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CHEMICAL AND PHYSICAL CHANGES IN THE OUTFLOW FROM WHAKAREWAREWA TO THE PUARENGA STREAM ROTORUA 1982-1988

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ABSTRACT

The Puarenga Stream forms part of the boundary of the Whakarewarewa thermal area and carries the discharge from Whakarewarewa to Lake Rotorua. The stream has been sampled on 57 occasions between 1982 and 1988.

The chloride content of the inflow and the enthalpy show a linear relationship which extrapolates well to other features in the area. The chloride inflow increased from early 1985 to early 1986 and again from mid 1987 to May 1988. When the effects of changes in flows from wells and a "blow out" that flowed into the Puarenga Stream are subtracted there is a nett increase of chloride from 60 to 71 g/s. This together with increased Cl/SO_4 ratios suggest more deep water is reaching the surface.

INTRODUCTION

The Puarenga Stream forms part of the boundary of the Whakarewarewa thermal area and carries the discharge from Whakarewarewa to Lake Rotorua.

Since September 1982 the stream flows, and stream temperatures have been measured by staff of the Water Resources Survey, DSIR, Rotorua, upstream of Whakarewarewa at the Hemo Gorge and downstream of Whakarewarewa at the Forest Research Institute (FRI). Figure 1 shows a schematic model of the main inflows to the Puarenga Stream as it flows through Whakarewarewa. On each date, a water sample was collected from each of the two sites and analysed by staff of Chemistry Division, DSIR, Wairakei for chloride and sulphate concentration and for pH.

Data collected between September 1982 and July 1984 were reported by Bradford and Glover (1984). Since then a further 38 sets of data have been collected.

Bradford and Glover's analysis of the data showed that the inflow from Whakarewarewa into the stream had a mean flow of approximately 140 1/s and an enthalpy equivalent to that of 70°C water. The chloride inflow was approximately 64 g/s but this fluctuated with time. A linear regression between chloride and enthalpy extrapolated reasonably well to other features in the area. The average Cl/SO_4 ratio of the stream inflow was 4.6 indicating a mixture of water from acid and alkaline springs together with water found in the shallow groundwater holes (G7, G8 and G10) is entering the stream.

SOURCES OF INFLOW TO THE STREAM

The expected inputs to the stream are shown schematically in Figure 1. Runoff R is the runoff into the stream from areas outside and northwest of the thermal area including some stream runoff and some bore discharge. This has been estimated at -5 1/s (R. Murray, pers. comm.). Spring S952 was formed by an eruption on 17 December 1984, and flowed into the Puarenga Stream. Runoff W represents the rainfall runoff across the thermal

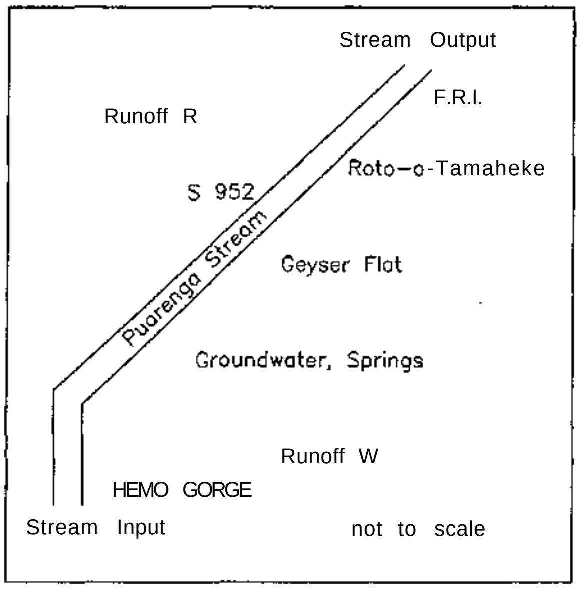


Figure 1: Schematic model of the main inflows to the Puarenga Stream as it flows through Whakawerawera.

area. This causes the inflow to be cooler just after rainfall, although the increased mass flow results in an increase in the heat flow to the stream, Grant (1984).

The thermal inflow from Whakarewarewa has been split into three viz. the Roto-a-tamaheke area, Geyser Flat, and other springs and groundwater. The Geyser Flat input is variable depending on geyser activity and weather conditions. However, the effect of changing geyser activity is probably buffered as the water mainly flows to the stream via the large lakelet S172.

