WATER TEMPERATURES OF THE NGARURORO RIVER AT THREE STATIONS

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ABSTRACT

From 349 random measurements of water temperature during 1961-76, at Kuripapango, Whanawhana and Fernhill on the Ngaruroro River, it was found that both mean monthly and mean maximum monthly water temperatures at each station followed an annual cycle with respective amplitudes of about 12°C and 15°C and they correlated highly with mean monthly air temperature at Napier. The number of months during which stated water temperatures may be exceeded at each station increased in the downstream direction.

A 5-month thermographic record of water temperature supplemented random measurements to define the high temperature limits at Fernhill in relation to flow rates. Highest water temperatures are likely to occur in the 10–20m³/s flow range and the indication was that below 10m³/s the water temperatures decrease rather than increase. This phenomenon is probably the effect of channel underflows and is reinforced during recession by base flow.

A temperature duration pattern and models for the prediction of daily maximum and daily minimum water temperatures at Fernhill are given.

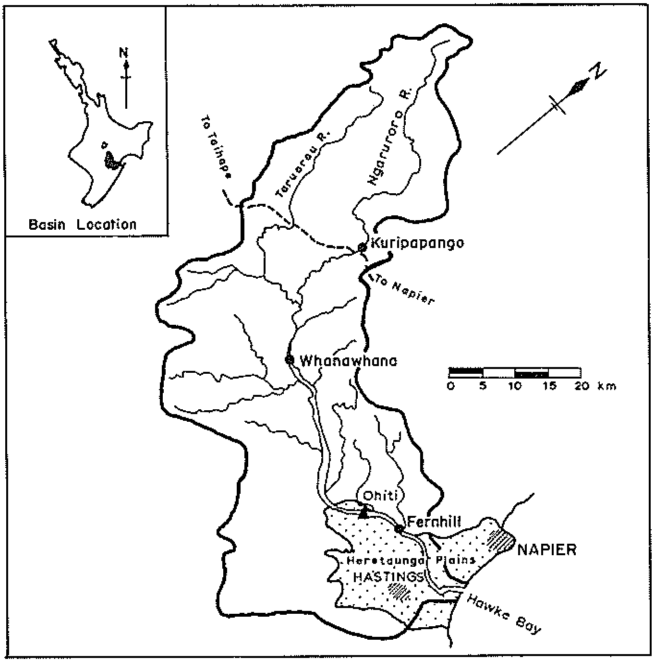

FIG.1 — Ngaruroro River basin and flow measurement stations.

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NGARURORO RIVER

The Ngaruroro River, which is 164 km long and has a drainage area of 2512 km^2, flows into Hawke Bay on the east coast of the North Island (Fig. 1). The three flow measurement stations concerned are Kuripapango, Whanawhana and Fernhill. From the river head these are respectively 65 km, 104 km and 146 km (Fig. 1).

For much of the distance downstream to Kuripapango the river is in a greywacke rock gorge and channel width is seldom greater than 35m. From Kuripapango to Whanawhana the river continues to be confined in a deep gorge but channel width progressively widens to around 100m. Immediately downstream of Whanawhana, at a fault line, softer siltstones and sandstones commence and channel width abruptly increases to about 320 m. Concurrently, the upstream single-thread channel changes to a braided pattern which tends to dominate downstream to Fernhill; some channel sections being as wide as 1.3 km.

A typical summer water yield pattern for the basin was presented by Grant (1965) who at the same time demonstrated that the Ngaruroro River constitutes the major source of recharge for the groundwater system of the Heretaunga Plains. Fernhill is downstream of the recharge zones.

MEASUREMENT STATIONS

At Kuripapango and Whanawhana a manned cableway is used for all flow measurements except the very low flows. At Fernhill the river is spanned by a concrete bridge from which flood measurements are made; low flow gaugings are done by wading. Each station is equipped with an automatic water level recorder.

Station altitudes are: Kuripapango 488 m, Whanawhana 183 m and Fernhill 13 m. Respective drainage areas are: 370 km^2, 1093 km^2 and 1927 km^2.

RANDOM WATER TEMPERATURES

When a flow measurement is carried out it is standard practice to make a water temperature measurement. This may be done near a bank when wading, or at any point in the water section from a bridge or cableway. In the latter two cases a dip-thermometer is used which collects a water sample surrounding the thermometer. Thermometers used are of different non-standard types and seldom has one been checked against a standard.

