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HEAT AND CHLORIDE INFLOW INTO THE PUARENGA STREAM FROM WHAKAREWAREWA

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ABSTRACT

The Puarenga Stream forms part of the boundary of the Whakarewarewa thermal area and carries the discharge from Whaka to Lake Rotorua. Fifteen minute flow and temperature gaugings are mads at Hemo Gorge upstream of Whaka and at P.R.I. bridge downstream. Mean daily estimates of the heat flow into the stream and the enthalpy of this flow are made and show changes with rainfall and air temperature, but have otherwise remained fairly constant.

The stream has been sampled on 21 occasions over a two year period. All samples were analysed for chlorlde, pH, and sulphate. Solar heating effects and the stream flow time between Hemo Gorge and F.R.I. bridge have been taken into account. The chloride content of the inflow and enthalpy, show a linear relationship which extrapolates well to other features in the area. The chloride inflow Is generally constant but shows definite low values. Cl/SO_4 ratios indicate a mixing of spring discharges and groundwater.

INTRODUCTION

The Whakarewarewa thermal area is the focus of much spectacular discharge (e.g. geysers) from the Rotorua geothernal system in New Zealand. A monitoring programme has been set up to investigate the relationship of discharge of wells and the behaviour of natural features. This paper describes the data obtained from the monitoring of the mass, heat, and chemical flow from Whakarewarewa into the Puarenga Stream since September 1982.

The stream flows close to the northwest boundary of the Whakarewarewa and on to Lake Rotorua receiving the discharge from the thermal area (Fig. 1). To measure this discharge, the gauge height and temperature are measured at 15 minute intervals at Hemo Gorge, and near the Forest Research Institute (F.R.I.) bridge upstream and downstream of Whakarewarewa, respectively. The sample positions are separated by 3 km. The recorders are maintained by the Water and Soil Division of the Ministry of Works. The flow rate is calculated from the gauge height by using a rating curve. Chemical samples have been taken by D.S.I.R. and H.W.D. staff on 21 days during the period.

VARIATION IN STREAM HATER

Both the flow rate and temperature in the stream show variations throughout the day. The temperature has a diurnal cycle assumed to be caused by solar heating. The flowrate has a more complicated pattern; at least some of the variation is due to intermittent pumping of water out of the stream above Hemo Gorge by the Rotorua District Council Cor city water supplies. There is likely to be a diurnal fluctuation of Lnflow of groundwater into the stream. The stream temperatures (Fig. 2b) have an annual cycle similar to the mean daily air temperature. The apparent base flow rate (Fig. 2a) varies with

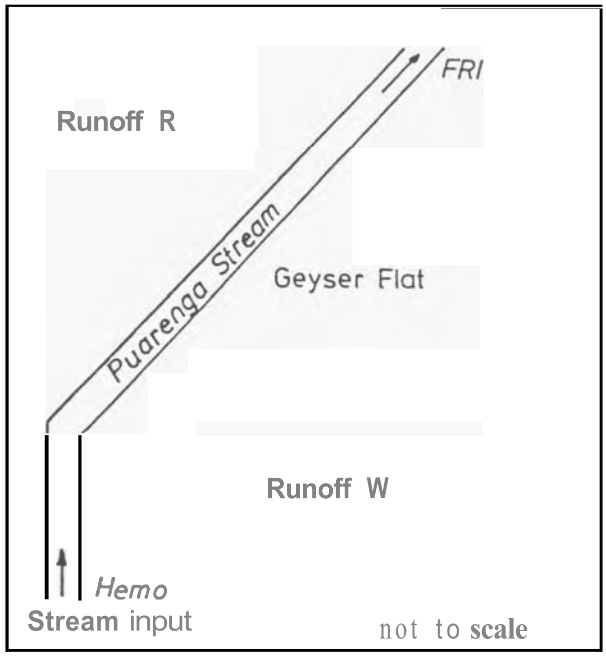

Figure 1: Schematic model of the main inflows into Puarenga Stream as it flows through Whakarewarewa.

the amount of rain in the recent past. Following rainfall, the flow rate increases, and the temperature decreases. The daily flow difference (Pig. 2d) and temperature difference (Fig. 2b) have remained approximately constant except for rainfall induced changes. The diurnal fluctuations in the flow rate are of the same order as the flow difference. The flow time from Hemo Gorge to F.R.I. depends on flow rate and can be estimated approximately from the data e.g. 1.5 - 2 hours at times of low flow.