PHYSICAL MEASUREMENTS

Accuracy of Physical Measurements

Gauge heights are measured to within about 2 mm corresponding to 20 1/s. As the daily flow variation is about 100 1/s in 1000 1/s and the flow time is somewhat variable it is difficult to specify meaningful accuracy for the flow difference. Temperatures are measured to about 0.3°C with a temperature difference between 4 and 6°C.

Accuracy is further jeopardised in cases where a continuous (15 minute interval) recording of temperature and flow is not available due to recorder problems and only spot readings were taken. Another factor that decreases accuracy is when measurements are taken during high and rapidly changing stream flows.

CHEMICAL MEASUREMENTS

Fifty six surveys have been concluded between 9 August 1982 and 20 July 1988. Samples were collected in triplicate i.e. from the left bank, centre stream and right bank at the two stations (Hemo Gorge and FRI). Analyses from the triplicate samples at the same station were within ±1 g/t. Typical values were: Chloride concentrations at Hemo = 5 g/t. Chloride concentration at FRI = 60 g/t; sulphate concentration at Hemo = 5 g/t; sulphate concentration at FRI = 35 g/t.

DATA COLLECTED

Data for PS/4 to PS/59 are shown in Table 1:

Sample	Sample Code Number
Date	Date of Sample collection
FF	Flow at FRI (litres/sec)
HF	Flow at Hemo Gorge (litres/sec)
AF	Flow difference between FRI and Hemo = FF - HF (litres/sec)
FT	Temperature at FRI (°C)
HT	Temperature at Hemo (°C)

