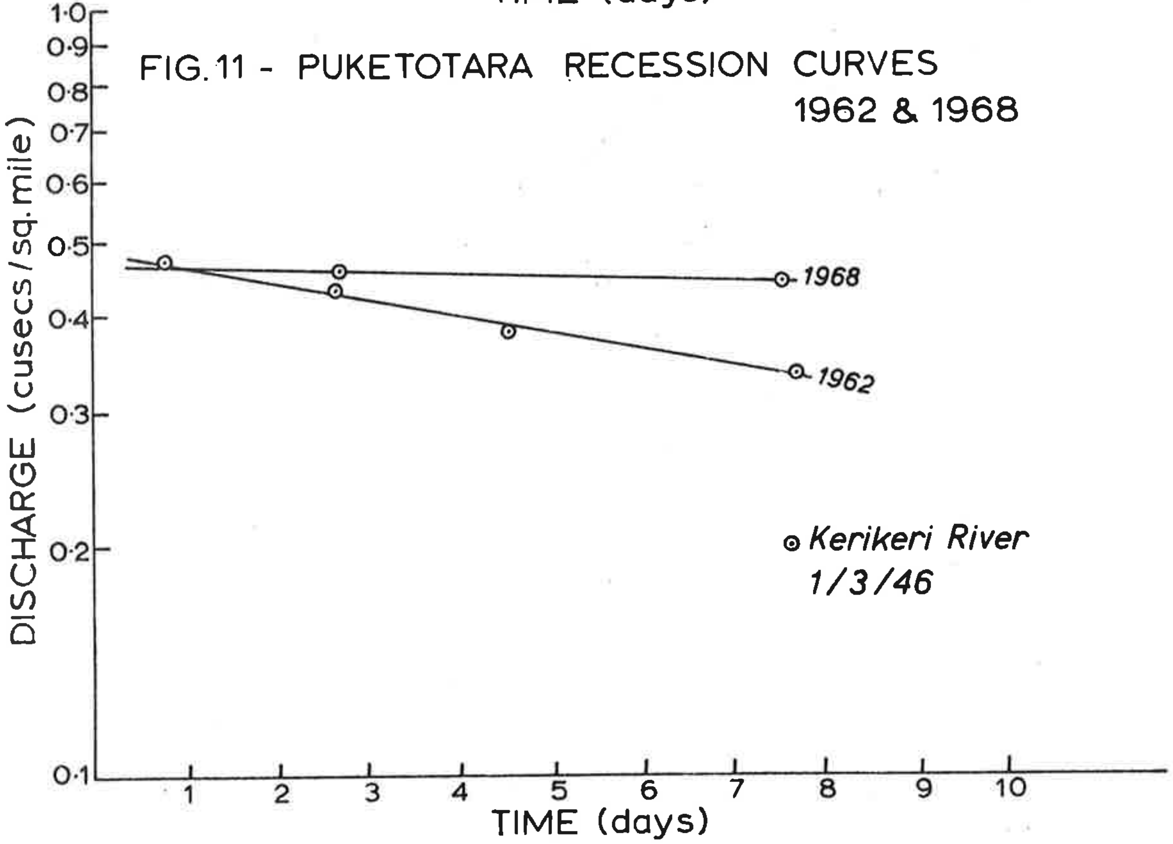


FIG. 11 - PUKETOTARA RECESSION CURVES 1962 & 1968

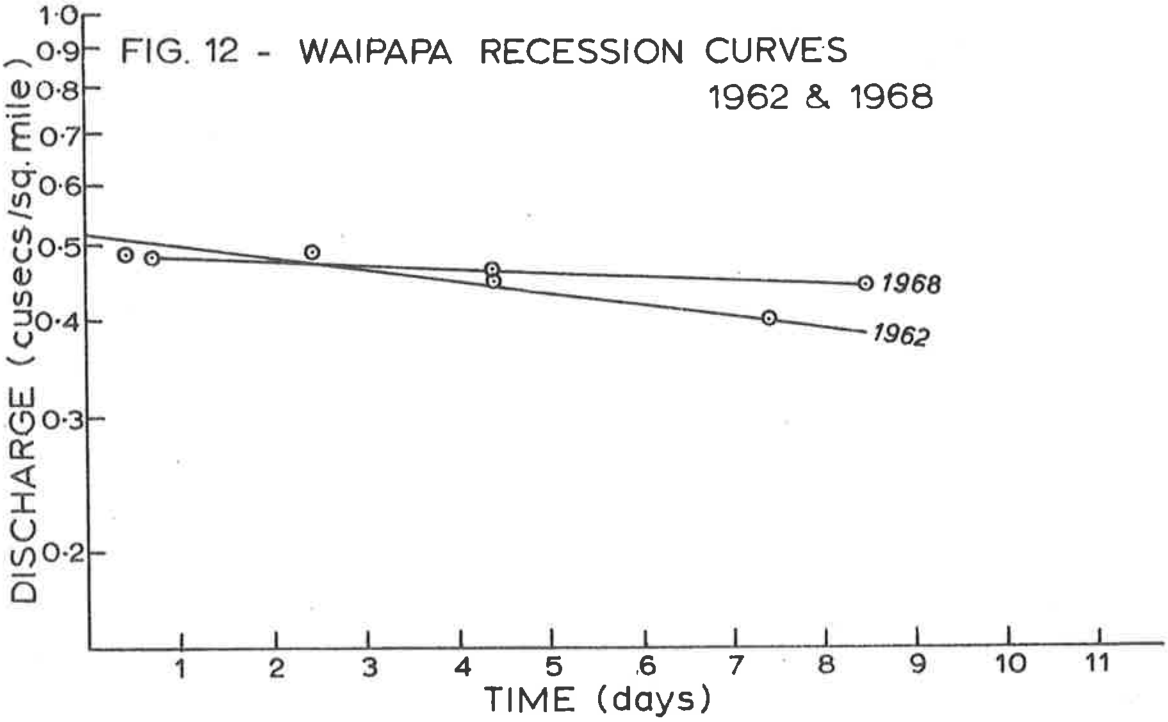


FIG. 12 - WAIPAPA RECESSION CURVES 1962 & 1968

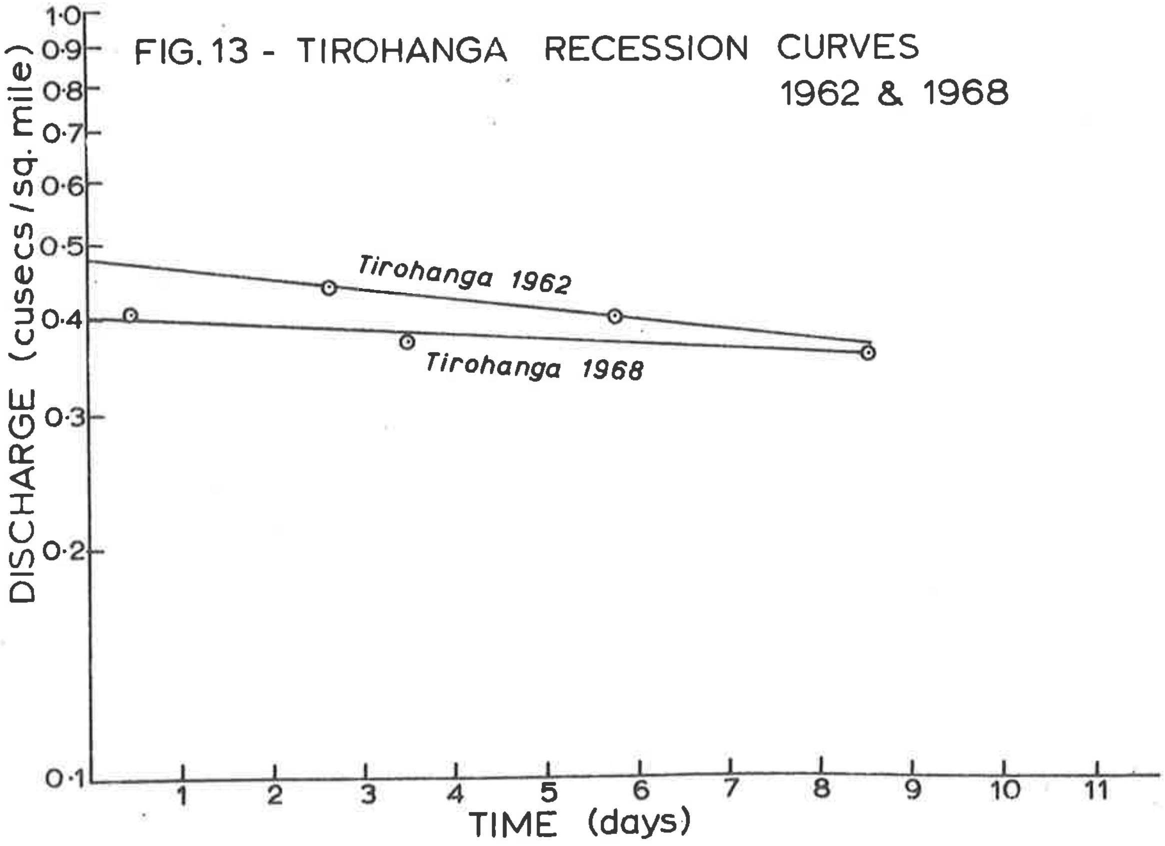


FIG. 13 - TIROHANGA RECESSION CURVES 1962 & 1968

the same pattern. The 1962 recession has the same steep slope as the other 1962 recessions, but the minimum flow at the end of the drought is greater than in 1968. This stream is in the same region as the Waipapa River (fig. 3) and there is no obvious explanation for this departure from the pattern shown in fig. 10-12.

Slope of Recession Curves, 1962 and 1968

The quite marked difference in the slope of the recession curves (fig. 10-12) can be accounted for by examining the rainfall data within the drought periods. In 1968 the drought ended on 6 March when over 1 inch of rain fell. The