The available chemical results, from samples taken once on a given day, show the chemical inflow has remained appproximately constant except for a few lower chloride values. Samples have now been taken every half hour over 24 hours to test for a diurnal variation in chemical content of the stream flow, but the analyses are not yet complete.

SOURCES OF INFLOW TO THE STREAM

The expected inputs to the stream ars shown schematically in Fig. 1. Runoff R is the runoff into the stream from areas outside and N.W. of the thermal area. It includes some stream runoff and may include some bore discharqe. This runoff has been estimated as ~5 l/s, (R. Murray, pers. comm.). Runoff W represents the rainfall runoff across the thermal area. Cold water causes the inflow to be cooler during and just after rainfall.

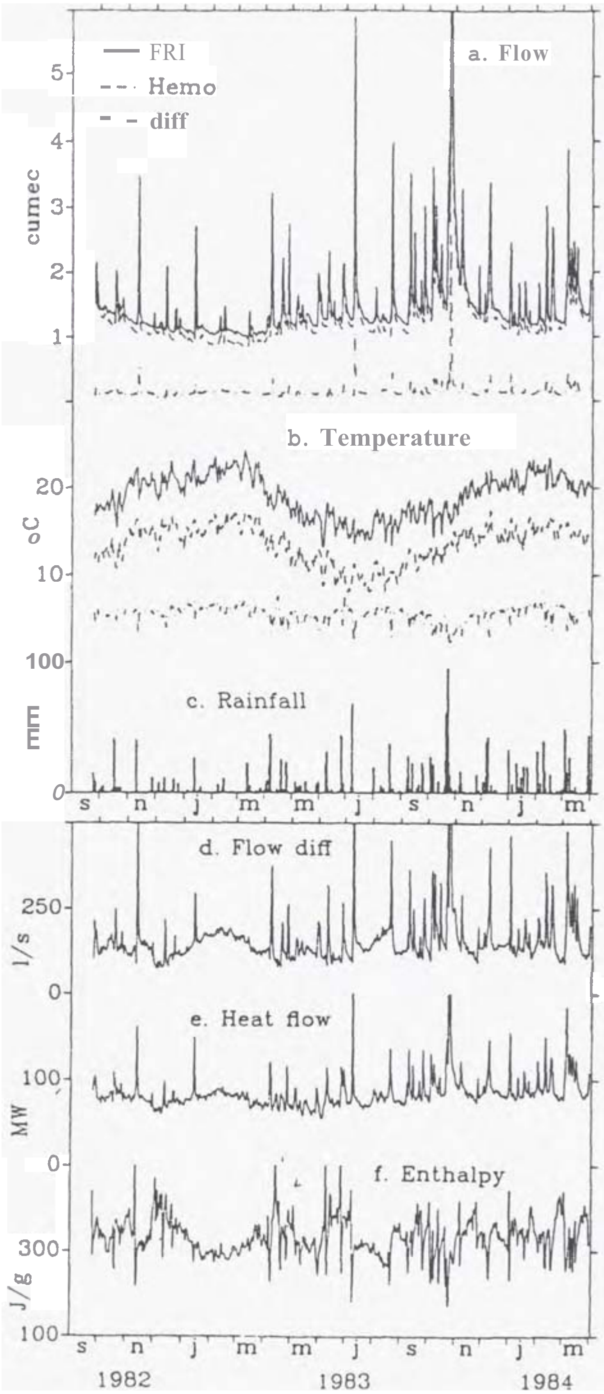

Figure 2: Physical quantities associated with the Puarenga Stream inflow from Whakarewarewa plotted as daily averages against time for the period from September 1882 to March 1984.