TABLE 1: Puarenga Stream Data

Sample	Date	FF	HF	AF	FT	HT	C1I	El	AC1	AS04	Cl/ cn/i	AMW
PS/4	30/09/82	1492	1346	138	18.6	13.3	483	299	66.7	44.1	4.1	41.2
PS/5	27/10/82	1392	1237	155	19.0	13.3	408	270	63.3	37.1	4.6	41.9
PS/6	24/11/82	1282	1087	195	20.3	14.8	333	213	64.9	34.0	5.0	41.6
PS/7	16/12/82	1156	1056	100	21.8	15.7	526	361	52.6	27.7	5.1	36.1
PS/8	21/04/83	1789	1621	168	*18.2	*13.8	392	254	65.9	41.4	4.3	42.7
PS/9	11/05/83	1288	1080	208	17.1	12.5	314	172	65.4	44.3	4.0	35.7
PS/10	24/05/83	1153	965	188	15.9	11.0	296	172	55.3	30.6	4.9	32.3
PS/11	14/06/83	1384	1268	116	17.2	11.1	553	351	64.2	37.2	4.7	40.7
PS/12	28/06/83	1719	1480	239	15.9	11.0	264	194	63.2	42.6	4.0	46.3
PS/13	09/08/83	1304	1095	209	17.1	10.6	339	214	70.9	40.5	4.7	44.8
PS/14	06/09/83	1226	1048	178	17.2	11.3	331	217	59.0	33.6	4.7	38.7
PS/15	02/11/83	2150	1982	214	17.2	12.7	314	231	67.1	50.3	3.6	49.4
PS/16	05/12/83	1320	1230	90	21.7	15.3	641	457	57.7	33.8	4.6	41.1
PS/17	20/02/84	1478	1329	149	20.8	14.7	425	315	63.3	34.8	4.9	46.9
PS/18	29/03/84	1356	1224	132	21.0	15.3	454	309	59.9	31.6	5.1	40.8
PS/19	02/05/84	1272	1118	154	17.8	12.2	425	245	65.4	35.4	5.0	37.7
PS/20	21/06/84	1419	1289	130	18.1	12.3	496	317	64.5	35.7	4.9	41.2
PS/21	10/07/84	1291	1143	148	14.3	8.5	359	247	53.1	37.5	3.9	36.6
PS/22	23/08/84	1866	1665	201	17.5	12.6	354	243	71.2	54.3	3.6	48.9
PS/23	5-6/9/84			178			359		63.8	40.3	4.3	
PS/24	18/10/84	1304	1174	130	20.4	13.9	448	331	58.2	41.4	3.8	43.1
PS/25	06/12/84	1280	1133	145	23.5	17.3	483	303	70.1	39.5	4.8	43.9
PS/26	10/01/85	1104	990	114	21.3	13.9	520	358	59.3	38.5	4.2	40.8
PS/27	04/03/85	1240	1086	154	23.3	16.1	461	310	71.0	43.1	4.5	47.8
PS/28	29/04/85	1102	959	143	18.8	12.3	438	261	62.7	36.7	4.6	37.4
PS/29	29/05/85	1057	913	144	17.2	11.5	390	223	56.1	34.0	4.5	32.2
PS/30	16/07/85	1395	1226	169	16.7	10.9	374	246	63.1	36.3	4.7	41.6
PS/31	14/08/85	1234	1064	170	15.2	9.1	326	223	55.5	37.8	4.0	38.0
PS/32	23/09/85	1367	1193	174	18.3	12.5	372	243	64.8	39.9	4.4	42.3
PS/33	24/10/85	1400	1254	146	*22.0	*16.0	522	308	76.2	39.1	5.3	45.0
PS/34	02/12/85	1432	1241	191	*21.8	*16.1	353	246	67.5	42.1	4.3	47.1
PS/35	23/01/86	1544	1382	162	*23.5	*18.2	408	288	66.1	39.6	4.5	46.6
PS/36	12/02/86	1362	1216	146	*21.1	*15.0	477	301	69.7	36.8	5.1	44.0
PS/37	17/03/86	1380	1153	227	*22.8	*16.8	324	223	73.5	39.9	5.0	50.6
PS/38	27/08/86	1863	1694	169	*14.2	*9.0	330	278	55.8	34.8	4.3	46.9
PS/39	26/09/86	1722	1681	41	*16.8	*12.1		877				36.0
PS/40	13/10/86	1501	1324	177	*18.0	*12.3	381	254	67.4	36.7	5.0	44.9
PS/41	27/11/86	1280	1118	162	*18.1	*12.8	421	229	68.2	36.6	5.0	37.1
PS/42	08/12/86	1275	1029	246	*21.3	*15.0	274	200	67.4	36.7	5.0	49.1
PS/43	13/01/87	1086	931	155	*25.0	*17.3	439	298	68.1	35.1	5.3	46.2
PS/44	18/03/87	1227	1068	159	*20.0	*14.3	419	244	66.7	35.7	5.1	38.8
PS/45	20/05/87	1567	1392	175	*17.8	*12.3	384	258	67.1	41.9	4.4	45.1
PS/46	23/06/87	1231	1085	146	*13.2	*8.3	424	208	61.9	33.3	5.0	30.3
PS/47	21/07/87	1237	1074	163	*15.6	*10.1	388	217	63.3	34.5	5.0	35.4
PS/48	28/08/87	1536	1346	190	*16.1	*10.4	354	236	67.3	44.1	4.1	44.9
PS/49	18/09/87	1461	1358	103	*16.8	*11.5	900	363	92.7	42.3	6.0	37.4
PS/50	21/10/87	1229	1055	174	*19.9	*13.8	364	238	63.4	37.0	4.6	41.4
PS/51	26/11/87	1460	1070	390	18.7	12.3	192	152	75.1	50.6	4.0	59.2
PS/52	10/12/87	1611	1335	276	20.0	13.6	211	213	76.9	49.0	4.3	58.9
PS/53	27/01/88	995	855	140	23.4	17.0	482	262	67.5	33.9	5.4	36.6
PS/54	24/02/88	1216	967	249	21.0	14.7	279	190	69.4	44.4	4.2	47.4
PS/55	30/03/88	1209	963	246	19.1	14.9	275	149	67.6	36.9	5.0	36.6
PS/56	26/04/88	1160	840	320	*18.3	*11.5	221	151	70.6	34.8	5.5	48.4
PS/57	24/05/88	1327	1124	203	*16.3	*10.4	350	205	71.0	36.8	5.2	41.6
PS/58	24/06/88	1330	1140	190	*16.1	*10.0	378	221	71.9	38.0	5.1	41.9
PS/59	20/07/88	1270	1160	110	*15.0	*8.2	651	363	71.6	34.7	5.6	39.9

Averagei values (excluding PS/23 and PS/39).

30/09/82-10/07/84	1415	1255	162	18.3	12.7	409	269	62.4	37.3	4.6	40.9
23/08/84-8/12/86	1368	1201	167	19.7	13.8	401	267	65.4	39.2	4.5	43.5
13/01/87-20/07/88	1303	1104	199	18.4	12.4	395	233	70.1	39.0	4.9	43.0
" » **	1293	1088	205	18.5	12.4	363	225	68.7	38.8	4.9	43.3

A = Difference between F.R.I, and Hemo.
* Instantaneous measured temperatures no 15 minute values.
** Excluding PS/49.

