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THE INFLUENCE OF THE 1982-83 DROUGHT ON RIVER FLOWS IN HAWKE'S BAY

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ABSTRACT

During the summer of 1982-83 the Hawke's Bay region, North Island, New Zealand, experienced a very severe drought, resulting from the development of an extensive, persistent El Niño-Southern Oscillation event in the equatorial Pacific Ocean.

During February and March 1983 low flows in Hawke's Bay rivers were gauged on the Mohaka, Esk, Tutaekuri and Ngaruroro Rivers. Flow duration curves, variability indices and recession curves were used to check data consistency and indicate any regional variation. The return periods for the event from flow records at river stations ranged from seven to 40 years.

Data collected during the drought were used to compile a map of one-day minimum flows for a one-in-ten year return period. Specific discharges obtained during this survey were found to be consistent with those from low flows studied elsewhere in New Zealand.

INTRODUCTION

Rainfall in the Hawke's Bay region of North Island, New Zealand is highly variable, both monthly (Seelye, 1946) and annually (Seelye, 1940), and dry spells or partial droughts are common (Grant, 1968: Bondy, 1950). Recent regional expansion in horticulture and intensification in agriculture have substantially increased demand on a seasonally-limited water supply.

During the summer of 1982-83, a major drought developed which was to have a considerable economic impact on many parts of New Zealand. The drought reduced river levels along the east coast of the North Island. The onset of this event coincided with the beginning of a low-flow mapping study of central Hawke's Bay and provided a unique opportunity to assess the impact of a major drought on the flows of the region's rivers.

THE 1982-83 DROUGHT

Atmospheric changes triggered by the El Nino-Southern Oscillation (ENSO) phenomena can be detected as variations in the Southern Oscillation Index (SOI), an index based on departures in pressure from the seasonal mean (Wright, 1975). A precipitous drop in the Southern Oscillation Index during May-June 1982, followed by continued decline, resulted in a record low by December. Corresponding with a peak in equatorial sea-surface temperature anomalies (SSTAs), this indicated that dry conditions prevailing over the region could be expected to continue, with the possibility of a late summer, early autumn drought.

The development of strong high pressure anomalies north of New Zealand produced unusually frequent hot, dry, near gale-force westerly winds, and an almost complete absence of rain-bearing easterly winds during late spring and early summer (October—December) of 1982. Overall, the North Island received below normal rainfall for 1982, the greatest deficit (60-70% below normal) occurring in a broad band from the East Coast through the Volcanic Plateau to Northland (New Zealand Meteorological Service, 1982).

Low monthly rainfalls persisted into 1983, January to March recording only 16% of the normal at Napier. First reports of fish strandings came in early January, as river levels fell. By the end of that month confined aquifers on the Heretaunga Plains, the flood plain of the Tutaekuri and Ngaruroro Rivers, had reached their lowest levels in 12 years of record, while unconfined aquifers approached their lowest levels in 14 years of record, forcing several processing industries to halt production.

A more critical phase was reached in early February, when state forests in the headwaters of the major rivers became tinder dry. A total fire ban was imposed, followed by closure of the forests. In late February, some rain in the area brought a brief respite and a slight rise in river levels.

The situation worsened again in early March. Despite imposition of an irrigation ban throughout Hawke's Bay, the Ngaruroro River dropped well below the 2.8 m^3/s minimum set by the regional water board. By mid-March, the drought had reached disaster proportions, with over 10,000 head of cattle being trucked out of the district. Lambing percentages were down by as much as 25% relative to normal years. Irrigation bans were further extended. Towards the end of March sections of the lower Ngaruroro River were reported to be dry.

Early in April 65mm of rain fell over two days throughout most of the region, effectively ending the agricultural drought. However, as a result of a second higher peak in the equatorial sea-surface temperature anomolies in June, rainfall remained low until October, with major rivers staying below normal levels throughout the period.

THE STUDY AREA

The study area covers 5,400 km^2 and includes rivers and streams draining from the Kaweka, Ahimaniwa, Te Waka, Maungaharuru, Wakarara, southern Huiarau and norther Ruahine Ranges (Fig. 1).

The mountain ranges, rising to 1700 m, are composed of old, resistant greywackes and argillites deposited in the Triassic and Jurassic, and later elevated during the Tertiary and Quaternary. Adjacent hill areas are composed of mudstone, silstone, sandstone, limestone and conglomerates deposited during the Tertiary, and beyond these are alluvial outwash plains formed during the Pleistocene and Holocene.

Over the past two million years, volcanism to the west of the ranges has laid a mantle of ash and lapilli of variable depth and composition over the whole region. As a result, the high country at the head of the Mohaka, Ngaruroro and Tutaekuri Rivers is covered by moderately-leached, weathered, shallow yellow-brown pumice soils. A decline in rainfall east of the ranges is reflected by a change in soil type from these yellow-brown pumice soils to yellow-brown, then yellow-grey, earths. Soils of the plains comprise river-derived silts of more recent origin.

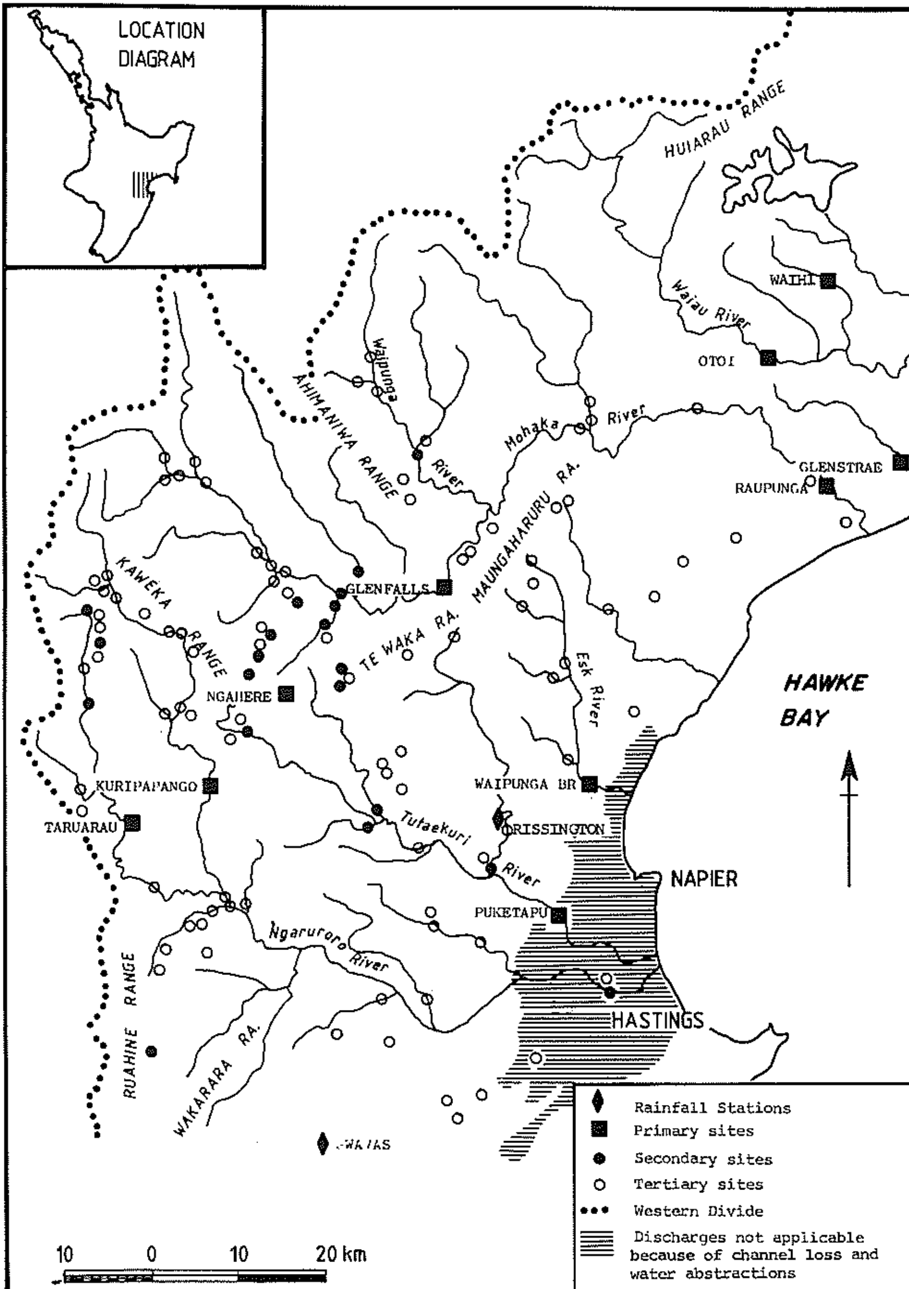


FIG. 1—Location of gauging sites and rainfall stations within the study area.