last preceding rainfall of any significance fell 20 days before on 15 February (over 0.5 inch in most areas). The bulk of the flow data presented in this paper was gathered in this 20-day period, especially in the last 15 days. In 1962 the drought ended on 26 February when over 0.80 inch of rain fell. The last preceding significant rainfall fell 15 days before on 11 February (over 0.5 inch), and the low-flow gaugings were carried out from 15 February. The low-flow conditions which prevailed in the summer of 1962 are shown by the minimum flows at the end of the series of gaugings. Some of the earlier gaugings appear to be influenced by the preceding rain (see fig. 10) and so produce a steeper recession.

Antecedent Rainfall

The main difference between the droughts of 1962 and 1968 is in the antecedent rainfall. Fig. 14 shows the cumulative difference between the monthly rainfall totals and the long-term monthly averages. For the 1962 drought, the 4 months before the drought (i.e., September-December) all had below-average rainfall, and as droughts are the result of a cumulative deficiency in moisture the conditions at the end of December 1961 were highly favourable for a major drought to develop in January and February of 1962. For the 1968 drought only one of the five preceding months had below-average rainfall (fig. 4). Hence, at the end of December 1967 there was a surplus of moisture and some of it must have infiltrated down through the soil to increase the ground-water storage. The very dry conditions which developed in January and February of 1968 allowed the rivers to draw on this ground-water storage, but because of the greater amount of antecedent rainfall the minimum flows in 1968 were not as low as in 1962.