Water temperature measurements, as for flow gaugings, were carried out at any time during a working day, the most common period being from around 0900 hours to 1600 hours. Consequently for a particular day a measured water temperature may have been well below the daily maximum, or even mean value. Furthermore water temperature may vary with rate of flow.

The measurement period was 1961–76 and the flow ranges were: Kuripapango 2.83–106 m^3/s, Whanawhana 6.23–618 m^3/s and Fernhill 1.66–908 m^3/s.

Temperature Patterns

For Kuripapango, Whanawhana and Fernhill, water temperature values were plotted against time of year (Figs 2, 3, 4). Monthly mean values were calculated and plotted but because of inadequate sample numbers they are first approximations only, although they do demonstrate a marked seasonal pattern at each site. These monthly values correlated highly with mean monthly air temperatures at Napier (for 1961-73) as follows:

Kuripapango, $r = 0.976$*)
Whanawhana, $r = 0.977$) $p < 0.001$
Fernhill, $r = 0.987$)

Smoothed curves were then fitted to the plotted mean monthly points giving due consideration to the distribution of samples in each month. From the curves mean monthly values were graphically estimated (Table 1).

TABLE 1 – Approximate mean monthly water temperatures (°C)

	Kuripapango	*Whanawhana*	*Fernhill*
Jan	16.8	18.9	20.3
Feb	16.2	18.5	20.0
Mar	14.7	16.9	18.4
Apr	12.3	13.8	15.8
May	9.2	10.5	12.1
Jun	5.0	7.3	8.8
Jul	4.3	6.3	8.1
Aug	5.5	7.9	9.8
Sep	8.7	10.5	12.3
Oct	12.0	13.1	14.7
Nov	14.3	15.7	17.0
Dec	16.0	17.7	18.9
Average	11.3	13.1	14.7
Highest	16.8	18.9	20.3
Lowest	4.3	6.3	8.1
Range	12.5	12.6	12.2

The tabulated values (Y) correlated even more highly with Napier mean monthly air temperatures (X). Correlation coefficients and regression equations with standard errors (S.E.) were:

Kuripapango: $r = 0.990$ ($p<0.001$); $Y = 1.21X - 6.0$, S.E. = 0.6
Whanawhana: $r = 0.998$ ($p<0.001$); $Y = 1.21X - 4.0$, S.E. = 0.3
Fernhill: $r = 0.998$ ($p<0.001$); $Y = 1.17X - 1.9$, S.E. = 0.3

For practical purposes patterns of high water temperatures are probably of greater value than either the mean or low values. Accordingly on Fig. 2, 3 and 4 envelope curves, which are probably conservatively located, define the approximate high temperature limits, referred to as temperature maxima. From these curves monthly mean maximum values were graphically extracted (Table 2).

These values correlated with Napier mean monthly air temperatures (X) as follows:

* Three decimal figures shown for comparisons only.

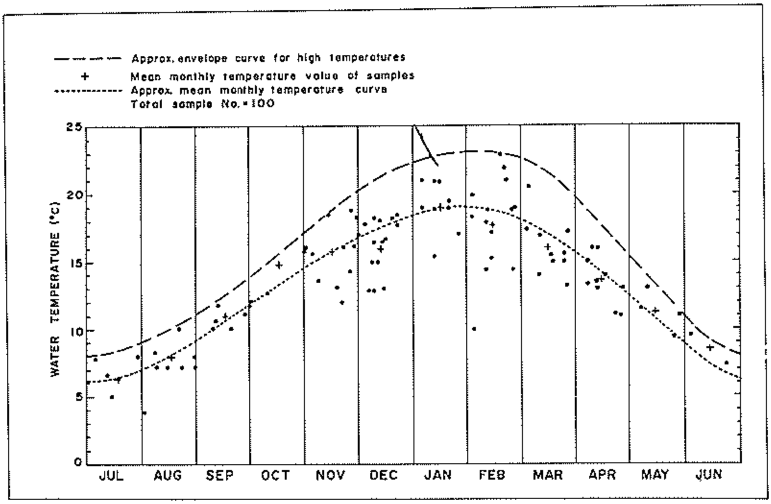

FIG.2 – Monthly water temperature patterns of the Ngaruroro River at Kuripapango.