TABLE 1—Water-level recording stations.

Site Number	River Name	Station Name	Map Reference	Records Start	Records End	Catchment Area (km^2)	Min. flow (l/s)	k = recession rate (per day)	Recession half life (days)	Variability
21410	Waihi	Waihi	N105/564136	1968	C	49.7	109	0.994	106	0.38
21601	Tahekenui	Glenstrae	N115/661925	1969	C	20.6	1.71	—	—	0.75
21801	Mohaka	Raupunga	N115/542895	1958	C	2370	15282**	0.994	113	0.29
21803	Mohaka	Glenfalls	N114/072775	1959	C	997	8007**	0.994	113	0.28
*22802	Esk	Waipunga Br.	N124/244523	1963	CD	254	1835	0.998	475	0.23
*23001	Tutaekuri	Puketapu	N134/211367	1968	CD	793	2650	0.994	110	0.29
23005	Ngahere	Ngahere Weir	N123/860640	1968	C	0.52	0.47	0.993	96	0.50
23104	Ngaruroro	Kuripapango	N123/783533	1963	C	370	2426	0.990	69	0.32
23106	Taruarau	Taihape Road	N123/679464	1963	1980	259	828**	0.990	70	0.35

* HBCB Data
** Gauged minimum values
C Continuing
CD Continuous stage record, except during low-flow periods

METHODS

Rainfall data extending to before the "great drought" of 1911-16 were available from Gwavas, immediately south of the Ngaruroro catchment, and Rissington in the central Tutaekuri catchment. Records from both stations were plotted as cumulative departures of monthly from mean (full record) monthly values, with five-year running means fitted to indicate any apparent trend. Monthly departures from the mean were sequentially grouped in 6, 12 and 24 month periods and the five largest recorded deficits for each isolated. Dry spells were then ranked and their times of occurrence listed.

The technique of Herbst *et al* (1966) was used to identify and evaluate droughts of major hydrological significance, using data for Gwavas, the station with the longest and most consistent rainfall record. Following calculation of monthly excesses and deficits, small adjustments to the record, through weighting factors, were required to allow for the carry-over of any surplus or deficit into the following month. The average deficit was termed the intensity of the event and the length of time its duration. By multiplying intensity by duration a severity index was derived for individual events, allowing comparison of other major droughts with the 1982-83 event.

Continuous flow records, up to 26 years in length, were available from a series of primary stations within the region (Table 1), although only four of those with records exceeding 15 years are still operational. A further three sites on the Taruarau, Esk and Tutaekuri Rivers had historic flow records and were gauged routinely at 1-2 week intervals throughout the drought. Gaugings from these and additional (secondary) sites were plotted to establish concordance; supplementary (tertiary) sites were gauged to improve interpolation of data.

The consistency of flow-series data, and any apparent regional variations, were checked using flow duration curves; discontinuities or changes in slope were taken as an indication of serious data errors.

Variability of river flows at primary sites was assessed by calculating indices from series data, using the method of Lane and Lei (1950). Reducing variability to a single value for each site allowed direct comparison of river flows at several stations. The index, as determined by Lane and Lei, is the standard deviation of the logarithm of the discharge.

Spatial interpolation of data was most difficult for the headwaters of major rivers. Initially, more accessible sites around the base of the Kaweka Range were gauged at approximately weekly intervals. To complement these gaugings and determine the effect of elevation and aspect on yield, a traverse was made across the top of this range on 7 March, 1983. A helicopter survey of the upper reaches of the Mohaka and Ngaruroro Rivers was conducted on 25 March to assess base flow from the major tributaries and relate them to recorder stations. Throughout February and March additional gaugings were conducted in the foothills east of the ranges, to broaden the data base.

Where appropriate, gauged flows from secondary and tertiary sites upstream of, or near, primary sites were related to that site. Simultaneous discharges recorded at all of these sites were plotted on logarithmic paper and the slope and intercept of the straight line obtained by least-squares regression. In the lower reaches of the major rivers, flows of the lower Ngaruroro and Tutaekuri Rivers could not be related to any primary sites within these areas.

Flow data for the four primary stations was extrapolated by calculating 1, 7, 14 and 28-day minimum flows, for return periods of up to 50 years. The flow series were ranked in ascending order and converted to plotting positions with the formula:

$$T = \frac{N + a}{i - b}$$

Where T is the return period,
N is the sample size,
i is the rank of the extreme value,
and a = 0.20 and b = 0.40, as recommended by Maguinness (1977).
The method of moments was used to fit the log Pearson Type 3 distribution to the data.

Daily low flows for return periods of up to 50 years were also calculated for selected stations with incomplete data sets.

Flow reliability of rivers and streams within the region was determined by plotting recession curves and computing half lives from gaugings conducted during March, when rivers were at their lowest levels. This data was subjected to a rigorous elimination process; any suspect data that could be attributed to rainfall, poor site conditions, unsatisfactory gauging procedures or water abstraction were removed from the data sets. The remaining values were checked for consistency by plotting on semilogarithmic paper with straight lines fitted to the data. Sufficient points were taken to characterise each line, the discharges then being converted to specific discharges and plotted arithmetically as curves fixed to a common one-month period.

One-day minimum specific discharges recorded during the drought were mapped, the values being either gaugings near the end of March, or reduced by an appropriate k value from a gauging conducted earlier in the month. Isohyets represent catchment areas greater than 20 km^2 below 1,000 m, as small, low-altitude basins generally have ephemeral flows during dry spells.

A map of one-day, ten-year return period, low flows was then compiled using the map of minimum flows, adjusted in accordance with return periods calculated at the primary sites and the regressions established with secondary and tertiary sites. A one-day ten-year unit was considered suitable for mapping, as this had been applied successfully elsewhere (McKerchar and Dymond, 1981; Otago Catchment Board, 1976:1983).

Finally, the results of the study compared with results from other New Zealand low flow studies.

RESULTS

Rainfall

Although they are 45 km apart, Gwavas and Rissington have similar rainfall records, with normal (1941-70) annual rainfalls (New Zealand Meteorological Service, 1975) of 1069 and 1087 mm, and mean monthly values of 64-112 and 69-117 mm, respectively. Of the two sites, Rissington is the more variable, exceeding the Gwavas maximum monthly rainfall of 357 mm on 10 occasions since 1907, its maximum for that period being 662 mm. For both stations, 1983 was the driest year on record, with 572 mm of rain at Rissington and

703 mm at Gwavas. Low rainfall in 1982, 710 mm at Rissington and 669 mm at Gwavas, produced the third and second driest years on record, respectively.

Cumulative departures from the mean (Fig. 2) show a correspondence in peaks and troughs between the two stations, a feature more apparent in the five-year running mean. Troughs, indicating periods of below-normal rainfall, occurred on average at 19-year intervals.

Periods with the greatest rainfall departures from the mean for durations of up to 24 months are given in Table 2. For a six month period the most extreme departures for Gwavas were in 1914-15, whereas at Rissington they occurred in 1914 and 1982-83. For 12 months, 1914-15 ranks highest at Gwavas, whereas at Rissington the driest year on record was from the 1982-83 event. For a 24-month period the 1982-83 event occupied the top rankings at both stations.

