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FLOW IN THE ROTO-A-TAMAHEKE CATCHMENT

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ABSTRACT

The Roto-a-Tamaheke catchment is situated at the eastern end of the Whakarewarewa Thermal Reserve at Rotorua. It contributes about 30% of the flow from the Whakarewarewa area and is the largest natural feature in the area. The two outflows and the rainfall are monitored continuously. The component of flow generated by rainfall is calculated in two ways. One uses a model of the catchment with parameters estimated from knowledge of a neighbouring catchment. The other uses the data analysis techniques. Once the rainfall component has been removed, the remaining flow comes from springs and thermally heated ground water. The variation of this spring flow is considered in relation to changes in the shallow ground water, and geothermal aquifer pressures.

INTRODUCTION

The Whakarewarewa thermal reserve in Rotorua is one of the last remaining areas in the world where geysers play naturally. In 1982, a monitoring programme was set up to investigate the relationship of the discharge of wells and the behaviour of natural features. This paper discusses the results from a water balance study of the Roto-a-tamaheke catchment which is an ongoing part of that monitoring programme.

Lake Roto-a-tamaheke is the largest natural feature in the Whakarewarewa thermal reserve. It is fed by flow from numerous geothermal springs as well as the normal processes of rainfall runoff in its catchment. The fluid outflow from the catchment contributes about 30% of the input to the Puarenga stream as it flows through Whakarewarewa. The spring flow component shows a tentative correlation with the changes in the geothermal aquifer caused by changes in withdrawal.

The Rotorua monitoring programme committee initiated a monitoring plan of Roto-a-tamaheke in 1983, with the main objectives being:-

1. To identify the short term (monthly and seasonal) and long term (annual) fluctuations in the water balance.
2. To identify the flow changes and trends in the hot spring component of the outflow.
3. To use the results, if required, as an immediate reference to an event and to provide data to further refine the theoretical field model.

This paper describes the catchment and the monitoring that has been undertaken to determine the water balance. The data collected has been used in two ways to estimate the spring flow. The first method uses data from a neighbouring catchment to estimate the runoff. The second method estimates at least the fast runoff component using the time series regression techniques being developed to analyse other data collected in the Rotorua geothermal monitoring programme. The basic features of the spring flow are the same in both methods. Some insight into the response of spring flow to rainfall comes from their coherence. The relation of the spring flow to ground water and geothermal pressure is described.

CATCHMENT DESCRIPTION

The physical characteristics of the (see Figure 1) catchment show that it has an area of 0.446 km2, has an average altitude from 293 metres to 366 metres, with one point the Pohaturoa trig at 433 metres. Apart from the areas occupied by the lakes and hot pools the majority of the area is covered in trees and scrub. The lakes and hot pools occupy approximately the bottom third of the catchment. The area has a northerly aspect.

Within the catchment there are two small cold streams (approximately 3 litres/second) that flow from smaller pools overland into Roto-a-tamaheke.

Outflow from the catchment is by two streams, both outflows are measured.

At the NW end of the catchment, the outlet is through a 305 millilitre concrete pipe which discharges into a bathhouse before continuing to join the Puarenga Stream, the flow through the pipe into the bathhouse had been controlled for many years by the locals using boards across the entrance of the concrete pipe.

A new bathhouse was built at this outlet (in the same position as the old one) during the period 16.7.84 to 8.10.84, and the outlet was closed. Less water is now required to operate the bathhouse, probably because there are no longer any leaks. Flow is greater in winter than in summer.

The second outlet is on the pathway at the NE end of the catchment below the main lake outlet. There have been various natural and'man-made controls at the lake outlet over the years, including an extraction point for geothermal water to pools in the city.

The hot spring area between the lake outlet and the path contributes a significant hot water flow. From the path the water flows to the Puarenga Stream.

Some water is presently extracted from the lake area for a private hot pool, but for this exercise the total flow is deemed insignificant (0.5-1.0 l/s).

Due to the substantial storage in the pools and lakes, the rainfall runoff tends to be suppressed and discharges over a longer period than would be normal in a stream channel.