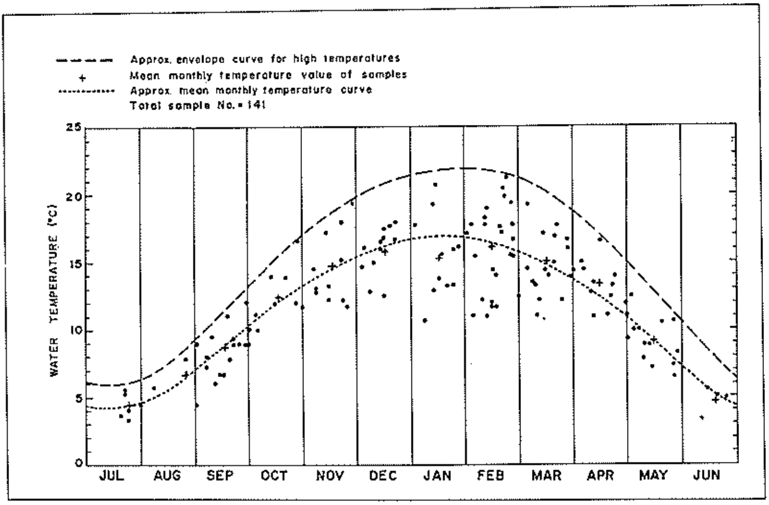

FIG.3 – Monthly water temperature patterns of the Ngaruroro River at Whanawhana.

TABLE 2 – Approximate mean maximum monthly water temperature (°C)

	Kuripapango	*Whanawhana*	*Fernhill*
Jan	21.6	22.8	24.9
Feb	21.6	22.8	24.9
Mar	20.2	21.6	23.4
Apr	17.2	17.6	20.2
May	12.8	13.2	15.7
Jun	8.5	9.0	11.6
Jul	6.0	8.3	10.4
Aug	7.6	10.0	13.0
Sep	11.4	12.6	16.2
Oct	15.5	15.6	19.3
Nov	18.7	18.8	21.9
Dec	20.6	21.6	23.8
Average	15.1	16.2	18.8
Highest	21.6	22.8	24.9
Lowest	6.0	8.3	10.4
Range	15.6	14.5	14.5

Kuripapango: $r = 0.989$ $(p<0.001)$; $Y = 1.51X - 6.3$, S.E. = 0.8
Whanawhana: $r = 0.998$ $(p<0.001)$; $Y = 1.45X - 4.5$, S.E. = 0.3
Fernhill: $r = 0.994$ $(p<0.001)$; $Y = 1.39X - 1.0$, S.E. = 0.6

The above relations demonstrate the high dependence of river water temperature on solar energy. They also strengthen credibility in the water temperature patterns presented.

The randomness of the data does not permit estimates of the duration of water temperature above a given value. Such durations for any month, or for a year, will vary greatly in response to flow and insolation characteristics. Furthermore the data were collected during daylight hours when water temperatures are higher than at night. However, at least to compare the three stations, it is reasonable to list the number of months during which a stated water temperature may be exceeded. Such values (Table 3) were derived from the limit curves for high temperatures.

Discussion

The average rate of increase of mean monthly water temperature (Table 1) was 0.05°C/km from Kuripapango to Whanawhana, and 0.04°C/km from Whanawhana to Fernhill. Respective average rates of increase of mean maximum monthly temperature (Table 2) were 0.03°C/km and 0.06°C/km. Comparison for the two channel segments of channel type and climate with its decreasing average cloud cover and increasing average air temperature towards the east (Fig. 1), suggests that average rates of increase of river water temperature should be greater from Whanawhana to Fernhill. This is indicated for mean maximum water temperatures only, but it is possible that even this ratio (.06 : .03) is lower than could be theoretically expected, as is the rate ratio for mean monthly values (.04 : .05).