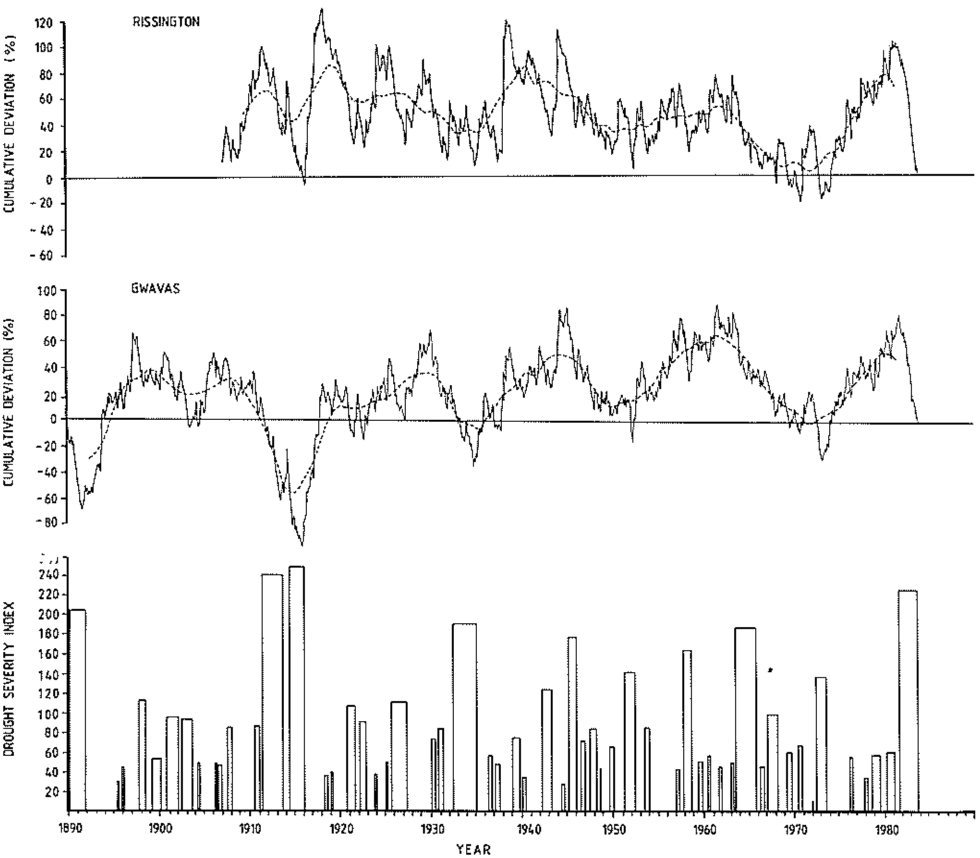


FIG. 2—Cumulative departures from the normal of monthly rainfalls at Rissington and Gwavas, with 5-year running means and drought-severity indices for Gwavas for the period 1890-1983.

TABLE 2—Rainfall data for Rissington and Gwavas, ranked for the five periods of greatest rainfall deficit on record for durations of 6, 12 and 24 months. Year and month give the last month of each dry period.

Rissington

Rank	Duration (Months)		
	6	12	24
1	1914.11	1983.09	1983.12
2	1914.12	1915.05	1983.11
3	1983.03	1983.07	1983.08
4	1983.05	1983.08	1983.09
5	1913.07	1983.04	1983.10

Gwavas

Rank	Duration (Months)		
	6	12	24
1	1914.12	1915.05	1983.11
2	1914.11	1946.02	1983.12
3	1915.02	1915.06	1983.08
4	1958.08	1983.04	1983.09
5	1915.01	1983.03	1983.10

The drought evaluation technique ranks the 1982-83 drought as one of the most severe at Gwavas in the past 93 years (Fig. 2). The severity of the 1982-83 event is more a function of its extended duration (25 months), exceeded only by the droughts of 1913 (28 months), 1935 (32 months) and 1965 (28 months). Of equal significance was its low intensity, the value being exceeded by 55% of all recorded droughts. The most intense droughts were of short duration — the 1906 and 1925 events lasted only three months. The six most severe droughts were all of low intensity, but of long duration ($\bar{x}$ = 26 months).

If the 1911-16 drought is treated as one extended event, the six highest-ranked droughts fall at an average interval of 20 years (1890-91, 1911-16, 1932-35, 1945-46, 1963-65 and 1981-83), with a 13-28 year range between the starting dates. For Gwavas an average of 12 (± 2) lower-ranked events occurred within each 20-year period.

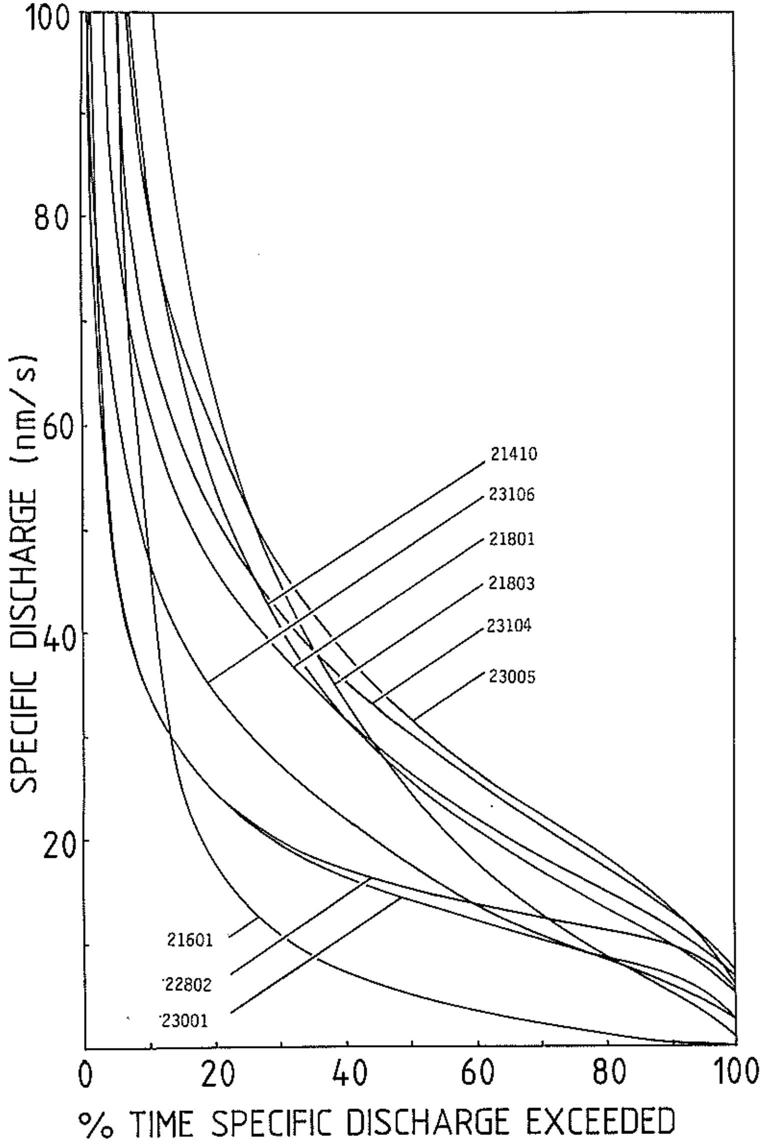


FIG. 3—Flow duration curves for total station records.