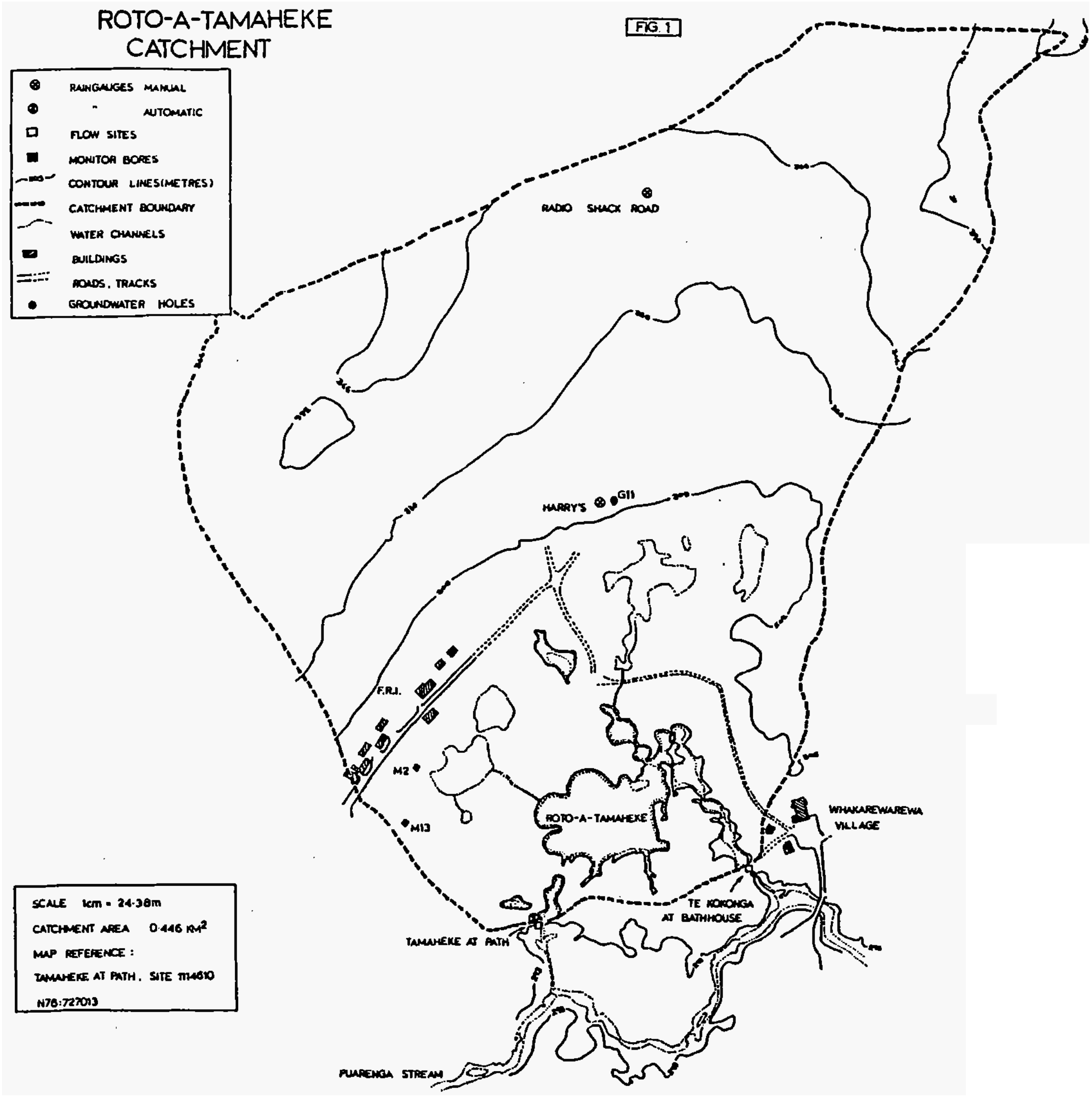

Figure 1: Map of Roto-a-tamaheke catchment

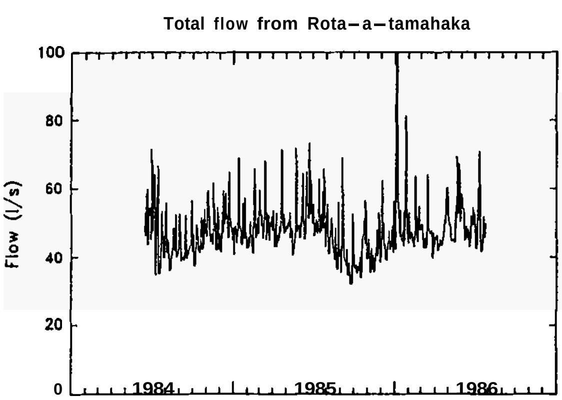

Figure 2: Total flow from Roto-a-tamaheke. Daily average values are used. The high flow values in January 1986 are off scale.

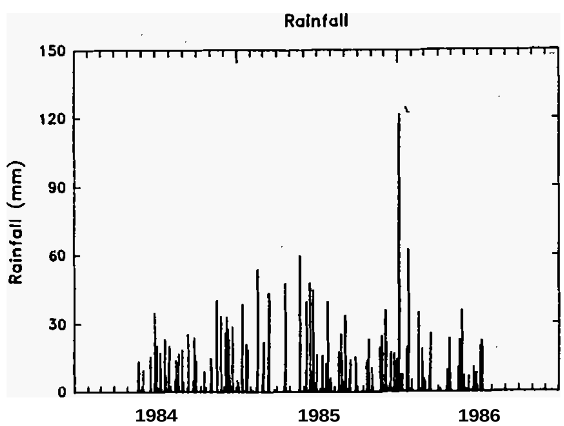

Figure 3: Daily total rainfall in the Roto-a-tamaheke catchment

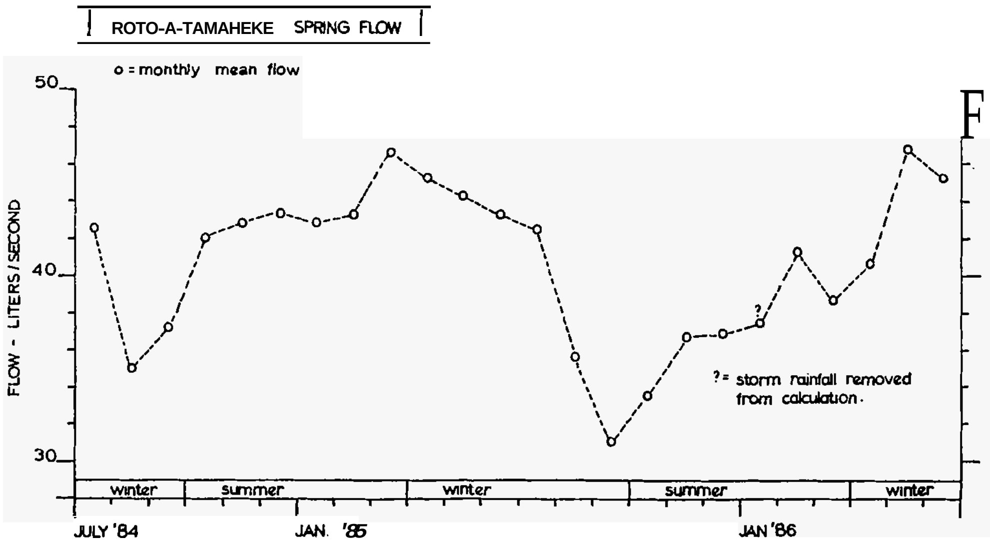

Figure 4: Monthly mean spring flow from Roto-a-tamaheke by method 1

Table 1: Roto-a-tamaheke flow

The columns contain, the date, monthly total rainfall (Rain), the estimated evapotranspiration loss (Evap), rainfall - evapotranspiration (Runoff) in mm and l/s, the measured monthly mean total flow (Total Q) in l/s, and the spring flow estimated by methods 1 and 2, (SprQ1) and (SprQ2).