C1I Chloride content of the inflow (g/t)
= (chloride at FRI x FF - Chloride at Hemo x HF)/AF
EI Enthalpy of inflow (J/g)
= (FT x FF - HT x HF) x 4.1868/AF
AC1 Chloride inflow (g/s)
= (FF x chloride at FRI - HF x chloride at Hemo)/1000
ASO, Sulphate inflow (g/s)
* = (FF x sulphate at FRI - HF x sulphate at Hemo)/1000
Cl/SO* Chloride/sulphate mole ratio of the inflow
H = AC1 x 2.71/ASO4
AMW Heat inflow (MW) = (FT x FF - HT x HF) x .0041868

Bradford and Glover noted that under normal flow conditions it took approximately 90 minutes for the water to flow from Memo to FRI. Thus the value of the flow at Hemo (HF) was taken 90 minutes prior to that at FRI. However, they assumed that changes in temperature with time at Hemo were due to solar heating and that the same solar heating occurred to the stream as it flowed between Hemo and FRI. Thus they didn't put a time lag into the temperature data but took values at both stations at the same time. Further examination of the data indicates that the diurnal temperature change at Hemo is more likely due to the changing temperature of small streams supplying the Puarenga above Hemo and that solar heating between Hemo and FRI is negligible. Thus in the present data the temperature has been lagged by 90 minutes also. The flow rate at Hemo is changed by rainfall and by intermittent pumping of water out of the stream by Rotorua District Council for city water supplies. A retrospective correction to the rating at FRI for data before 1985 has changed early flow values (c.f. Table 1 with data in Bradford and Glover 1982).

Bradford and Glover reported the effects of changing the measured values at FRI for PS/14 and these are reproduced in Table 2.

These data show that inaccuracies in temperature and flow measurements have a larger effect on the calculated parameter than do inaccuracy in the chloride analyses.

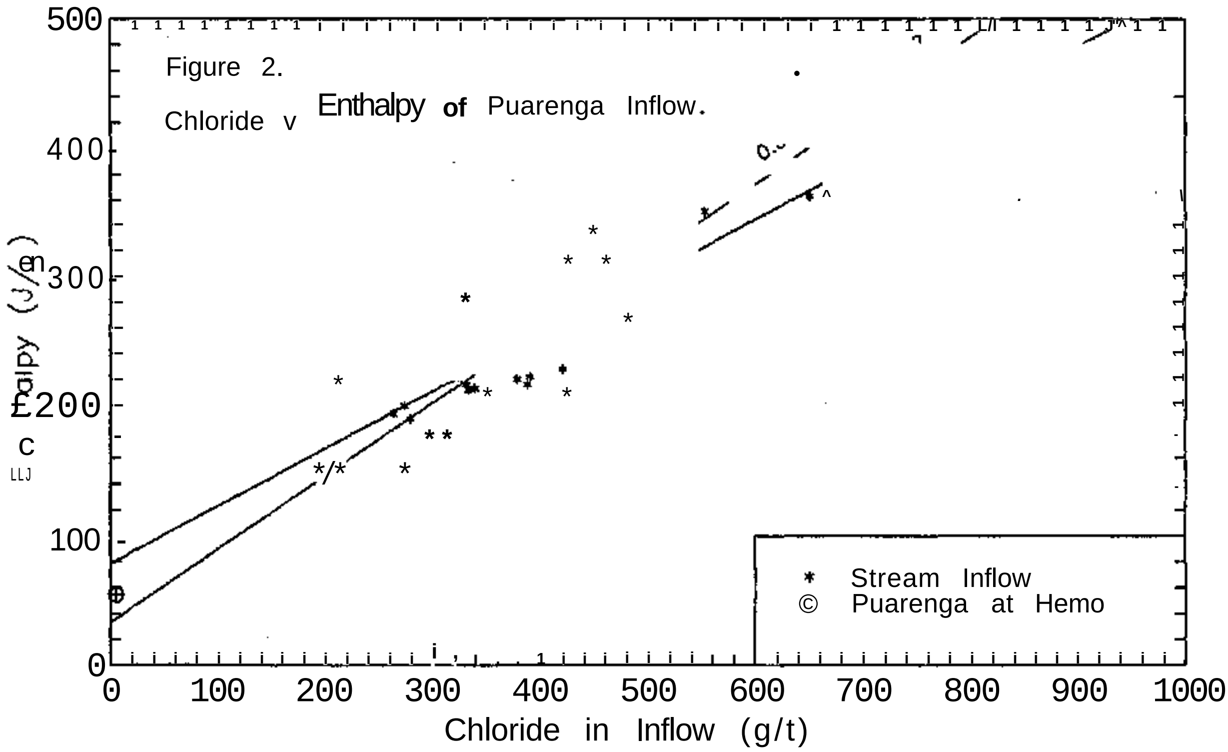
Table 2: Precision of calculated data for PS/14.