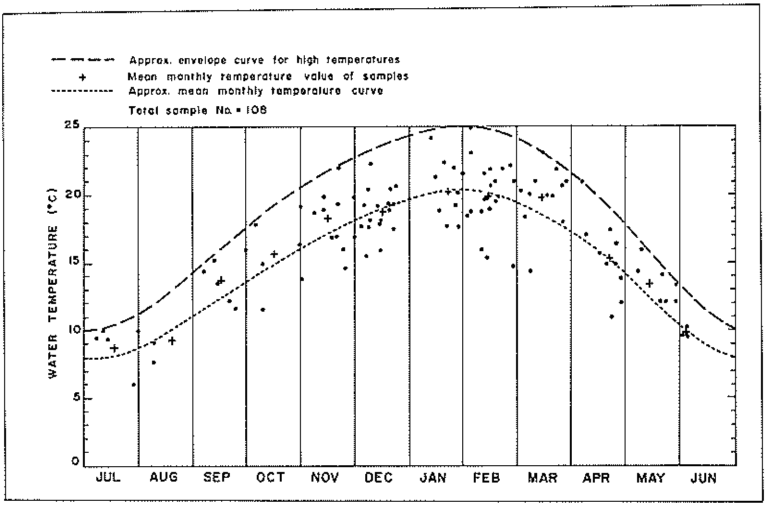

FIG.4 — Monthly water temperature patterns of the Ngaruroro River at Fernhill.

From Whanawhana to Fernhill the wide braided bed results in much water moving from channels and passing through gravel shoals as underflow, subsequently to seep into an open channel where it is much cooler than the main water in the channel. It is hypothesised that the underflow process buffers the insolation effects and consequently produces much lower water temperatures at Fernill than are theoretically possible.

FERNHILL TEMPERATURES

Fernhill is down stream of present and proposed major water extraction points and of the recharge zones for the groundwater system of the Heretaunga Plains (Grant, 1965). Recorded water temperatures equal to and exceeding 20.0°C and their related flow rates, during 1963-76, are given in Appendix 1. These show no useful correlation between water temperature and flow rate (Fig.5).

During December 1976 – April 1977 a continuous record of water temperature was obtained using a remote sensing thermograph at Ohiti 6.5 km up stream of Fernhill. Comparisons of available temperature data for the two sites during the period showed that overall their water temperatures were in close agreement. Therefore for practical purposes the Ohiti record applies to Fernhill. The highest thermographic water temperature/flow relations are also shown on Fig.5 and a curve approximately defines the high temperature limits in relation to flow rates. The limit curve indicates that the highest water temperatures are likely to occur in the 10–20m^3/s flow range. The striking feature is the indication that below about 10m^3/s the water temperatures do not increase but rather decrease. From the random data the two recorded flows less than 2m^3/s and their temperatures were included. It could be argued that the sample number in the low flow range is inadequate; but not one outlying relation has been recorded. Of 12 measurements made when flow equalled, or was less than, 5.0m^3/s (recorded in 1963, 1964, 1968, 1972, 1973) for only 9 occasions did water temperature exceed 18°C; and for 7 of these occasions measurements were done during the probable maximum water temperature period of 1300-1700 hrs. For the other 3 measurements the water temperatures were only 17°C (4.98m^3/s), 14.8°C (2.04m^3/s) and 14.5°C (2.71m^3/s). More samples may alter the shape of the temperature curve and extend its limits but they would be unlikely to change the broad pattern of decreasing temperature with decreasing flow rate less than 10–15m^3/s.

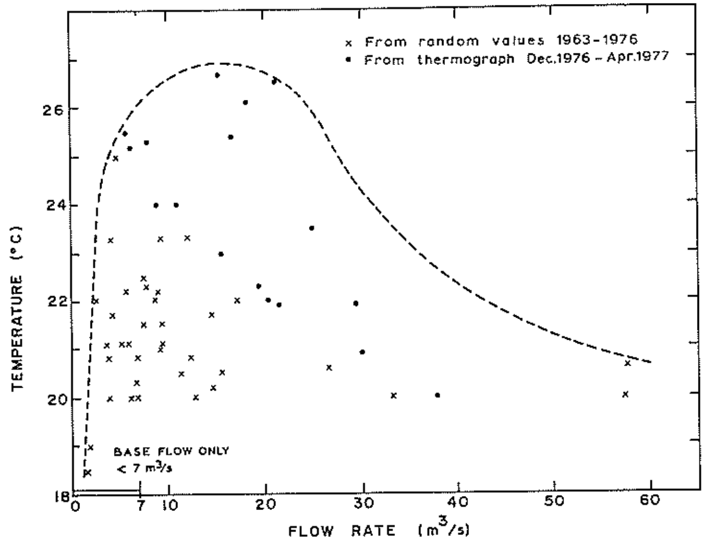

FIG.5 – Fernhill water temperatures, mainly ≥ 20°C, and related flow rates. The curve approximately defines the high temperature limits.