Date	Rain (mm)	Evap (mm)	Runoff (mm)	Runoff (l/s)	Total Q (l/s)	SprQ1 (l/s)	SprQ2 (l/s)
1984							
Jul	126.2	88.34	37.86	6.30	48.8	42.50	43.34
	109.5	59.13	50.37	8.39	43.4	35.00	38.59
Sep	92.2	56.24	35.96	6.19	43.4	37.20	39.45
Oct	18.8	0.00	18.80	3.13	45.2	42.07	43.46
Nov	110.7	75.28	35.42	6.10	49.0	42.90	44.50
Dec	186.6	141.82	44.78	7.46	50.9	43.42	42.89
1985							
Jan	118.4	81.70	36.70	6.11	49.00	42.89	43.66
Feb	73.4	47.71	25.69	4.74	48.00	43.26	44.60
Mar	94.4	66.08	28.32	4.72	51.32	46.60	46.91
Apr	76.0	52.44	23.56	4.05	49.30	45.25	46.24
May	75.0	46.50	28.50	4.75	49.13	44.38	45.99
Jun	220.7	156.70	64.00	11.00	54.25	43.24	45.38
Jul	107.0	50.29	56.71	9.44	51.98	42.54	46.44
	77.3	25.51	51.79	8.62	44.32	35.70	40.64
Sep	126.8	71.00	55.79	9.60	40.63	31.03	34.93
Oct	76.7	32.10	44.49	7.41	41.10	33.69	37.78
Nov	91.5	56.73	34.77	5.98	42.79	36.81	37.74
Dec	154.0	101.64	52.36	8.72	45.71	36.99	38.97
1986							
Jan	118.4	60.37	58.00	11.97	49.53	37.56	41.85
Feb	85.7	47.99	37.71	6.95	48.34	41.39	43.72
Mar	48.0	0.00	48.00	7.99	46.72	38.73	44.08
Apr	74.6	35.06	39.54	6.80	47.52	40.72	44.67
May	113.4	83.93	29.48	4.91	51.72	46.81	46.96
Jun	46.1	21.67	24.43	4.20	49.47	45.27	46.71
Means							
July 1984-85	1301.9 (total)			6.08		42.39	43.75
July 1985-86	1119.5 (total)			7.72		38.94	42.04

METHODS OF MEASUREMENT AND CALCULATION

The period used in this study was July **1984** to June **1986** inclusive. Monthly average (or total) measured values and estimated values discussed below are given in Table **1.**

1. Flow Measurements

Two flow sites were established at the catchment outlets. The northeastern outlet site. Tamaheke at Path, comprised of a **90** degree V notch weir with stilling well and recorder shed.

The western outlet site, Te Kokonga at Bathhouse consisted of a stainless steel control box attached to the head of the concrete pipe leading to the bathhouse. The box has a slide valve on the inlet to control the flow and **it** has a **305** millimetre outlet, with a small pipe to a stilling well and recorder house for the water level recording.

Both sites automatically record water level at **15** minute intervals on a punch tape recorder. The control structures have been flow rated in order to obtain flow from the recorded stage data. To obtain daily, nionthly. and annual mean flows, the data was filed and manipulated on the Vogel Computer. Total daily flow is plotted in Figure 2.

2. Rainfall Measurements

To find the rainfall on the catchment, three raingauges were installed. Two of these were at the head and middle of the catchment respectively. These gauges were manual and read once a week. The third gauge recorded the rainfall automatically and was installed at the Tamaheke at Path site. The data was filed and manipulated on the VCC.

Using the three raingauges, an annual arithmetical mean basin rainfall was calculated. As the annual total from the automatic gauge was within less than **0.1%** of the arithmetical mean, the data from the automatic gauge was used in all the calculations. Daily rainfall is shown in Figure **3.**

3. Spring Flow Calculation - Hethod **1**

In order to define the water balance and hot spring component, the theoretical rainfall runoff had to be found. The monthly loss (evapotranspiration) values from a neighbouring catchment (Pomare) of similar size and rainfall, but of different land use, were applied to the Roto-a-tamaheke data as a percentage of rainfall, and the theoretical monthly runoff calculated.

The runoff was subtracted from the total outflow and the hot spring flow found. This estimate is plotted in Figure **4** and the values given in Table **1.**

The level of Roto-a-tamaheke lake was also taken on a weekly basis. These readings were used to calculate any storage effects that the lake might have on the runoff. However, the maximum monthly storage/loss in the lake that was experienced accounted for less than 1% of the total outflow.