(a) Flowrate at F.R.I., Hemo Gorge and the flow difference. The values have been clipped at 6 cumec *(6000* l/s). The flow at F.R.I. in the October 1983 flow was over 10 cumec.

(b) Temperature at P.R.I. Hemo Gorge and the temperature difference.

(c) Rainfall at Rotorua Airport.

(d) The flow difference on an expanded scale. Values over 500 l/s are not shown,

(e) The heat flow difference in the stream. values over 200 MW are not shorn.

The thermal inflow has been split into three parts. The first, from Lake Roto-a-Tamaheke, has a variable discharge which is partly due to rainfall. The second is from the Geyser Flat area, and varies with geyser activity and weather conditions. The third *is* Crom the smaller springs and the groundwater.

The temperature of the groundwater varies in different parts of the thermal area and the springs have various temperatures and discharge rates, The thermal waters at Whakarewarewa can be classified in three chemical types, i.e. chloride, chloride-sulphate, and sulphate.

PHYSICAL MEASUREMENTS

Accuracy of physical measurement

Gauge heights are measured to within about 2 mm which converts to approxmately *20* l/s. *As* the daily flow variation is about 100 l/s on around 1000 l/s and the flow time somewhat variable, it *is* difficult to specify meaningful accuracy for the flow difference (normally 120-150 l/s) from the raw data. This applies to the other differences. Temperatures are measured to about 0.3°C. The temperature difference is around 5-6°C and the diurnal temperature variation can be 3 or 4°C.

There were recorder problems with both temperature measurements during the first half of 1983, and there have been several rating changes, mainly at P.R.I. bridge, due to changes in the stream bed configuration.

Results of physical measurement

For overall results, daily average values have been used to enhance the accuracy of the physical measurements and the flow time from Hemo Gorge to F.R.I. bridge has not been taken into account. However, to incorporate the chemical samples, a more sophisticated procedure is used as described later.

The heat flow at each site is given by:

heat flow = flow x temperature x specific heat of water

The heat flow difference can then be calculated. The enthalpy of the inflow *is* given by:

$$\text{enthalpy} = \frac{(\text{heat flow difference})}{(\text{mass flow difference})}$$

The heat flow difference and the enthalpy of inflow calculated from the daily average values are shown in curves (e) and (f) of Fig. 2.

The flow difference, the temperature difference, the heat flow difference and the enthalpy are roughly constant (Fig. 21, if the immediate effects of rainfall are axcluded (Table 1). As a first approximation to the outflow from Whakarewarewa the mean values are used. Various approximate methods of removing the rainfall dominated data can be devised but all give roughly the same results. Here averages are calculated after the days with rainfall, and any remaining days with flow greater than 1500 l/s (1.5 cumec) at Hemo Gorge have been removed.

The mean enthalpy of the inflow is equivalent to about 70°C water. The 'no rain' standard deviations can be used as an estimate of the accuracy of daily avsraqe values, obtained from the internal consistency of the data.

The results for the weekly measurements of inflow from Geyser valley into the Wairakei stream in 1951-52 are shown for comparison. The

TABLE 1: Inflow data - Hemo Gorge to F.R.I.

		all data	no rain	Wairakei 1951-52
Flow diff	mean	160 l/s	137 l/s	100 l/s
	sd	2562 l/s	28 l/s	
Temp diff	mean	5.58 C	5.86 C	
	sd	.87 C	.55 C	
Heat flow	mean	42.5 MW	38.9 MW	52 MW
	sd	12.6 MW	4.3 MW	
Enthalpy	mean	291 J/g	291 J/g	520 J/g
	sd	60 J/g	51 J/g	
Chloride	mean	*64 g		130 g
	sd	*2.0 g		

* from 14 chemical samples (see text), for which the flow difference mean = 145 ± 20 l/s.

There are periods when the flow and heat flow differences show trends away from the mean values, e.g. there is a long rise and fall of the flow differences during the relatively dry summer of 1982-1983. The enthalpy shows some abrupt changes, the sizes of which are mainly within the accuracy limits.