Parameter Precision at FRI	Effects of change on C1I (g/t)	AC1 (g/t)	AF (g/t)	El (J/g)
Chloride +1, -l g/t	+9, -9	+1.1, -1.1	nil	nil
Temperature +0.3, -0.3°C	nil	nil	nil	-12 +15
Flow +20, -20 1/s	-59, +81	+1.0, -1.0	+20, -20	-23,' +33

CHLORIDE/ENTHALPY RELATIONSHIP (Figure 2)

Figure 2 shows that there is a linear relationship between the chloride concentration and enthalpy of the inflow. Deep high temperature aquifers usually, have a constant chloride concentration and thus the heat flow can be calculated from the chloride outflow (Ellis and Wilson, 1955). Deep water mixing with cold rain water or groundwater will dilute the chloride concentration and decrease the enthalpy resulting in the trend seen in Figure 2. Variations away from the linear trend will occur if steam which contains heat but no chloride escapes to the atmosphere or is dissolved in groundwater and thus reaches the stream. Another cause of variation is when heat is lost by evaporation or conductive cooling by air as in the discharge of a geyser. PS/49 shows this latter effect and two regression lines are plotted, excluding and including this data, i.e. H = 0.5652 Cl + 32.92 and H = 0.4442 Cl + 78.276 respectively.

Bradford and Glover plotted El as the independent variable (x) and C1I as the dependent variable (y). This showed a chloride content 146 g/t at 10°C in the diluting water. In Figure 2 chloride, as the most accurate determined variable, is taken as the independent variable and enthalpy as the dependent variable, this results in a more "sensible" zero value i.e. zero chloride at 32.92 J/g (8°C) or 78.28 J/g (18.6°C). Chloride concentrations at 99°C (atmospheric boiling point are 676 or 758 g/t. The average chloride concentration and enthalpy of the stream at Hemo are 5.11 g/t and 55 J/g respectively.



CHANGES WITH TIME

Chloride in the inflow (C1I). enthalpy of of the inflow (El), and mass flow (AF)

Arithmetical average values for all data are shown at the bottom of Table 1 for three periods. The first (Tl) includes all samples up to July 1984, the second (T2) from August 1984 to December 1986 and the third from the beginning of January 1987 to July 1988.

Cl I and El are about constant for Tl and T2 at approximately 405 g/t and 268 J/g respectively. The third period shows a possible drop in chloride (C1I) and a definite drop in enthalpy (El), this is linked with an increased mass inflow (AF) from 165 to 200 1/s. Thus the increase in chloride flow (ACI) is due to a larger flow of water of similar chloride concentration but lower temperature. This is probably due to the rising water level in the geothermal aquifer. As the water level rises so the boiling point at any level increases. Thus water loses heat to the rocks, particularly at shallow levels. This process will decrease the enthalpy of the fluid, so that with increased mass flow the chloride flow will increase but the heat will not increase as much and may even decrease.

Heat Inflow (Figure 3)

Heat flow through a geothermal system is affected by a number of processes but particularly by changes in the mass flow. In a steady state the heat flux into the system is equal to the heat flowing out of the system. Of the heat outflow at Whakarewarewa some reaches the stream and some is lost by steam and evaporation. In the case of a rising water level in the aquifer heat is lost from the fluid to the rocks (see above). Thus, although the average mass flow since 1986 is higher than previous to that date, the heat flow to the stream has remained relatively constant. If this explanation is valid heat flow should increase in the future as the water levels stabilise. The increase in heat flow through 1985 and 1986 appears to be partly related to spring S952 (see detailed discussion below).

Chloride Inflow (Figure 4)

In Figure 4 the chloride inflow to the Puarenga Stream is shown as a function of time. The LOWESS statistical programme has been used to smooth the data with a smoothing parameter S = 0.3 (denoted by circles).