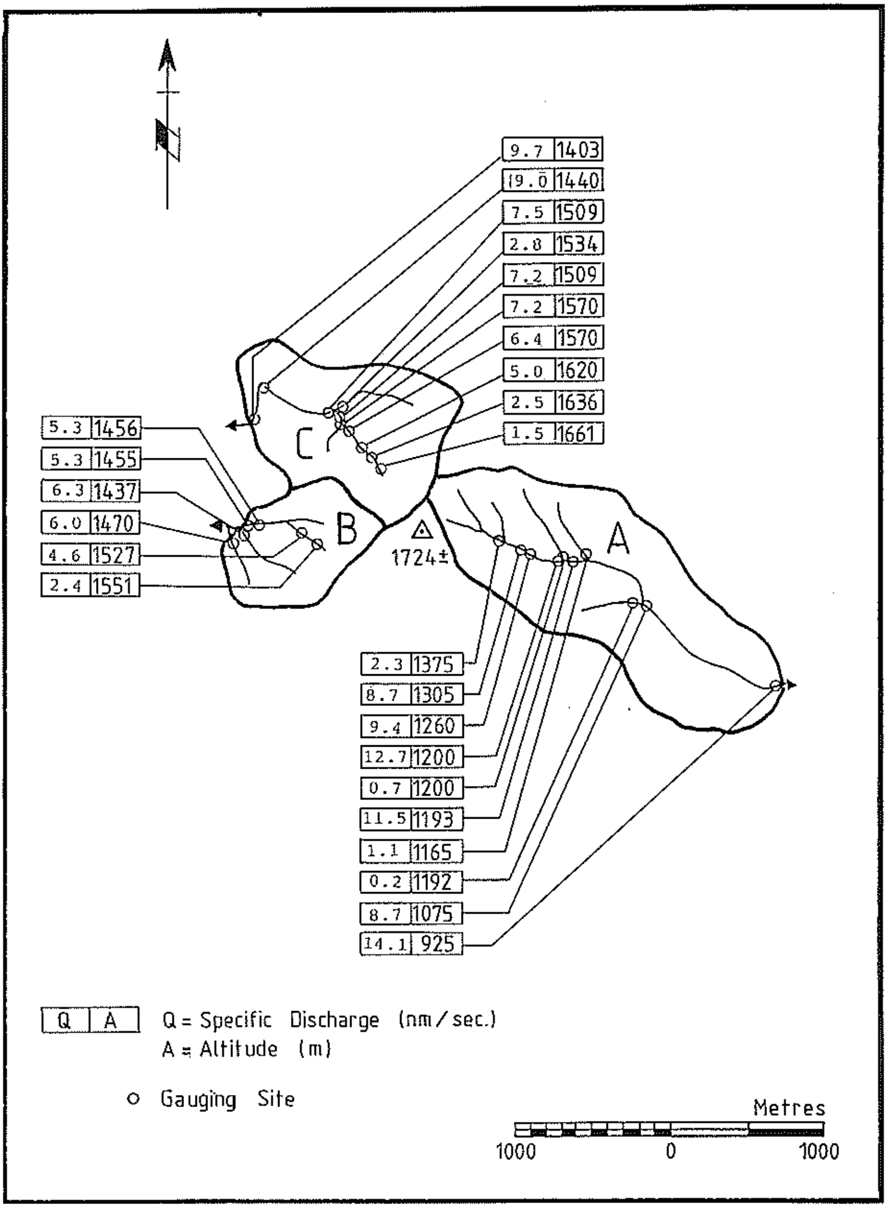


FIG. 4—Gauging data for the Kaweka Range traverse of March 1983, showing specific discharge against altitude for sites on Dons Stream (A), Kiwi Stream (B) and Rocks Ahead Stream (C).

RIVER FLOWS

Flow duration curves (Fig. 3) do not indicate any obvious data irregularities; form and shape are consistent into the low-flow range. Catchments close to the main divide, for example Ngahere and Waihi, produced the most sustained flows, with discharges exceeding 11 nm/s* for 90% of the time. By contrast, lower-elevation coastal catchments like Tahekenui River produced discharges exceeding 11 nm/s only 25% of the time.

Flow variability indices are given in Table 1. Within the study area the least variable river was the Esk (0.23), and the most variable the Tahekenui (0.75). A three-year flow record from a secondary station on Kaumatua Stream, Ruahine Range, gave the lowest regional value of 0.21, while a site on Omakere Stream, 35 km south of Ngaruroro, produced the highest value of 1.11. On the Ngaruroro River variability increased from 0.32 in the upper reaches to 0.43 on the Heretaunga Plains.

The traverse of the Kaweka Range revealed a progressive decline in specific discharge with increasing elevation (Fig. 4). On the east face of the range Dons Stream recorded 2.3 nm/s at 1375 m with the channel dry at 1400 m, while in Boulder Stream, immediately north, specific discharges ranged from 10.6 to 11.6 nm/s between 1359 and 1508 m, with the minimum of 7.4 nm/s at 1554 m. On the west face of the range, specific discharges of 5.3-9.7 nm/s were recorded at 1400-1460 m, with flow visible in stream channels almost to the top of the catchments.

The survey of the headwaters of the Ngaruroro and Mohaka Rivers revealed that, in the main river channels, the proportion of flow generated was related directly to catchment area, where this exceeded 80 km^2 (Fig. 5). Subcatchments located away from main river channels were less consistent in response, being more influenced by local relief and geology; for example sites 23116B, 23124B and 21822 (Fig. 6), aligned southwest-northeast along the west face of the Kaweka Range, recorded disproportionately greater yields than other sites around them. Larger (50-190 km^2) subcatchments east of the Kaweka Range showed a closer yield-to-area relationship, for example, sites 21823 and 21811. A greater proportion of total catchment flow was produced from the more westerly subcatchments.

Plots of instantaneous discharges at secondary and tertiary sites against concurrent discharges at the primary stations (Fig. 7) indicate that the closest relationships were obtained where gaugings were conducted upstream of the primary site. Greater scatter occurred with gauging sites downstream of the primary station; for example, sites 23132 and 23140. At sites recording low discharges from small catchments, as in the Taruarua series (sites 23121/B, 23116/B and 23119/B with areas of 53.0, 1.5 and 0.7 km^2, respectively), scatter increased as catchment size decreased.

Estimated low flows for stated return periods for primary stations are shown in Tables 3 and 4. Gauged minimum flows at all stations had return periods of between 7 and 40 years. The lower reaches of the Tutaekuri River produced a return period of 30 years (Hawke's Bay Catchment Board, pers. comm.), close to the 35 years calculated for Ngahere in its headwaters. The large

* nm/s is the reduced form of the unit litres s^{-1} km^{-2}

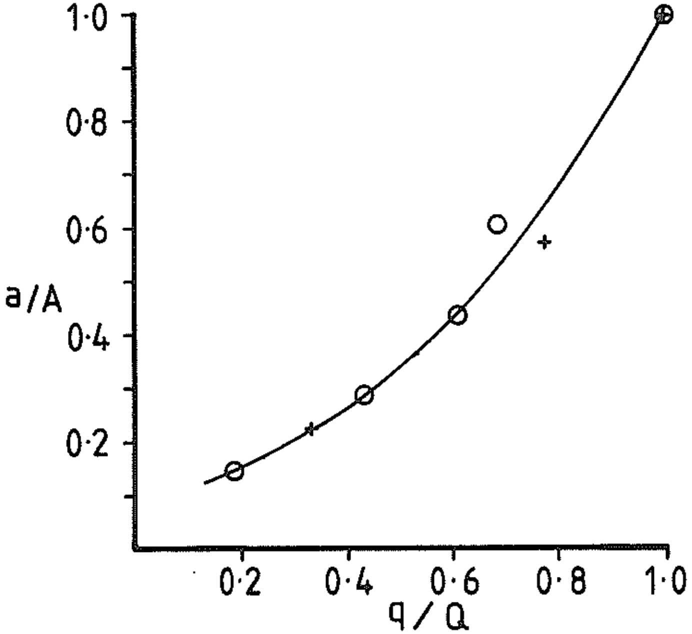


FIG. 5—Yield to area relationship for headwater sites on the Mohaka and Ngaruroro Rivers — (a) is the subcatchment area, (A) the total catchment area for either site 23104 or 21803, (q) is the subcatchment discharge, and (Q) the total catchment discharge for either site 23104 or 21803.
+ Ngaruroro River
o Mohaka River

catchments of the Mohaka and Esk, north of the Tutaekuri, appeared less affected by the drought than the Ngaruroro, immediately south of it.

Recession curves from the stations indicate regional consistency in base flow (Fig. 8), with primary and secondary sites producing k values greater than 0.985. Half lives in excess of 200 days were recorded in areas of sedimentary deposits of the Wanganui series of Pliocene age, irrespective of their location.

Low-flow data from all sites were used to compile a map of instantaneous minimum discharges as of 31 March 1983 (Fig. 9). Although catchments less than 20 km² in the headwaters zone produced useful data from which to derive gradients for the isohyds, the regional mapping was based on larger catchments where perennial streams were less directly influenced by geologic and topographic changes. Specific discharges ranged from 2 to 20 nm/s and gradients were most clearly defined on the Te Waka, Kaweka and Ruahine Ranges. Consistent with rainfall (Fig. 10), relief and geology, the isohyds show pronounced southwest and northwest alignments. Specific discharges for the one-day duration, 10-year return period, low flows, although displaying a similar pattern to that of the instantaneous minimum discharges (Fig. 11),