As the enthalpy minima correspond with the flow maxima (with the daily average values), Grant (1984) has estimated that there is negligible penetration of the cold run-off into the hot ground at Whakatewarewa. The changes in temperature of the run-off from Whaka result from the mixing and displacement of surface hot waters.

CHEMICAL MEASUREMENTS

Twenty one surveys have been concluded, from 9/8/82 to 21/7/84. Samples were collected from the left bank, centre stream, and right bank at three stations, i.e. Hemo Gorge, Whaka Bridge and F.R.I. Temperature and gauge height were read and chloride, pH, and sulphate determined on each sample. Analyses of samples from the same station were within ± 1 mg/l.

M.W.D. flow and temperature data was used so the corrections could be made for solar heating and flow time between Hemo and F.R.I. Whaka bridge data are not reported due to large uncertainties In the flow data.

The method used was:

a. Plot temperature and flow data for Hemo and F.R.I. from 0700 to 1700 hrs; data from PS/5 (27/10/82) is shown in Fig. 3.

b. FT, temperature at F.R.I. (°C) = the temperature read on the graph at the sampling time.

c. HT, temperature at Hemo (°C) = the temperature read from the graph at the time the F.R.I. sample was taken. This makes the best correction for solar heating between Hemo and F.R.I.

d. FF, flow at F.R.I. (l/s) = the flow read from the graph at the sampling time.

e. HF, flow at Hemo (l/s) = the flow read from the graph 1 to 2 hours before the F.R.I. sampling. This allows for the flow time between Hemo and F.R.I.

€. ΔF, flow difference (l/s) = FF - HF.

g. The chemical flux at each station (g/s) = mass

h. ΔCl (g/s) = chloride flux at F.R.I. - Chloride flux at Hemo.

i. ΔSO_4 (g/s) = sulphate flux at F.R.I. - sulphate flux at Hemo.

j = ClI, chloride concentration of the inflow (mg/l) = ΔCl/ΔF.

k. EI, enthalpy of the inflow (J/g) = Δheat flor - ΔF.

l. Cl/SO_4, chloride/sulphate mole ratio of the inflow $(\Delta Cl \times 2.71)/\Delta SO_4$.

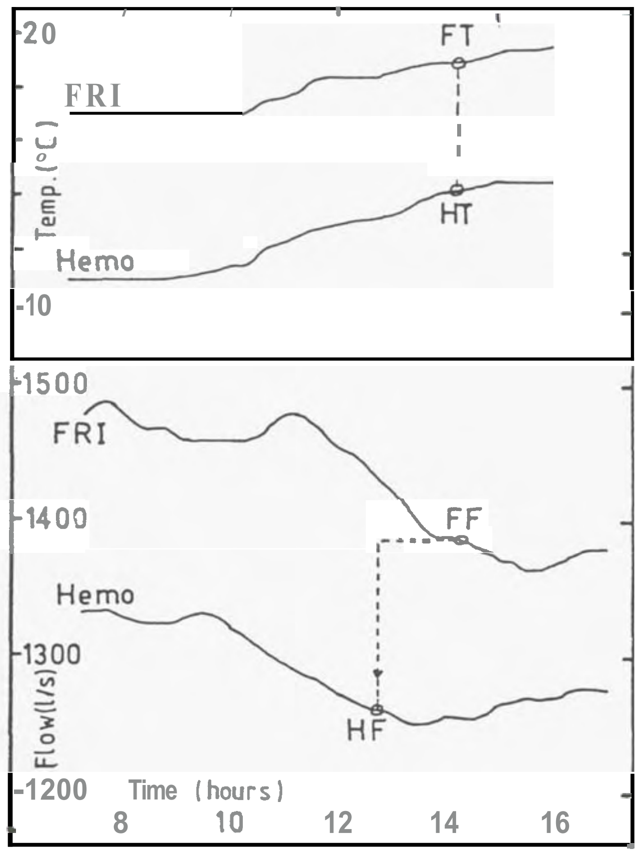

Figure 3: Flow and temperature data at P.R.I. and Hemo recorded at 15 minute intervals by H.W.D., Rotorua. PS/5, 27/10/82.