Two other chloride flows have been plotted

1. A = the chloride flow from six wells that discharged into the Puarenga Stream, i.e. RR273, RR427, RR527, RR576, RR595, and RR616. As part of the Ministry of Energy well closure programme they were eventually closed and this is seen in the decline in chloride flow which finally ceased in January 1988. The flow was 2.5 g/s at the beginning of 1985. i.e. the chloride inflow of about 63 g/s from 1982 to the end of 1984 contained 2 to 3 g/s from these wells.

2. + = the chloride flow from spring S952, a blowout which occurred in December 1984 on the west bank of the Puarenga Stream. This attained chloride flows of up to 6 g/s but by May 1987 had decreased to about 1 g/s. Flows after this date are about 0.75 g/s.

Measurements were made on the Puarenga Stream at 30 minute intervals from 0400 on 5 September 1984 to 0400 on 6 September 1984. Forty seven values of the chloride inflow were calculated and averaged 63.6 g/t with a standard deviation of 2.94 g/t. This value is close to the average for September 1982 to July 1984 (= 62.5 g/t).

The smoothed curve shows an average of 63.4 g/s chloride inflow from the start of measurement to the end of 1984. This is close to the average measured in the 24 hour survey. If the flow from the six wells is subtracted a nett value of 60 g/s is obtained.

The increased flows from early in 1985 to the end of 1986 which peaked at 68 g/s can be related to the S952 blowout which contributed about 3.5 g/s over the period i.e. a nett average value of 62 g/s. Since the well closures and a reduction of S952 flowrate to approximately 0.75 g/s, the inflow to the stream from Whakarewarewa has risen to 71.7 (less 0.75 = 71 g/s). This indicates a nett increase from about 60 to about 71 g/s i.e. 11 g/s. The main increase has occurred since late 1986/early 1987.

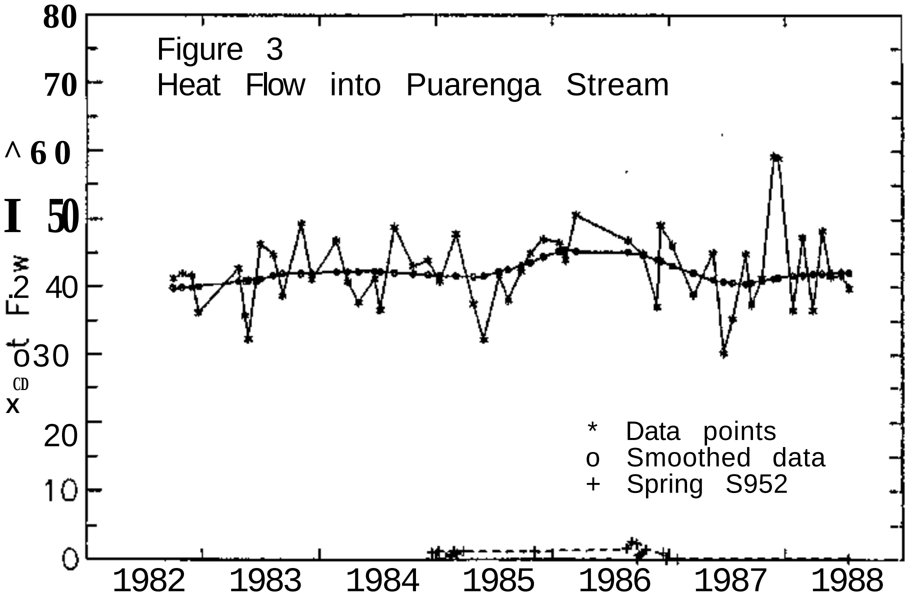
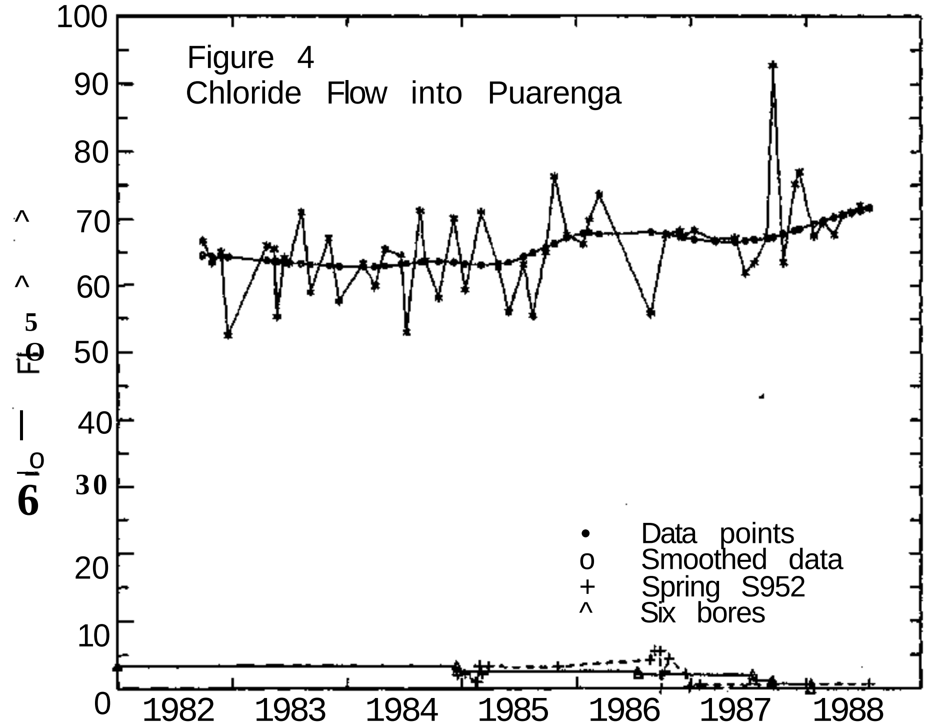