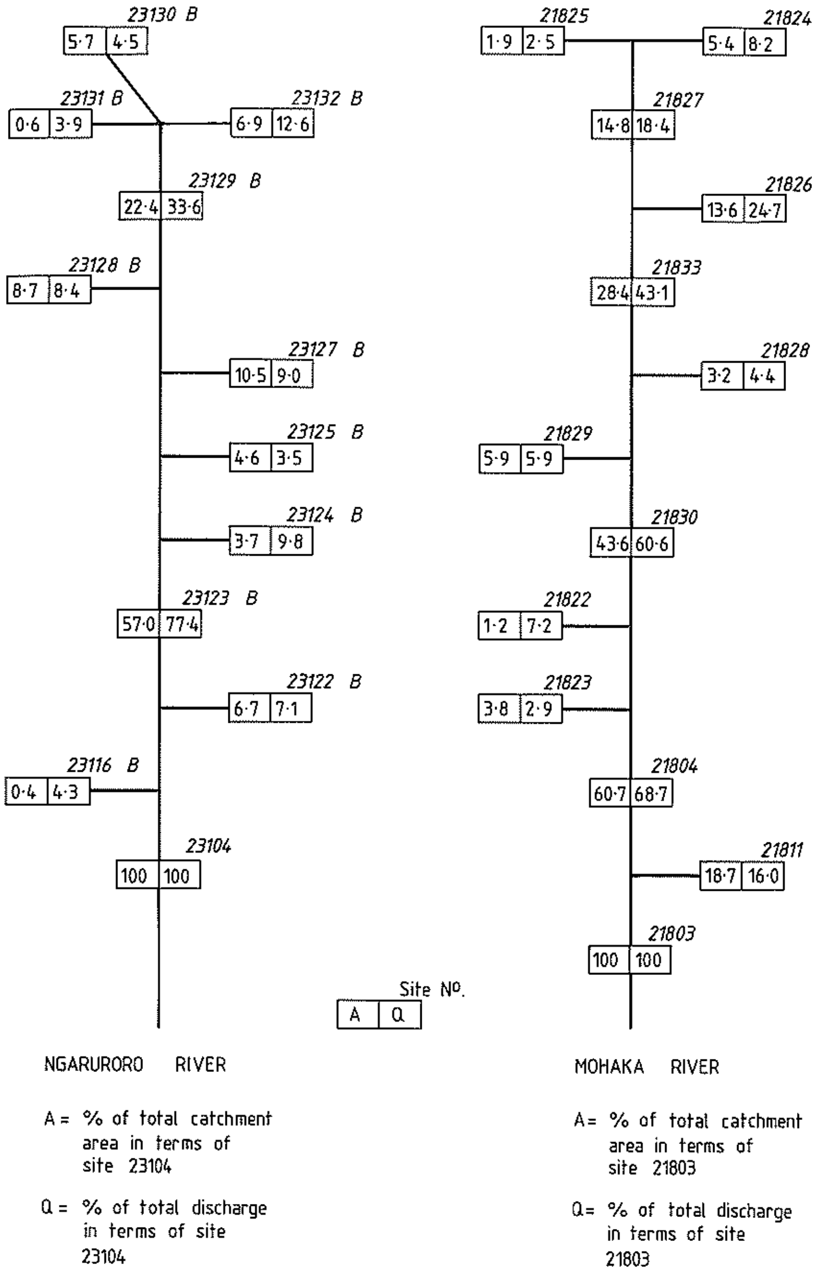


FIG. 6—Yield to area values for headwater sites on the Ngaruroro and Mohaka Rivers relative to sites 23104 and 21803.

TABLE 3—Return periods from flow records at sites on the Tutaekuri, Ngaruroro and Mohaka Rivers. N = number of years in sample.

Ngahere at Ngahere (23005) (N = 15)

Return period (yrs.)	1 day minima (ml/s)	7 day minima (ml/s)	14 day minima (ml/s)	28 day minima (ml/s)
5	1130	1200	1340	1640
10	820	870	960	1160
20	590	620	690	810
50	410	430	480	560

Ngaruroro at Kuripapango (23104) (N = 20)

Return period (yrs.)	1 day minima (ml/s)	7 day minima (ml/s)	14 day minima (ml/s)	28 day minima (ml/s)
5	3150	3270	3400	3740
10	2840	2940	3020	3260
20	2600	2680	2730	2890
50	2390	2450	2490	2570

Mohaka at Glenfalls (21803) (N = 21)

Return period (yrs.)	1 day minima (ml/s)	7 day minima (ml/s)	14 day minima (ml/s)	28 day minima (ml/s)
5	8400	8740	9160	9960
10	7610	7870	8170	8780
20	7050	7240	7450	7910
50	6590	6720	6840	7180

Mohaka at Raupunga (21801) (N = 26)

Return period (yrs.)	1 day minima (ml/s)	7 day minima (ml/s)	14 day minima (ml/s)	28 day minima (ml/s)
5	19080	19850	20590	22140
10	17380	18220	18800	19860
20	16010	16960	17420	18100
50	14790	15860	16230	16570

TABLE 4—Estimated one-day-duration low flows (l/s) for stated return periods, for sites with discontinuous flow records.

River	Site Number	Return period (years) 5	10	20	50
Waihi	21410	229	189	155	126
Tahekenui	21601	2.01	0.77	0.24	0.06
Esk	22802	1870	1724	1608	—
Taruarau	23106	1153	1004	885	779

required adjustment to the isohyds west of the Te Waka and Maungaharuru Ranges.

DISCUSSION

Rainfall data from the two stations establish the 1982-83 drought as one of the most severe in Hawke's Bay over the past 90 years. Cumulative departures from the mean monthly rainfall indicate that dry spells occurred on average at 19 year intervals, while the drought evaluation technique isolated major events at an average interval of 20 years. Periodicity in droughts has been noted elsewhere: Thompson (1973), using ten-year running means, noted a 20-22 year period in the timing of mid-latitude droughts. Tomlinson (1980a; 1980b) determined an 18-21 year oscillation in New Zealand rainfall, and by using filter analysis predicted the onset of a dry period commencing in 1983. Apart from 1982-83 other major droughts have resulted from past El Niño-Southern Oscillation events, the most notable being the "great drought",