Chemical results

Data for PS/4 to PS/21 are shown in Table 2, (there are no 15 minute recorded values for PS/1-3).

The effect of msasursment error on calculated parameters.

The effects of chanqing measured values at F.R.I. for PS/14 are shown in Figs 4 and 5, and Table 3.

Chloride concentration of inflow, ClI v Enthalpy of inflow, EI - Fig. 4.

Pig. 4 shows a linear trend of ClI with EI. Deep hiqh temperature geothermal aquifers usually have relatively constant chloride concentration. Thus heat flow can be calculated from the chloride outflow (Ellis and Wilson, 1955). Using the linear regression line Fn Fig. 4 the chloride content at 80°C is 564 mg/l. This value is close to the chloride content of Te Horu, one of the

TABLE 2: Puarenga Stream Data

Sample	Date	PF	HF	ΔF	FT	HT	ClI	EI	ΔCl	$ΔSO_4$	Cl/SO_4
PS/4	30/ 9/82	1474	1354	120	18.6	14.5	548	272	65.7	43.5	4.1
PS/5	27/10/82	1387	1261	126	19.0	14.2	501	281	63.1	36.8	4.6
PS/6	24/11/82	1246	1115	131	20.3	14.8	480	281	62.9	33.5	5.1
PS/7	16/12/82	1171	1092	79	21.8	17.4	678	346	53.6	28.9	5.0
PS/8	21/ 4/83	1800	1648	152	*18.2	*13.8	436	276	66.2	41.5	4.3
PS/9	11/ 5/83	1307	1184	123	17.1	13.6	537	213	66.0	44.4	4.0
PS/10	24/ 5/83	1174	1073	101	15.9	11.2	552	275	55.8	30.5	5.0
PS/11	14/ 6/83	1394	1274	120	17.2	12.1	539	299	64.7	37.5	4.7
PS/12	28/ 6/83	1686	1520	166	15.9	11.2	371	247	61.6	41.2	4.0
PS/13	9/ 8/83	1220	1050	170	17.1	11.4	390	219	66.3	37.7	4.8
PS/14	6/ 9/83	1198	1075	123	17.2	12.6	467	240	57.4	32.4	4.8
PS/15	2/11/83	2150	1985	165	17.2	13.6	379	253	65.5	48.7	3.6
PS/16	5/12/03	1403	1255	148	21.7	16.2	416	286	61.6	36.4	4.6
PS/17	20/ 2/84	1492	1334	158	20.3	16.0	404	257	63.9	35.1	4.9
PS/18	29/ 3/84	1380	1245	135	21.0	15.4	452	304	61.0	32.1	5.1
PS/19	2/ 5/84	1298	1118	180	17.8	12.3	372	218	66.9	36.3	5.0
PS/20	21/ 6/84	1429	1289	140	18.1	12.6	464	288	65.0	36.0	4.9
PS/21	10/ 7/04	1265	1143	122	14.3	9.2	426	260	52.0	36.6	3.9

* Instantaneous measured temperatures. No 15 minute values.

TABLE 3: Precision of calculated data for PS/14.

Parameter	Precision at F.R.I.	Effects of change on ClI (mg/kg)	ΔCl (g/s)	ΔF (l/s)	EI (J/g)
Chloride	+1, −1 mg/l	+9, −9	+1.1, −1.1	nil	nil
Temp.	+0.3, −0.3°C	nil	nil	nil	−12, +15
Flow	+20, −20 l/s	−59, +81	+1.0, −1.0	+20, −20	−23, +33