The rainfall in January **1986** was of the order of 363mm, 235mm of this fell over a two day period. Due to this excessive rainfall and all the runoff not going through the flow structure, 6 days data have been deleted from the calculations.

The mean rainfall component of the catchment outflow was only 6.9 litres/sec. or **17%.** but in order to identify fluctuations and trends **it** was reasonable to remove the rainfall component in such a way that the baseflow during low rainfall months was also removed. Hence the use of the neighbouring catchment data.

The calculation and plotting of a monthly mean rather than weekly was done in the knowledge that the runoff tends to be suppressed by the storage in the lower half of the catchment and monthly data should be less subject to error from missed flow.

The minimum flows occur at the end of the winter each year (Figure **4)** with a reduction from the summer peak flows of **11** l/s and **15** l/s **(1984-85** and **1985-86).**

4. Spring Flow Calculation - Hethod 2

In this method a transfer function is used to remove the immediate response to rainfall. Daily average values are used. There are two terms in the transfer function, one contains the rainfall and some of its lags and the other is an exponentially smoothed rainfall, which allows for storage dependent upon the amount of rain in the past. The exponential smoothing was started using rainfall values from the manual gauge at Whakarewarewa back to the beginning of **1983.** The smoothing constant is chosen empirically as **10** days. A similar method was used by Young **(1984,** and references therein) for the Bedford-Ouse catchment. Young also included a temperature dependent factor. This was omitted method **1** showed no obvious seasonal variation. Very long term ground water storage is not fully included. Again, data related to the heavy rainfall in January **1986** was omitted.

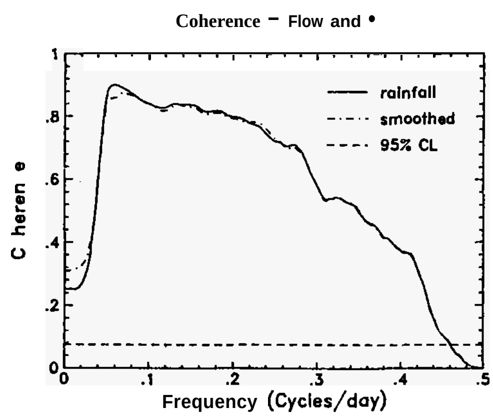

***Figure* 5:** Coherence between total Roto-a-tamaheke flow and rainfall. Both the daily rainfall and the rainfall which has been exponentially smoothed are used.

The coherence between the rainfall and flow (Figure 5) shows how they are related. The coherence is small at low frequencies (the total flow has a long term pattern unrelated to rainfall). is high through the mid frequency band and drops away again at high frequencies. The lack of coherence at high frequencies comes partly from the random nature of rainfall throughout the day. Also, **it** seems that spring flow can be stimulated or destimulated by rainfall in the short term. Both responses have been noticed in Spring **426** which is located in the catchment. The coherence between the daily averaged flow and the daily rainfall and the exponentially smoothed rainfall are essentially the same; the coherence shows that there is a relation between the flow and rainfall extending back 10 to 20 days. There is a phase shift between the flow and rainfall suggesting lagged terms.

The transfer function used included the rainfall and lagged values from the previous two days. ***rain(0)***, ***rain(1)*** and ***rain(2)*** and the exponentially smoothed rainfall, snroin. The background is approximated by an AR(2), MA(1) process with coefficients *ar(1)*, *ar(2)* and *ma(1)*. The values of the coefficients are

Variable	*value*	*S.E.*	*T*
rain(0)	*0.3156*	*0.0168*	*18.8*
rain(1)	*0.3349*	*0.0156*	*21.5*
rain(2)	*0.0781*	*0.0145*	*5.4*
smrain	*0.6199*	*0.1364*	*4.5*
ar(1)	*1.3298*	*0.0467*	*28.5*
ar(2)	*-0.3380*	*0.0446*	*-7.6*
ma(1)	*0.8712*	*0.0266*	*32.8*

The estimate for the spring flow after removing the rainfall contribution is shown in Figure 6. The points which were removed from the calculation are not plotted. There is still considerable variation in the data. A smoothed curve obtained using the robust smoother LOWESS (Cleveland 1979) is drawn to indicate the trend in the data. Monthly average values are given in the last column of Table 1.