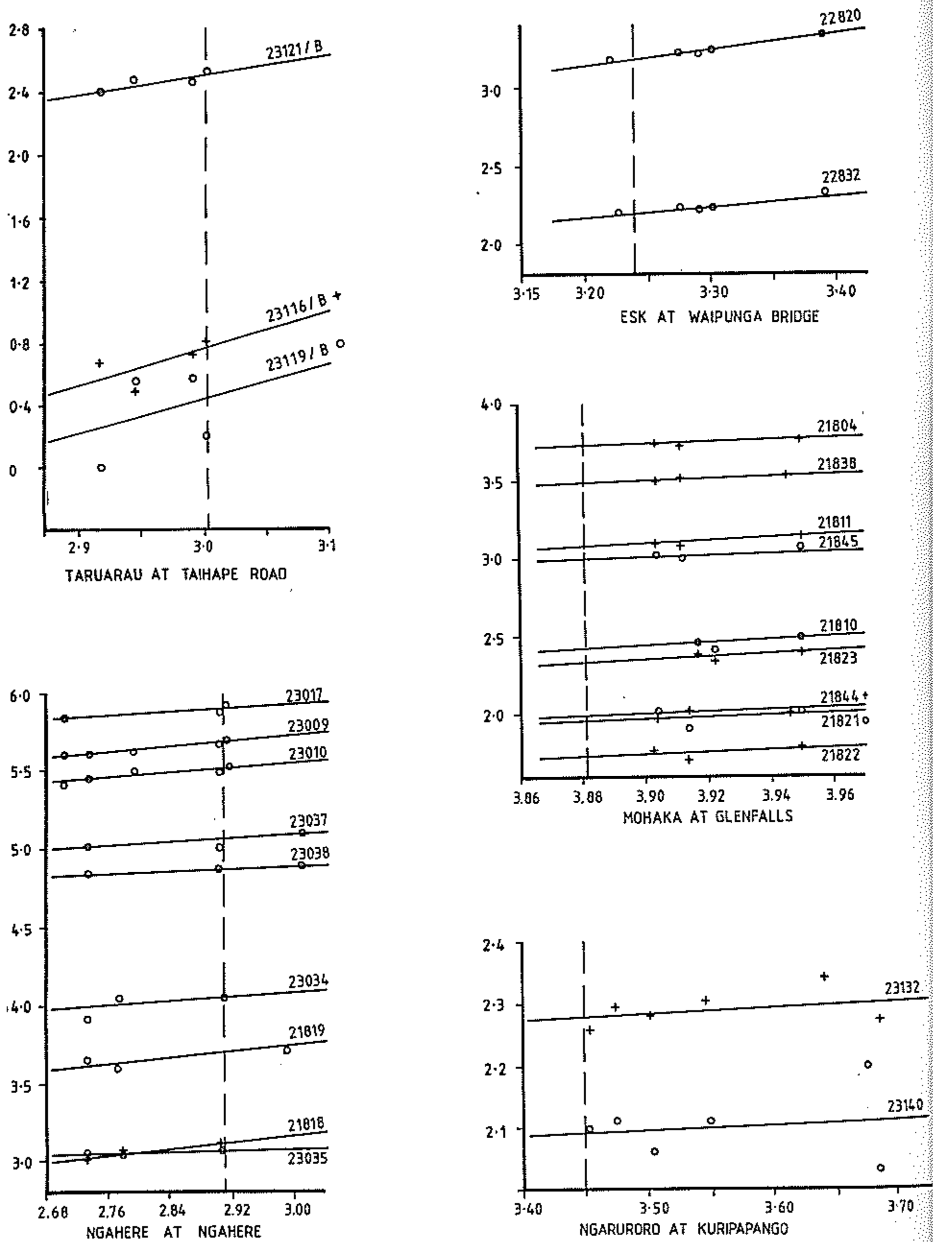
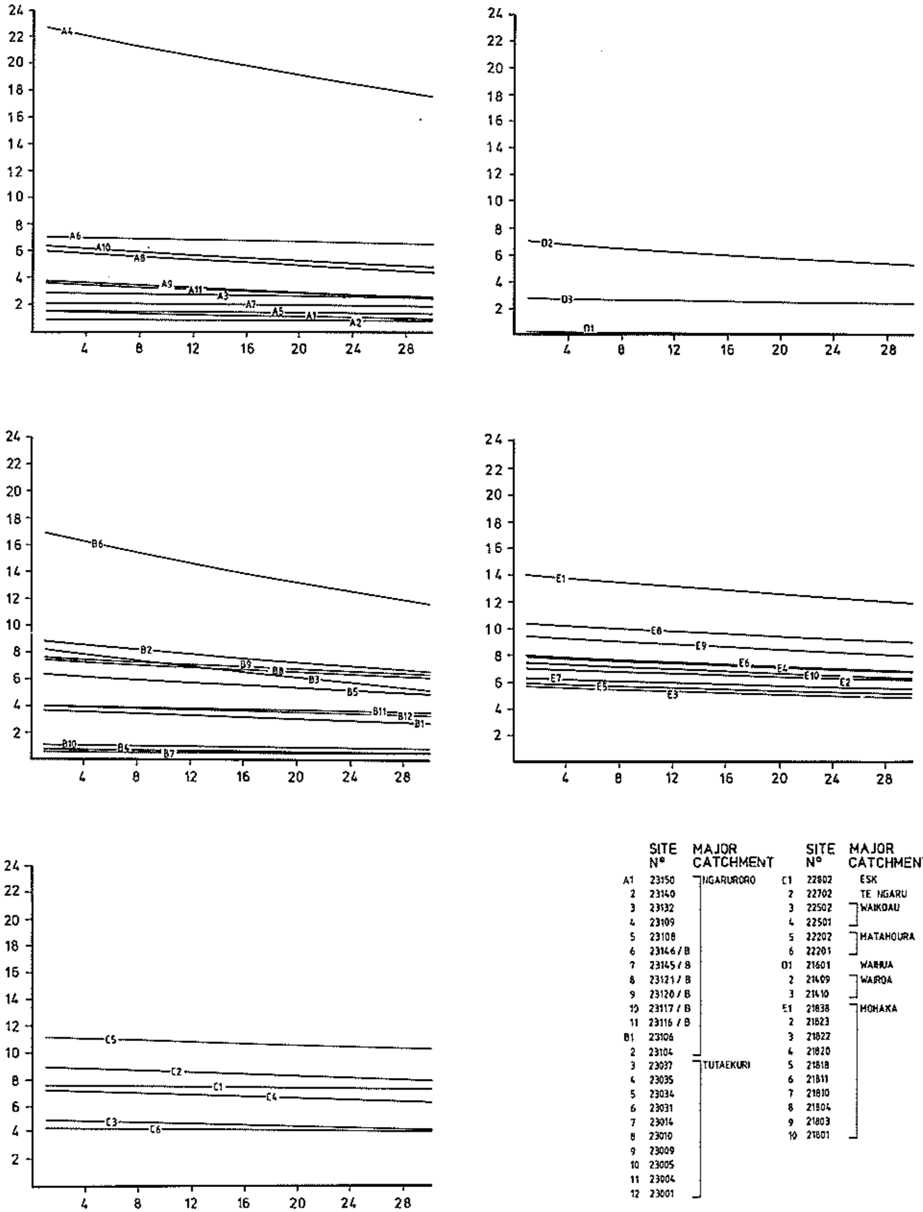


FIG. 7—Flow gaugings from pairs of sites. Simultaneous measurement of $\log_{10}$ (flow l/s) are plotted on the regression line fitted. Vertical line represents the 1-in-10 year discharge at the primary site.



	SITE N°	MAJOR CATCHMENT		SITE N°	MAJOR CATCHMENT
A1	23150	NGARURORO	C1	22802	ESK
2	23140		2	22702	TE NGARU
3	23132		3	22502	WAIKOAU
4	23109		4	22501	
5	23108		5	22202	HATAHOURA
6	23146 / B		6	22201	
7	23145 / B		D1	21601	WAIHUA
8	23121 / B		2	21409	WAIROA
9	23120 / B		3	21410	
10	23117 / B		E1	21838	MOHAKA
11	23116 / B		2	21823	
B1	23106		3	21822	
2	23104		4	21820	
3	23037	TUTAEKURI	5	21818	
4	23035		6	21811	
5	23034		7	21810	
6	23031		8	21804	
7	23014		9	21803	
8	23010		10	21801	
9	23009				
10	23005				
11	23004				
12	23001				

FIG. 8—Recession curves for sites. Specific discharges (nm/s) are presented on the Y axis, with number of days (over a total period of one month) on the X axis.

where 15 of 17 seasonal values between March 1911 and May 1915 recorded negative departures in pressure from the Southern Oscillation Index, and 1972-73 which had a similar effect on rainfall and river flows in the study area (Fig. 12).

Rivers in central Hawke's Bay recorded low specific discharges in the mean to low flow range and substantial variability in flow. The network of primary sites used was adequate for sampling regional variations in geology and climate, although some deficiencies were apparent in hill country in the middle reaches of the Tutaekuri and Ngaruroro Rivers. Within this zone, mapping was based on data from secondary and tertiary sites located on catchments of moderate (less than 350 km^2) size underlain by sedimentary rock.

The regional map revealed the following four zones of highest base flow:

1) The headwaters of the Mohaka and Ngaruroro Rivers recorded maximum specific discharges of 16.7 and 12.3 nm/s, respectively. Within this zone, catchment area was the most significant factor regulating base flow, however differences in geology and location produced some variations. More westerly valleys are mantled in volcanic material to considerable depth, some being traversed by the Ngamatea fault. As a result, their storage potential is greater but the hydrological boundaries are less clearly defined than in catchments further east. Also the moderate to high (600-1600 m) elevation of this area results in more frequent exposure to westerly rain-bearing winds than in those catchments further east. Gaugings from the Waipunga River demonstrated a marked flow gradient towards the headwaters, with recorded specific discharges agreeing with Pittams (pers, comm.) estimate of 15-30 nm/s for a five-year return period low flow in Hinemaiaia Stream and Waitahanui River, immediately west.
2) The headwaters of the Tutaekuri River produced high specific discharges along the base of the east face of the Kaweka Range. A decline in specific discharge above this was considered to be structurally related to permeability changes in the rock undermass, lithological variations, and the occurrence of a complex mosaic of faultlines associated with the Kaweka fault. As a result, for mapping purposes, the range was considered a single, large, uniformly-permeable unit and flows were partitioned with elevation.
3) The northern Ruahine and Wakarara Ranges produced high base flows in streams draining north to the Ngaruroro River. An automatic rain gauge on the range crest at Parks Peak recorded 55 mm for March 1983 against 32 mm at Ngahere, with 11 days with at least 1 mm of rain, compared to six days at Ngahere. The Ngahere gauge caught 6.3% less rainfall than Parks Peak for the 1982-83 drought, which indicates some limited augmentation of flow by rainfall in the area. Rivers draining north traverse an area of thick, late-Pliocene sedimentary rock (Kingma, 1957) in the Ohara depression, and storage within these deposits may also have sustained high base flows. Results from this area are in accordance with Grant's (1973) survey of the 1972-73 event on the Tukituki River, where rivers draining the eastern face of the Ruahine Range recorded specific discharges of 23.6 nm/s (Waipawa), 18.0 nm/s (Makaroro) and 17.5 nm/s (Tukituki), the return period estimated as being in excess of ten years.
4) In the headwaters of the Esk River variations in discharge between catchments resulted from variations in the composition, strike and dip