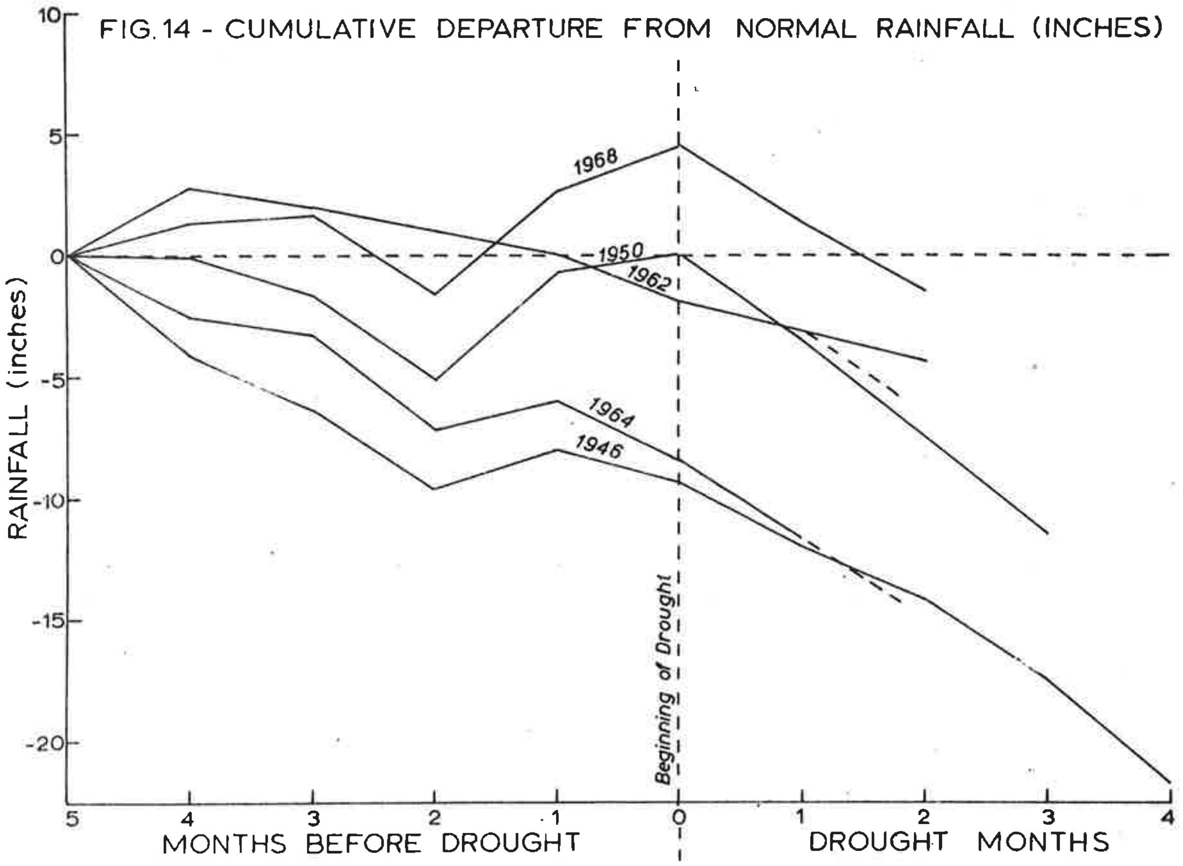


FIG. 14 - CUMULATIVE DEPARTURE FROM NORMAL RAINFALL (INCHES)

As fig. 14 shows, in 1964 and 1946 the conditions before the drought started were similar to those in 1962, but more severe. In each case the below-average rainfall continued (see fig. 15) and produced severe droughts of 10-year and 50-year frequency respectively. The drought of 1950 was preceded by conditions similar to those of 1968 (fig. 14). Three months of below-average rainfall were offset by 2 months of above-average rainfall so that the following 3 months of drought did not produce conditions as severe as those which developed in 1946. In the case of the 1945-46 drought the deficit in antecedent rainfall can be traced back to July 1944; only 3 months between July 1944 and April 1946 had above-average rainfalls.