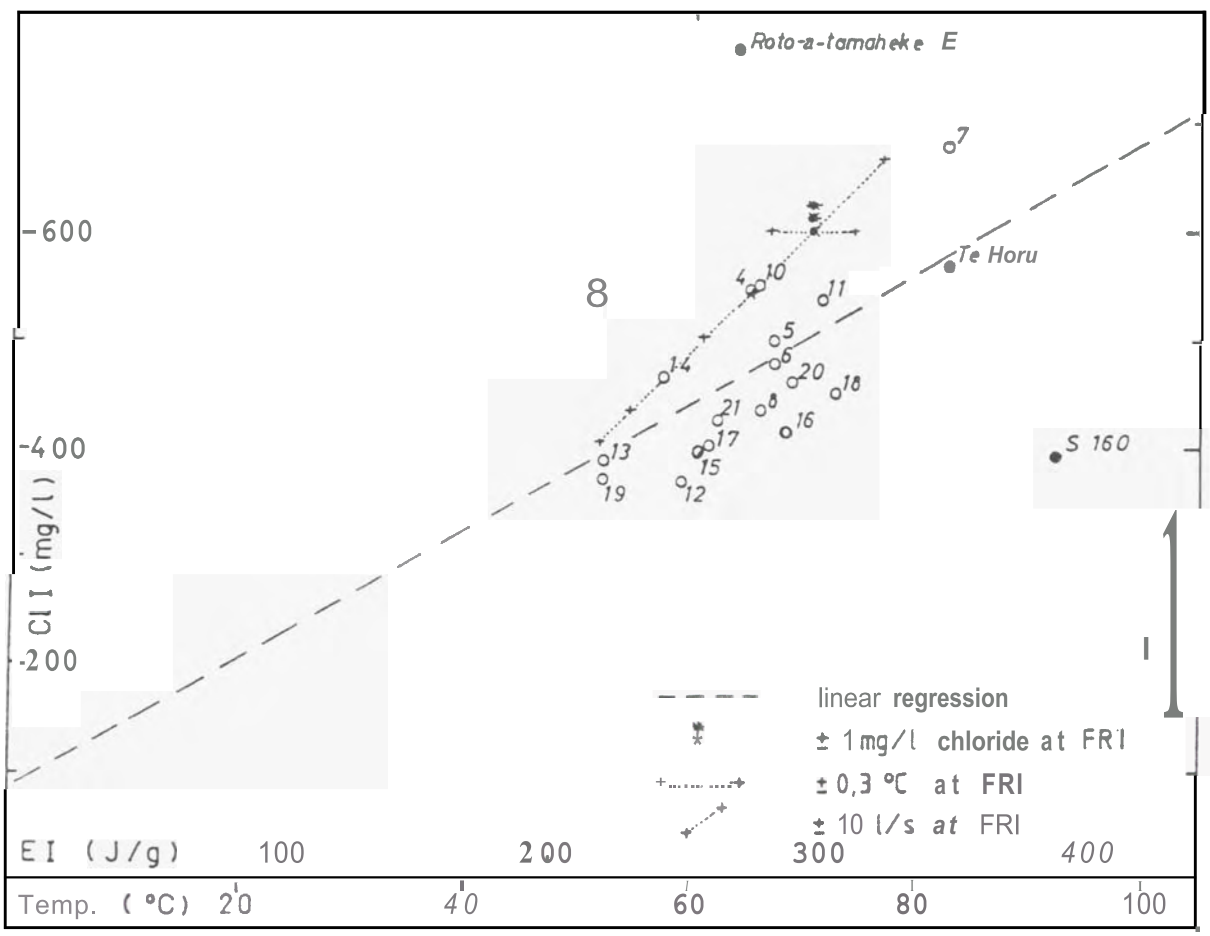

Figure 4: Chloride content (ClI) versus Enthalpy (EI) of the Puarenga Stream input.

A similar extrapolation to 213°C yields a chloride content of 1359 mg/l which compares well with 1375 mg/l measured in the deep well RR889 (M9), which taps water at 213°C. This linearity suggests a relatively simple dilution of the deep fluid with cold groundwater.

Chloride inflow, ΔCl v mass inflow, ΔF – Fig. 5

Is the chloride inflow constant or variable? Fourteen values of ΔCl lie between 61 and 67 g/s, i.e. relatively constant (see Table 1). However four low values of 53.6, 55.8, 57.4, and 52.0 are recorded. These differences are much greater than are expected from measurement errors (Table 3) and thus show that the chloride inflow does vary. These low values are not related to specific times of the year. However they occur at lower ΔF values, suggesting that there is a lower thermal flow from Whakarewarewa at these times.