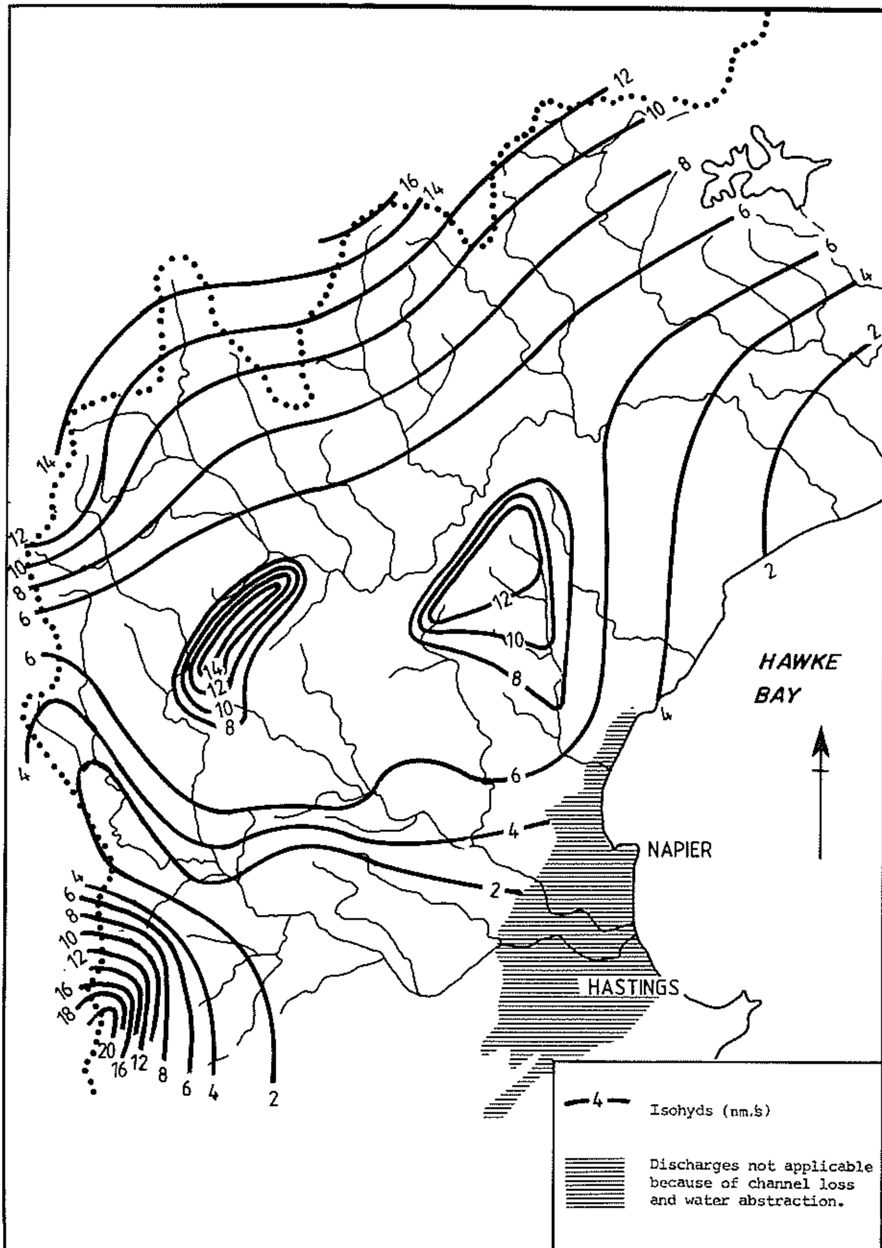


FIG. 9—Minimum flows for 31 March 1983 for the 1982-83 drought.

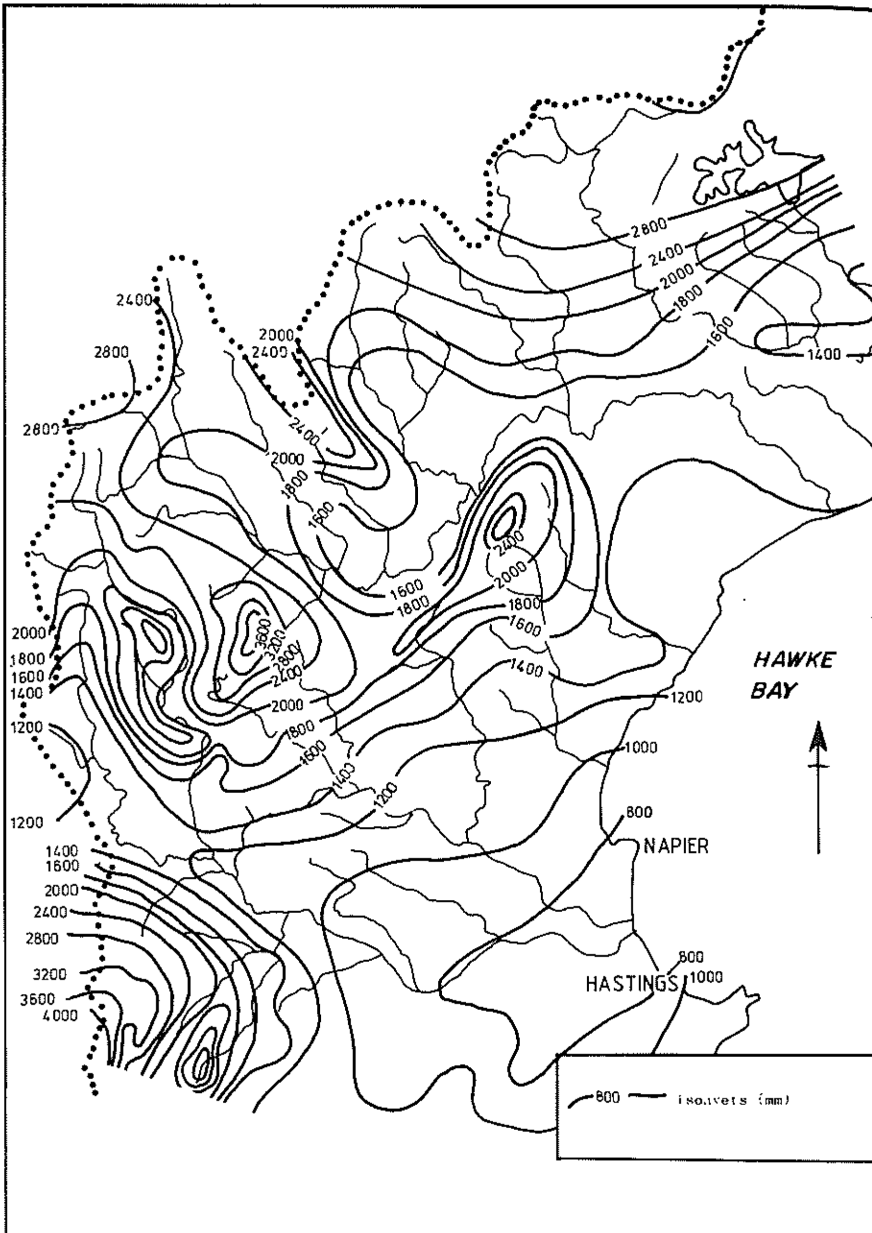


FIG. 10—Provisional normal rainfall isohyets for the period 1941-70 (Grant, pers. comm.)