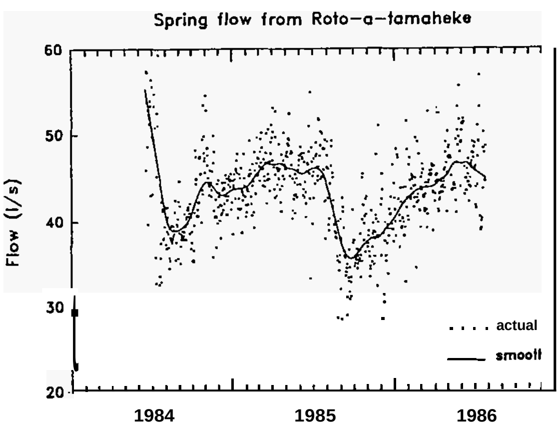

Figure 6: Spring flow from 'Roto-a-Tamaheke by method 2. Daily average values are used. The smoothed curve shows the date trend.

The estimated spring flow from this method is generally higher than that obtained with method 1; this is expected because some of the base flow is omitted. The annual cycle is smoother than obtained in method 1. This may also be due to lack of very long term storage. It could also be due to variation in behaviour between the Roto-a-tamaheke and the Pomare catchments.

5. Nearby geothermal and ground water aquifers

The spring flow from Roto-a-tamaheke will be compared with the level variation of a nearby geothermal well. M16, (Figure 7). and with the level variation of the ground water well GII. (Figure 8).

The barometric response has been removed from M16, using a transfer function. The coherence between the daily average H16 variation and the barometric pressure is high over most of the frequency range, dropping somewhat at low frequencies. The barometric efficiency of H16 is high (around 90%), and the coefficients of lagged terms are not significant, consistent with its proximity to a twophase region. Data known to be significantly in error is excluded. The background term can be closely approximated by a first difference. The daily average barometric pressure values have been taken, in the main, from the datalogger originally located at Whakarewarewa and now at the Ministry of Works building, Rotorua. Gaps are filled in using the charts recorded by the Meteorological Office at Rotorua airport. Water level values in M16 are measured hourly and stored upon the Vogel computer.

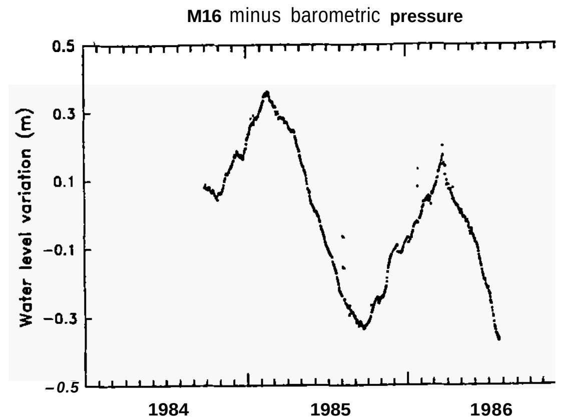

Figure 7: Water level variation of M16 with barometric pressure removed. The points well away from the main line are data errors. M16 represents presure variation in the geothermal aquifer close to Whakarewarewa.

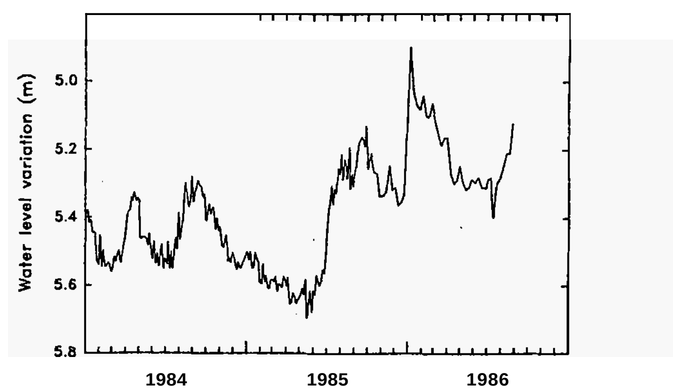

Figure 8: Water level variation of GII. GII is a ground water well in the catchment.