Below about 7m^3/s the river flow consists only of base flow and because of its deep source, base flow from the Ngaruroro Basin could be expected to enter the channels with lower temperatures than rapid runoff. Moreover as flow rate recedes an increasing proportion of the total flow in the Ngaruroro channel can be expected to travel as underflow. As already mentioned the underflow process would be very effective from Whanawhana to Fernhill. Therefore it is hypothesised that the broad pattern of high temperature limits for the lower flows (Fig.5) results largely from the increasing influence of the underflow process as flow rates recede. This effect may be strengthened during recession in the base flow regime.

Thermographic Record

The thermographic record, which was for a snow free period in the Ngaruroro Basin, was related to a nearby short-term thermographic record of air temperature. It was found that daily minimum water temperature usually occurred from 1 to 2 hours after daily minimum air temperature and daily maximum water temperature occurred from 2 to 4 hours after the air maximum. Most daily minimum water temperatures occurred between 0600 and 0800 hours and the majority of daily maximum water temperatures occurred from 1300 to 1700 hours.

The extreme diurnal temperature range (daily maximum minus daily minimum) for each month was: Dec, 10.1°C; Jan, 10.8°C; Feb, 9.9°C; Mar, 9.0°C and Apr, 7.2°C. The recorded extreme minimum water temperature was 9.2°C in April and the extreme maximum was 26.7°C in January. Fig.4 shows a January maximum of about 25°C. This comparison illustrates the already suggested conservatism of the random temperature values.

Daily maximum and minimum water temperatures were separately regressed on Napier daily maximum and minimum air temperatures over three consecutive days. From the stepwise regressions the most reliable prediction model (in °C) for Fernhill daily maximum water temperature was:

Max WT(d) = 0.31 Max AT(d) + 0.55 Max AT(d-1) + 1.2 (S.E. = 1.7)
($R = 0.84$, significance level $P < 0.001$)

Where Max AT(d) is the maximum air temperature for the date of maximum water temperature and Max AT(d-1) is the maximum air temperature for the previous day.

Similarly the best prediction model (in °C) for Fernhill daily minimum water temperature was:

Min WT(d) = 0.36 Min AT(d) + 10.2 (S.E. = 1.3)
($R = 0.71$, significance level $P < 0.001$)

Where Min AT(d) is the minimum air temperature for the date of minimum water temperature.

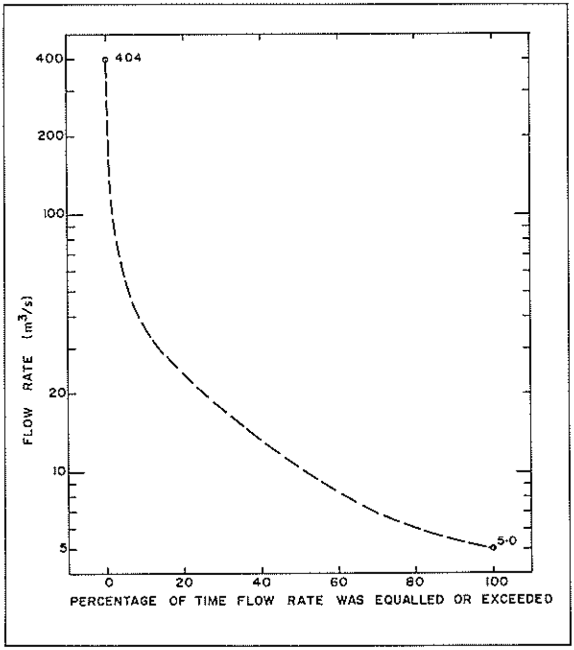

FIG.6 — Fernhill flow duration pattern during Dec 1976–Apr 1977.