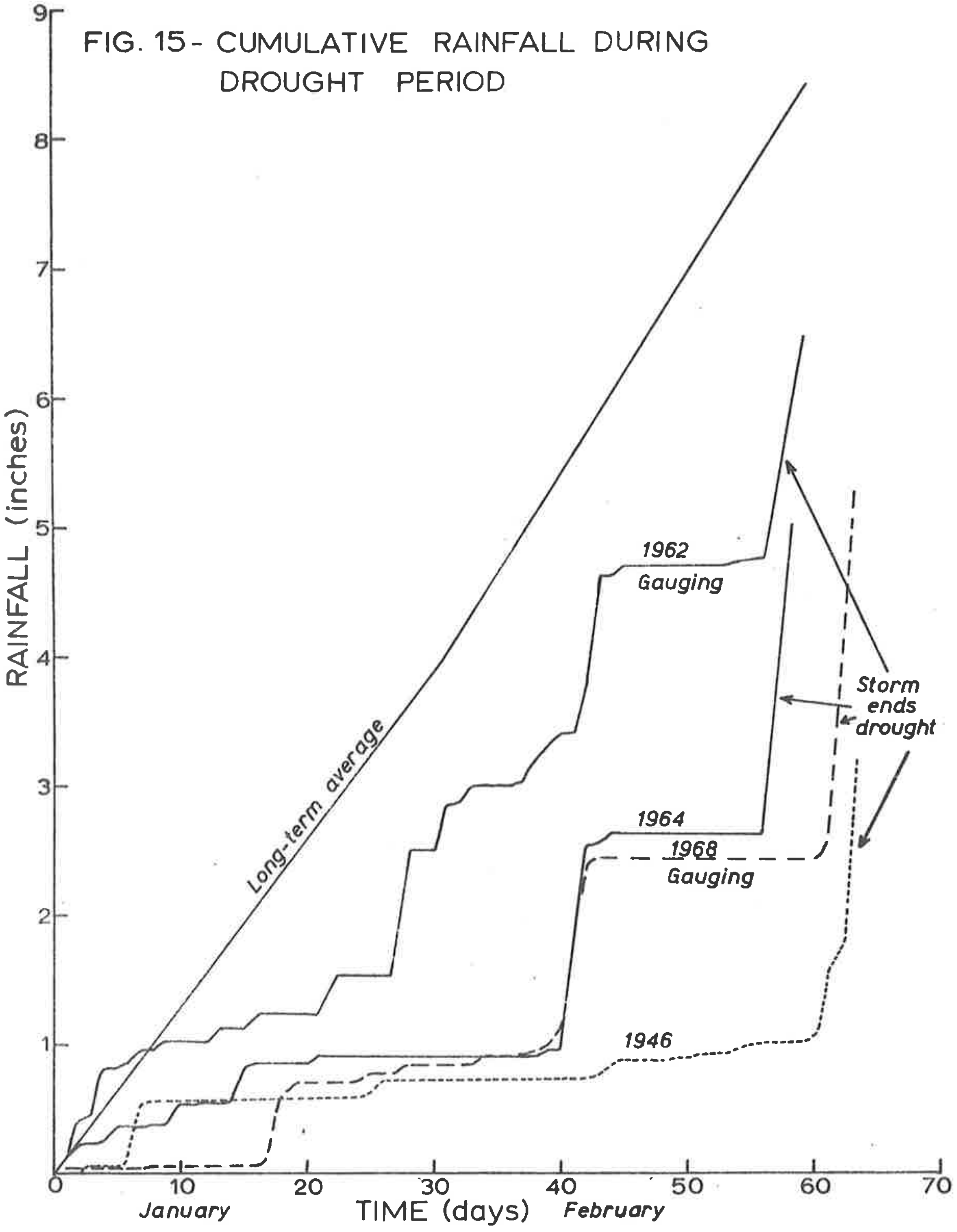


FIG. 15 - CUMULATIVE RAINFALL DURING DROUGHT PERIOD

Effect of Rainfall During Drought

Another difference between the various droughts is the amount of rain which falls during the drought. A drought is considered to be a prolonged period of low rainfall at the beginning and end of which are rainfalls of over 1 inch. Some droughts are broken temporarily by a rainfall of 0.5 inch or more, but if the extremely dry weather continues the rivers soon return to their former level and the base-flow recessions continue. The cumulative rainfall for the various droughts is compared with the long-term average rainfall in fig. 15. The difference between the droughts is quite marked. In 1968 the rainfall to the end of February was only 29 percent of the average rainfall for January–February, whereas in 1962 the rainfall up to 25 February was 56 percent of the same January–February average. In 1968 the drought rainfall was less than in 1962 but the minimum flows were greater (fig. 10-12). The conclusion drawn from these facts is that the rainfall during the drought has less effect than the antecedent rainfall on the minimum flows at the end of a drought. It is most important that the antecedent rainfall conditions are clearly defined when low-flow data are used in water-supply planning.

CONCLUSIONS

1. The geology of the catchment area is the main influence on the low flows occurring during a drought.

2. Antecedent rainfall is the most important factor in accounting for the different minimum flows observed at the end of various droughts in a particular catchment.

3. The two, three, and four-monthly rainfall totals for drought periods can be used to allocate an approximate frequency to a particular drought. However, the gauging data available from 1962 and 1968 indicated that antecedent rainfall should also be taken into account in allocating a frequency to a drought. A more refined index of "drought" conditions needs to be developed for this purpose.

4. The bulk of the 1968 data available for Northland shows that the concept of using representative basins is quite sound, at least for low-flow data.

5. The low-flow data from the representative basins in Northland are quite typical of the data from streams in each region. Further low-flow gauging is needed to check on how representative Waiwhiu is of the streams in its region.

6. Droughts occur with sufficient frequency to be a problem in Northland and this should be recognised in future planning of urban, industrial, and rural water-supply schemes.

7. Catchments in the Waipoua and Whangerei regions (basalt and greywacke rocks) have the greatest potential for future water-supply schemes.

8. The future development of farming on the easy hill country of the Hokianga region could be restricted by inadequate water supply. In severe droughts the rivers and streams of this region rapidly dry up and quite large local storage areas may have to be provided as part of future rural water-supply schemes.

REFERENCES

Chow, V.T. (ed.), 1964: *Handbook of Applied Hydrology*. New York, McGraw–Hill.