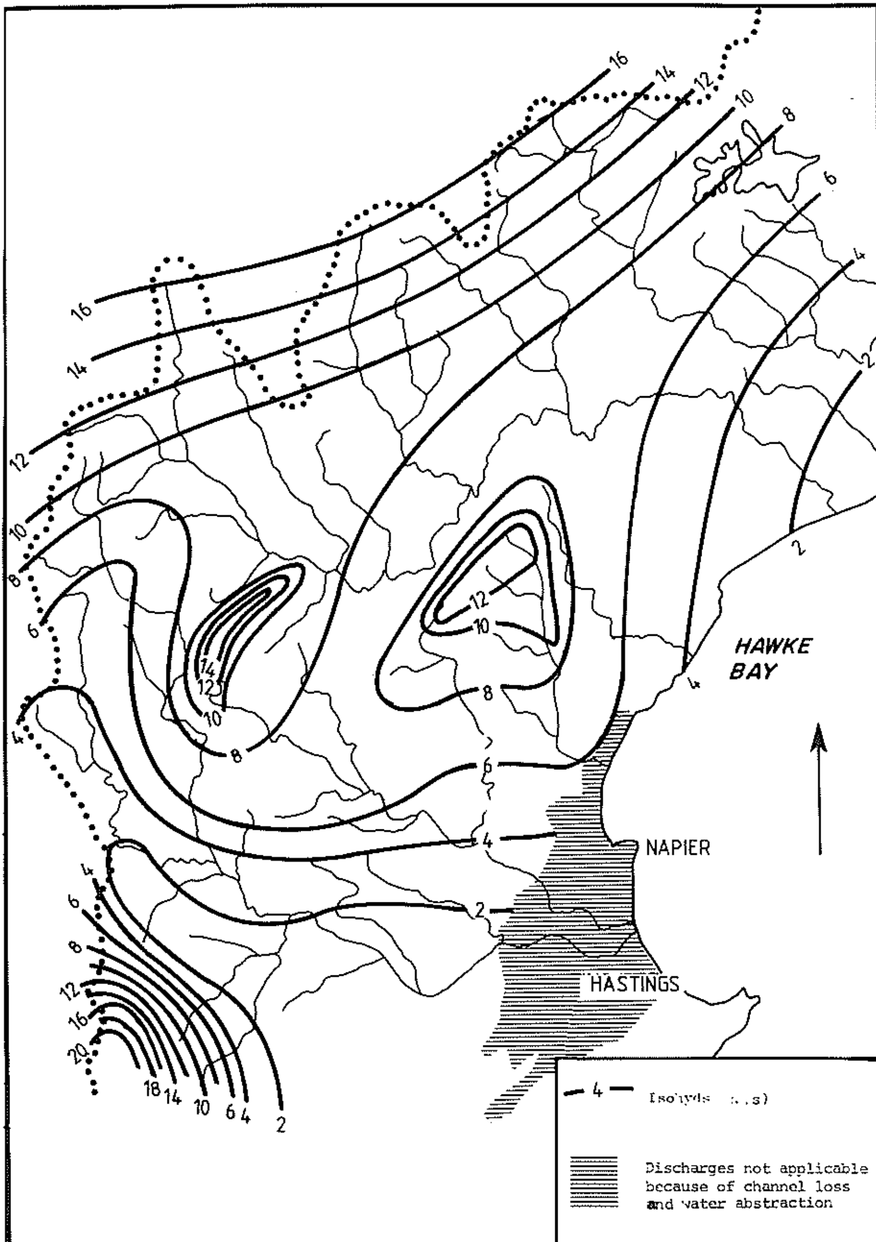


FIG. 11—Specific discharges nm/s for one-day-duration, 10-year return period low flows.

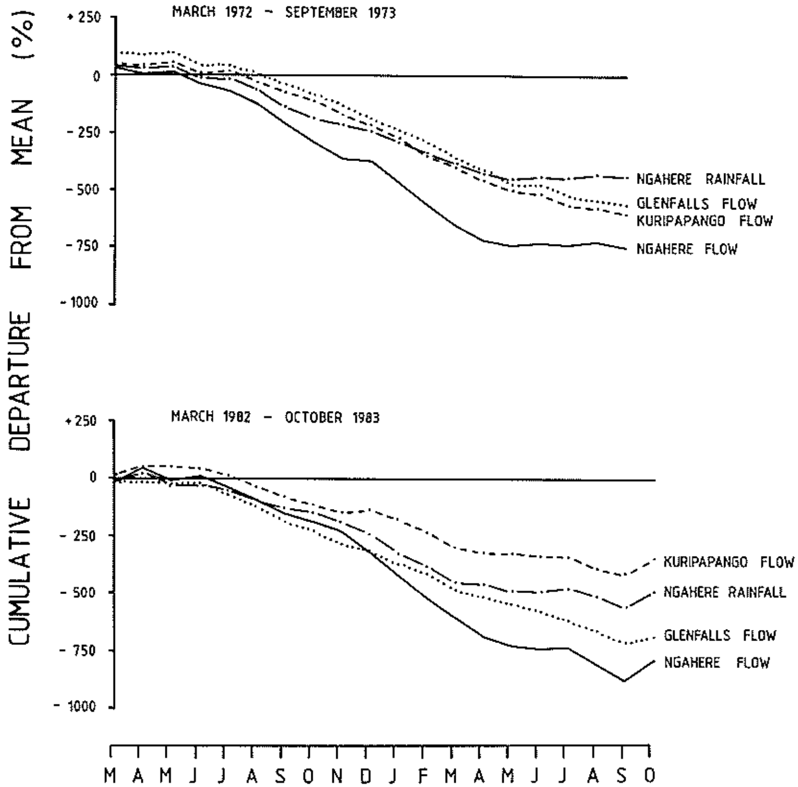


FIG. 12—Cumulative departures from the mean of rainfall and flow for the 1972-73 and 1982-83 droughts.

of the sedimentary rock sequence. Movement of water across topographical boundaries was apparent, the Ohakura Stream recorded a specific discharge of 8.3 nm/s from a catchment area of 14.7 km^2, while the main tributary of the Esk alongside recorded 22.1 nm/s from 13.6 km^2. Sedimentary rocks of similar lithology extended from the crest of the Maungaharuru Range at 1095 m down to 400 m on the east face.

Areas of lowest (less than 1 nm/s) base flow were:

1) Hill areas southwest and northeast of the mouth of the Mohaka River, where low elevation and low-permeability rocks (mudstones and siltstones) yielded barely measurable flows, in contrast to high flows from the adjacent Maungaharuru Range. Grant (1971) examined low flows from 35 small (mean area 10-32 km^2) catchments south of the Ngaruroro River. He found a significant difference in the recession coefficients between more porous limestone (k = 0.975) and less permeable siltstone (k = 0.924), a decrease in the k value being coupled with an increase in flow variability.

2) Hill country south and west of the Heretaunga Plains, where flow was lost by deep percolation through river channel gravels and by abstraction for stock water.

Throughout the remainder of the region the isohyds displayed an orderly progression consistent with topography, geology and climate, a feature also reflected in the ten-year return period low flows.

The minimum specific discharges for rivers and streams in the region were consistent with those recorded elsewhere. Pittams (pers. comm.) obtained higher values (in excess of 21 nm/s) for five-year return period flows for streams draining from central North Island volcanoes. McKerchar and Dymond (1981) also recorded high values (7-51 nm/s) for a ten-year return period flow for streams draining Mount Egmont. Freestone (Ministry of Works and Development, Wellington, pers. comm.) and Drost (1971) found minimum flows exceeding 25 nm/s were not uncommon on volcanic deposits of the central North Island. Beyond the volcanic zone, Pittams (pers. comm.) recorded discharges of 5-11 nm/s for a five-year return period for greywacke terrain east of Taupo, consistent with values of less than 8 nm/s estimated by Waugh (1970) for several hydrological regions of Northland. On the Ruataniwha Plains, east of the Ruahine Range, Grant (1973) found a decline in flows to below 12 nm/s, decreasing to less than 4 nm/s at Waipawa and 2.3 nm/s at Patangata. Smaller tributaries in the central catchment yielded less than 7 nm/s with most between 0.5 and 4 nm/s. Similar minimum specific discharges have been recorded on major rivers in the South Island: the Otago Catchment Board (1976) obtained monthly mean values exceeding 15 nm/s for the western Clutha catchment, declining to 0-0.5 nm/s for Central Otago for a return period of ten years.

High recession constants (greater than 0.990) were a feature of most sites in this study. Grant (1973) obtained approximate k values of 0.984-1.000 for sites on the Tukituki River, with most subcatchments centring on 0.990. The value for the Esk River (0.998) is, however, considerably higher than the value of 0.988 calculated by Grant (1974). Waugh (1970) obtained k values of 0.984-0.997 for Northland greywackes and Drost (1971) estimated values greater than 0.990 for Taupo pumice and rhyolite deposits in the central North Island. Freestone (pers. comm.) obtained higher values in the volcanic zone, but found rivers draining into the Bay of Plenty had lower k values of 0.977-0.984 during the 1969 drought.

CONCLUSIONS

The 1982-83 drought had a significant and sustained effect on rainfall and river flows within Hawke's Bay.

Low-flow gaugings confirmed that the headwaters of the major rivers provided the greatest base flow, with highest yield from the most westerly catchments. Within the headwaters, subcatchment discharges reflected catchment area, except where faulting or pervious limestone deposits redirected drainage. Areas of lowest specific discharge occurred on low elevation river plains and hill country underlain by less permeable rock.

Recession rates for all sites were regionally homogeneous and k values for moderate to large catchments all exceeded 0.980. Half lives ranged from 45-474 days.

Low flows for a one-in-ten-year return period reflected similar regional trends to the topographic, geological and rainfall maps, the isohyds following overall southwest or northwest alignments, except where distorted by elevated more-resistant terrain.

Specific discharges and k values corresponded well with those from low flow studies in the Northland, Taupo and Taranaki regions.

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