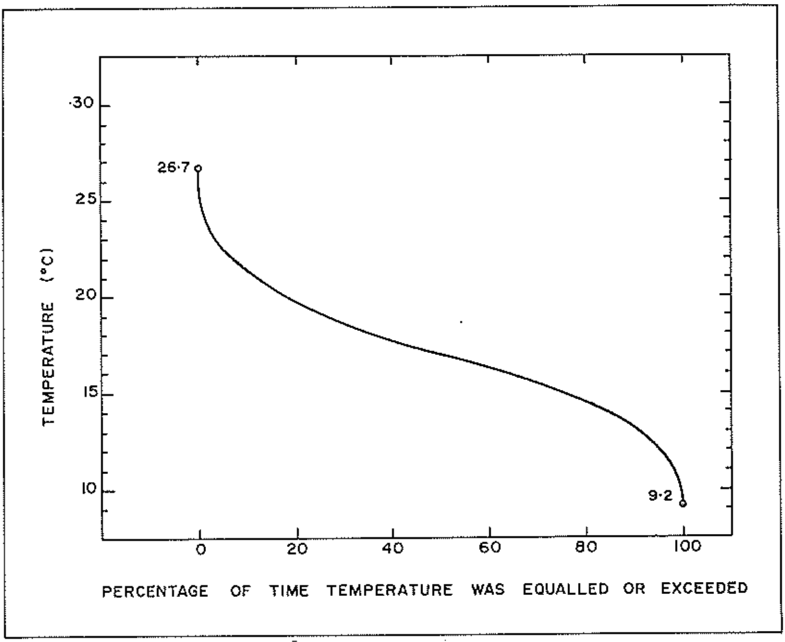

FIG.7 – Fernhill water temperature duration pattern during Dec 1976–Apr 1977.

The average air temperature at Napier was the same as normal (1941-70) for the thermographic record period. The Fernhill flow duration pattern for the period is given (Fig.6). From 2-hourly values of water temperature a temperature duration curve was derived (Fig.7). This duration pattern would be directly applicable to other summer-autumn periods which have closely similar temperature and flow regimes. For warm seasons which have markedly different temperature and/or flow regimes, it should be possible, for practical purposes, to derive a temperature duration curve by using the prediction models and the pattern of Fig.5 to adjust the pattern of Fig.7.

TABLE 3 – No. of months during which the stated water temperatures may be exceeded

	14	*16*	*18*	*20*	*22*	*24 (°C)*
Kuripapango	7.2	6.1	5.0	3.0	0	0
Whanawhana	7.3	6.3	5.2	4.2	2.6	0
Fernhill	9.1	8.1	6.9	5.8	4.5	2.7

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REFERENCE

Grant, P. J. 1965: The ground waters of the Heretaunga Plains – the Ngaruroro River as a major recharge source. *Journal of Hydrology (N.Z.) Vol 4* (2): 65-80.

APPENDIX 1 – Fernhill water temperatures, $\geq$ 20.0°C, and related flow rates

DATE	*WATER TEMP (°C)*	*FLOW RATE (m^3/s)*
27.2.63	21.1	9.68
26.3.63	20.8	3.96
5.2.64	25.0	5.04
13.2.64	21.7	4.39
18.2.64	21.1	5.43
31.1.67	21.7	14.80
19.12.67	20.6	26.88
5.2.68	23.3	9.54
15.3.68	23.3	4.30
29.3.68	21.1	3.90
12.11.69	20.0	7.05
21.11.69	22.2	5.91
28.1.70	20.3	6.90
10.3.70	21.1	5.97
8.12.70	22.5	7.56
7.12.71	20.6	57.79
13.1.72	23.3	12.17
20.1.72	21.5	7.53
26.1.72	22.2	9.28
16.2.72	20.8	7.02
21.2.72	20.0	6.37
17.3.72	20.0	33.49
23.3.72	22.0	17.33
7.4.72	21.0	9.39
14.2.73	20.0	4.07
16.2.73	22.0	2.94
21.11.73	20.5	15.84
15.1.74	21.5	9.63
29.11.74	20.0	13.04
23.12.74	20.8	12.55
21.2.75	22.0	8.92
25.2.75	22.3	8.02
3.3.75	20.5	11.58
21.3.75	20.0	57.49
8.3.76	20.2	14.85