Figure 7 shows clearly the changing seasonal trends in the level of H16. There is little scatter in the data, points away from the main trend of the data are known to be in error. Incidentally, the declining values of the winter minima and summer maxima show that the pressure in the geothermal aquifer is still declining: the rate of decline of pressure in a well close to the inferred source of the geothermal fluid and close to Whakarewarewa is very alarming.

The ground water well, G11 is measured manually. It is located within the Roto-a-tamaheke catchment, and is on the outer margin of the thermal area. The level in GII has been relatively high since July 1986.

COMPARISON BETWEEN SPRING FLOW AND M16 AND G11

It is fairly clear that the variation in flow out of Lake Roto-a-tamaheke is not directly related to the variation in the ground water as represented by G11. Any correlation that is shown is negative, mainly arising from the higher ground water levels in winter when the flow out of Roto-a-tamaheke is reduced. The permanent flow to the lake is small and variation proportional to the ground water level would be masked. However, changes in the ground water level will affect spring flow due to sub surface competition between the geothermal water and ground water. Higher ground water levels will contain the springs more and reduce the sub surface flow, and hence allow more surface discharge. Such a model of spring flow is described by Grant et al (1985).

The winter dip in flow out of Lake Roto-a-tamaheke in 1985 corresponds fairly well with the winter low in H16 in 1985. as does the incomplete recovery during the summer of 1985-86 when compared with the 1984-85 values; however recovery continued until Hay. H16 has been declining since the end of March. The situation in the Roto-a-tamaheke area was confused in 1984 due to the reconstruction of the bathhouse. One of the outlets to Lake Roto-a-tamaheke was closed for a period; this had the consequence that the lake level rose slightly. Abnormally high levels were observed in the area, as springs responded to the raised level of Roto-a-tamaheke. The reduced outflow may have been due to a redistribution of fluid in the area, rather than a reduced flow from depth. It is very unfortunate that H16 was not being used as a Monitor well before September 1984, as the flow minimum is somewhat before the October minimum in H16.

The near surface hydrology of a geothermal spring system is very complex; hot springs discharge sub surface as well as at surface. This sub surface water gradually cools and changes its chemical nature (becomes more acid). Changes in ground water level on the periphery of the system help control the amount of sub surface discharge. With declining geothermal pressures, the ground water invades the spring system, probably forcing colder more acid water back into the discharging springs. Chemical changes have recently been noted in Ororea which are consistent with ground water invasion (Ashley Cody, private comunication). Ororea is located close to Roto-a-tamaheke. so colder water is replacing the hotter more alkaline geothermal water which originates at depth.

DISCUSSION

The spring flow changes are assumed to be caused, in part, by a change in the geothermal aquifer pressure and therefore a result of drawoff. The late winter minima and late summer maxima are at similar times to those in the monitor bore H16. A connection is therefore indicated. At this stage there is insufficient data to identify trends, but it is noted that the flow recovery rate was slower 1985-86 than the previous year. Causes are subject to speculation. The apparently higher levels of spring flow during the early part of the 1986 winter may be due to the high level of ground water.

The on going monitoring of this catchment will be an important contribution to the knowledge of the Rotorua geothermal field.

Appendix A

COMMENTS ON TRANSFER FUNCTIONS.

The transfer function gives a way of regressing time series data which takes into account the structure of the data, that is, the fact that data values are related to immediately preceding values. This is not necessarily true for rainfall which is fairly random, but is true for flow, water level and barometric pressure. An extra term is included in the transfer function to account for this, and for any long term trend or other factor not explicitly included in the independent variables. The transfer functions used here are somewhat restricted.

Although daily average values are used, the number of 'points' in the regression is more like the number of events, that is, significant rainfalls, or the time between barometric lows (or highs). and not the number of days. This restricts the number of parameters which can be determined accurately.

Time series regression is particularly sensitive to data errors, (Martin. 1981) hence care is taken to remove 'outlying' points.

The coherence is used as one of the tools to determine when sufficient lagged terms have been added; the coherence between the residual and the independent variables is required to be small, usually below the 95% confidence limit. Other checks are on the significance of the coefficients. and the size of the residual mean square error.

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