Cross, W.P., 1949: The relation of geology to dry-weather stream flow in Ohio. *Am. Geophys. Union Trans.*: 563-566

de Lisle, J.F., 1964: Climate and weather. In: *National Resources Survey, Part III: Northland Region*, compiled by Ministry of Works, Town and Country Planning Branch. Wellington, N.Z. Government Printer. Havens, A.V., 1954: Drought and agriculture.

Havens, A.V., 1954: Drought and agriculture. *Weatherwise* 17: 51-55, 68.

Hay, R.F., 1952: The rocks of North Auckland Peninsula considered as potential aquifers. *N.Z. J. Sci. & Tech.* 33: 248-257.

Ineson, J. and Downing, R.A., 1964: The ground-water component of river discharge and its relationship to Hydrogeology. *J. Instn. Water Eng.* 18: 519.

Kear, D., 1959: Geology of the Kamo mine area. *N.Z. J. Geol. & Geophys.* 2: 541-568.

Kear, D., and Waterhouse, B.C., 1967: Onetahi chaos breccia of Northland. *N.Z. J. Geol. & Geophys.* 10 (3): 629-646.

Knisel, W.G., jr., 1963: Baseflow recession analysis for comparison of drainage basins and geology. *J. Geophy. Res.* 68 (2): 3649-3653.

Kunkle, G.R., 1962: The baseflow duration curve, a technique for the study of groundwater discharge from a drainage basin. *J. Geophy. Res.* 67 (4): 1543-1554.

N.Z. Ministry of Works, 1964: *National Resources Survey, Part III: Northland Region* (compiled by the Town and Country Planning Branch). Wellington, N.Z. Government Printer.

N.Z. Soil Bureau, 1954: General survey of the soils of North Island, N.Z. *Soil Bureau Bull.* n.s.5. Wellington, D.S.I.R.

Northland Catchment Commission, 1968: *Preliminary Report on the Water Resources of Northland.* Whangerei, the Commission.

Searcy, J.K., 1959: Flow-duration curves. In *Manual of Hydrology, Part 2: Low-flow techniques,* U.S. Geological Survey Water-Supply Paper 1542-A. Washington, U.S. Government Printer.

Singh, J.K., 1959: Some factors affecting baseflow. *Water Resources Res.* 4 (5), 985-999.

Thompson, B.N., 1961: *Geological Map of N.Z. (1:250,000): Sheet 2A, Whangerei.* Wellington, D.S.I.R.

Toebes, C., and Morrissey, W.B., 1962: Base-flow recession curves. *Handbook of Hydrological Procedures: Proc. No. 8.* Wellington, Ministry of Works, Water and Soil Division.

Toebes, C., and Neef, G., 1962: Regional hydrology. In: *Hydrology and Land Management.* Wellington, N.Z. Soil Con. & Rivers Contr. Counc.

Toebes, C., and Palmer, B.R., 1969: Hydrological regions of New Zealand, *Misc. Hydrol. Pub.* No. 4. Wellington, N.Z. Ministry of Works, Water and Soil Division.

Toebes, C., and Strang, D.D., 1964: On recession cruves, 1: Recession equations. *J. Hydrol.* (N.Z.), 3 (2): 2-14.

Trewartha, G.T., 1954: *An Introduction to Climate.* New York, McGraw-Hill.

Troxell, H.C., 1953: The influence of groundwater storage on the runoff in southern California. *Am. Geophys. Union Trans.* 34 (4): 552-562.

Vladimirov, A.M., 1966: Characteristics of formation and computation of the minimum flow of small rivers in the USSR. *Soviet Hydrology* No. 2.

Waterhouse, B.C., 1961: Note on Kawiti basalt and hydrology of the Kawakawa area, Northland. *N.Z.J. Geol. & Geophys.* 4: 357-371.

Waterhouse, B.C., 1966: Mid Tertiary stratigraphy of Silverdale district. *N.Z.J. Geol. & Geophys.* 9 (3): 153-172.

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The work described in this paper was carried out by the Ministry of Works to further knowledge of the water resources of New Zealand. The investigation was led by J.R. Waugh, with assistance from K.D. Russell, N. Williams, and W.T. Todd – all of whom are with the Ministry of Works, Whangerei. The paper examines the representativeness of the various regional hydrological stations now established in Northland and also highlights some of the problems facing the water-supply engineer in investigating potential water-supply catchments and presents one approach to assessing the water resources of an area during drought conditions.

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