The relatively constant chloride inflow at high ΔF indicates that high ΔF values are due to high rainfall runoff. This does not increase the chlorlde inflow or heat inflow, but lowers the average enthalpy, EI. Figs 4 and 5 confirm that high ΔF samples (PS/12, 13, 15, 19) have low EI and ClI values. A trend of ΔCl with time is not seen.

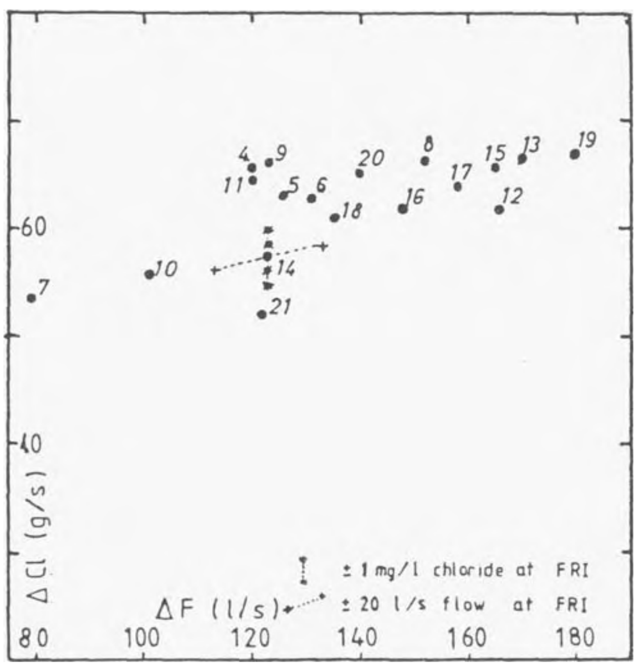

Figure 5: Chloride Input (ΔCl) versus Mass 'Input (ΔF) of the Puarsnga Stream.

Comparison of Whakarewarewa spring and stream inflow chemistries

The Cl/SO_4 ratio in the stream inflow is 4.6 ± 0.5. However the Cl/SO_4 ratio in the major alkaline chloride springs are much higher, e.g. Roto-a-Tamaheke East = 10.4; Parekohoru = 23; Geyser Plat average = 17; Papakura area = 20. If H_2S in these features is oxidised to SO_4 the Cl/SO_4 ratio is lowered a Little, e.g. Parekohoru = 16. Thus there is a Large contribution to the stream inflow from other sources. Some acid – chloride – sulphate features are known, e.g. S 160 (Cl/SO_4 = 2.5), a stream issuing near the bottom of the Geyser Flat terraces.

Three groundwater holes G7, G8 and G10 located within the Whakarewarewa thermal area are 6 m, 4 They contain 1000, 610 and 480 mg SO4/l and have Cl/SO_4 ratios of 1, 0.2 and 2.9..

Mixing of alkaline and acid springs and this groundwater accounts for the Cl/SO_4 ratio of 4.6 in the stream inflow.

well RR864 (F.R.I. 8) has a Cl/Total sulphur ratio in the downhole fluid of approx. 4.6. This suggests that, although steam and gas separate from the ascending fluid, essentially all the H_2S is trapped and oxidised in the groundwater and eventually reaches the Puarenga Stream.

CONCLUSIONS

The flow rate and temperature in the Puaranga Stream show daily and seasonal changes, and changes with rainfall. The differences between F.R.I. and Hemo Gorge show changes with rainfall and possibly slow changes with time, but these changes are less than the possible measurement error. The inflow into the stream has a mean value of approximately 140 l/s and enthalpy equivalent to that of 70°C water. A chlorlde inflow of 64 l/s shows only small changes but there are some lower chloride values which seem to occur at lower flow differences, i.e. at times there appears to be an actual decrease in the chloride flux and hence the deep fluid discharge to the surface at Whakarewarewa.

The linear regression between chloride and enthalpy extrapolates well to other features in the area. The Cl/SO_4 ratio of the stream inflow, requires a mixing of waters from springs and groundwater.

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