Figure 3
Heat Flow into Puarenga Stream



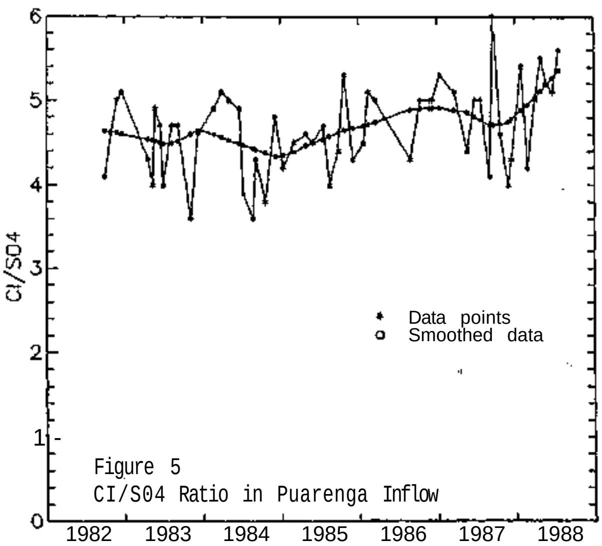
Chloride/Sulphate Ratio in Inflow (Figure 5)

Bradford and Glover noted that the Cl/SO_4 ratio in the stream inflow was 4.6 ±0.5 and that in the major alkaline springs was between 10 and 20. This showed that there was a large contribution to the stream inflow from other sources i.e. acid-sulphate and acid-chloride-sulphate features that have Cl/SO_4 ratios between 0.2 and 3.0.

The deep fluid in well RR864 (FRI8) had a Cl/Total Sulphur ratio of approximately 4.6 but a Cl/SO_4 ratio = 50 to 100. This suggested that at that time most of the H_2S was being trapped and oxidised in the groundwater and eventually reaching the Puarenga Stream.

A larger flow of deep fluid to the surface could result in more steam (and H_2S) escaping from the surface water and a larger proportion of deep fluid to groundwater reaching the stream. A high Cl/SO_4 ratio would follow.

The smoothed Cl/SO_4 values are more variable than the chloride (in Figure 5). This is to be expected as an inflow with low chloride and high sulphate could change the chloride by a small amount but have considerable effect on the Cl/SO_4 ratio. S952 appeared to have affected the Cl/SO_4 ratio but the main feature is the increase from mid 1987 onwards, suggesting an increase in deeper fluid and/or less steam heated acid water.



EFFECTS OF BORE CLOSURE PROGRAMME

The bore closure took place mainly from June to November 1987 and this appears to coincide with observed increases in chloride flow from Whakarewarewa and higher Cl/SO_4 ratios in the inflow to the Puarenga Stream.

Monthly data is being accumulated to confirm whether this change/trend is permanent or a cyclic feature unconnected to the bore closure programme.

ACKNOWLEDGEMENTS

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