CESSATION OF SPRING FLOW AND SPRING FEED DEPTHS, GEYSER VALLEY, WAIRAKEI

PAUL WHITE & TREVOR HUNT

Institute of Geological & Nuclear Sciences, Wairakei

SUMMARY Historic spring flow data show that the date of spring-flow cessation was not simply related to spring elevation. A model of the cessation of spring flows, using a reservoir pressure-elevation relationship applied to spring SP18, reasonably predicts the flow cessation date for five springs (Group A) but poorly predict that for seven other springs (Group B). These two groups of springs do not appear to be clustered at the ground surface. The pressure-elevation relationship suggests that the Group A springs have a feed fiom -90 to -130 mRL and Group B springs feed fiom -350 to -500 mRL. The spring flows therefore trace pressure variations in the geothermal reservoir in two zones. This model is consistent with the observation that the chloride in Group A springs declined at least three years earlier than that in Group B springs.

1. INTRODUCTION

Prior to development, Wairakei geothermal field contained many geysers, fumaroles, and hot springs. Most of these natural thermal features were located in Geyser Valley and the adjacent Waiora Valley (Fig. 1). Exploratory drilling began in 1950 in the Waiora Valley, where many production wells are located. No wells have been drilled in Geyser Valley. Initially, the effects of mass withdrawal for well testing on the natural features were small and isolated. During 1953-54 there were decreases in mass discharge fiom some thermal features in Geyser Valley, but there was little or no change in temperature of the waters. The decreases were thought to be caused by natural climatic variations because the data showed that although some features changed during the testing period others did not. Between 1954 and 1957 some springs ceased discharging.

Commissioning of the Wairakei Power Station began in late 1958, and there was a large increase in mass withdrawal. At the same time there was a rapid decline and death of many remaining thermal features in Geyser Valley. This decline was surprising at the time because the conceptual model for the geothermal system envisaged that any fluid withdrawn fiom the upper part of the reservoir would be rapidly replaced by hot fluid fiom deeper in the reservoir, so that the natural features would be unaffected (Wilson, 1976). Most of the natural features were in Geyser Valley, about 0.5 - 1 km distant fkom the production wells, so it was thought that mass withdrawal from depths of less than 500 m would not affect them.

2. PREVIOUS MODELLING

To better understand the processes involved in the decline of the springs, simple numerical modelling was done by White & Hunt (2000). The models considered mixing of groundwater and geothermal fluid, Darcy flow, and changes in reservoir pressure. The changes in flow rate and chemistry of spring SP18 were modelled; this spring was chosen because it had the best record of changes in flow rate and chemistry. The modelling also showed that predictions of source flow rates in the reservoir and groundwater zone are very dependent on reservoir pressure, but relatively independent of source chemistry and temperature. The models suggested that, prior to development, the observed flow rate of 3 l/s was comprised of about 2.1 l/s fiom the reservoir and about 0.9 l/s fiom the groundwater. As pressure in the reservoir declined, the reservoir component declined but the groundwater component remained near constant until the spring had nearly ceased flowing. The source of the spring was estimated to be at -115 mRL, assuming it was fed by a single source.

The model developed for SP18 predicted the flow fiom Spring SP55 would cease in July 1956, however, flow actually ceased in February 1958. It was suggested that the difference in the predicted and actual cessation of flow in SP55 could be due to different feeder depths for the two springs andor a reservoir pressure-elevation relation which differs fiom that assumed.

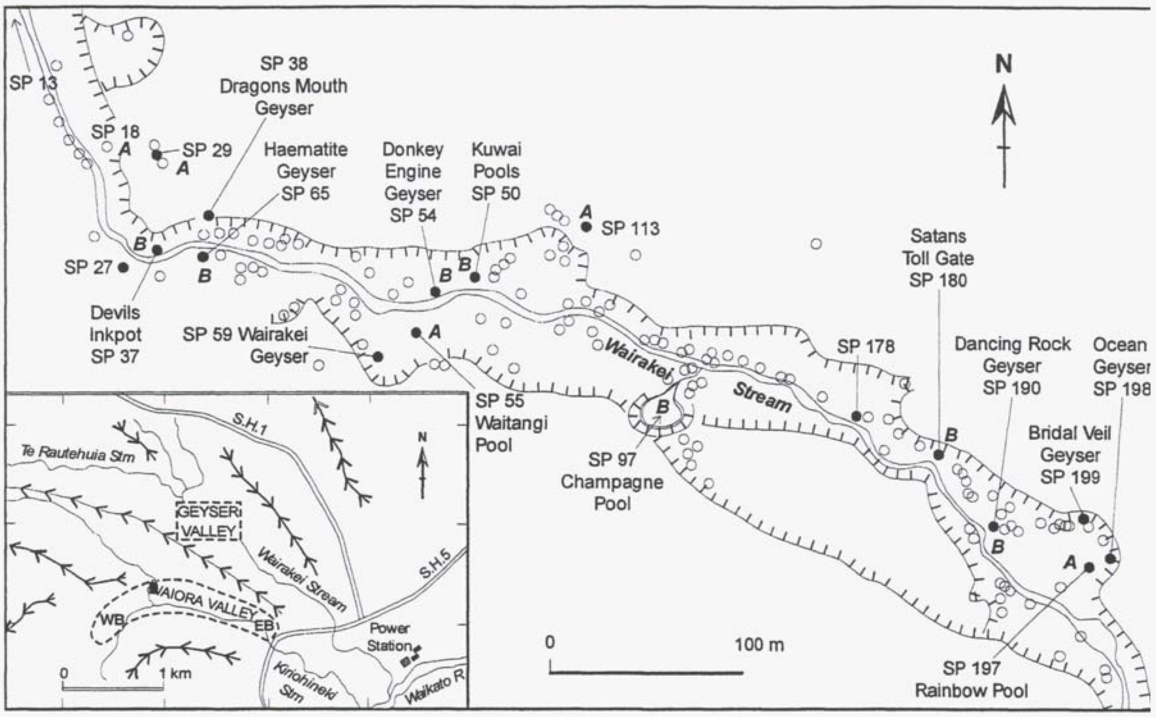

Fig. 1. Map of Geyser Valley, Wairakei, showing location of the springs referred to (solid dots) and other thermal features (circles). Group A and Group B springs are shown by bold italic letters. Note the scatter of both groups.

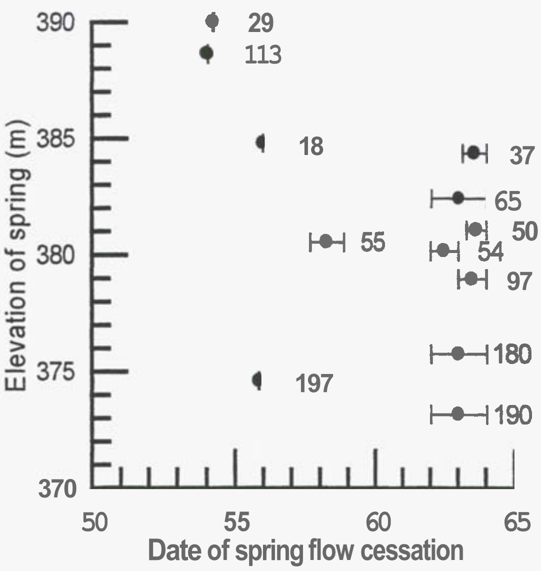

Fig. 2. **Spring** elevation and date of cessation of spring **flow.** Error bars show range of intermittent flow.

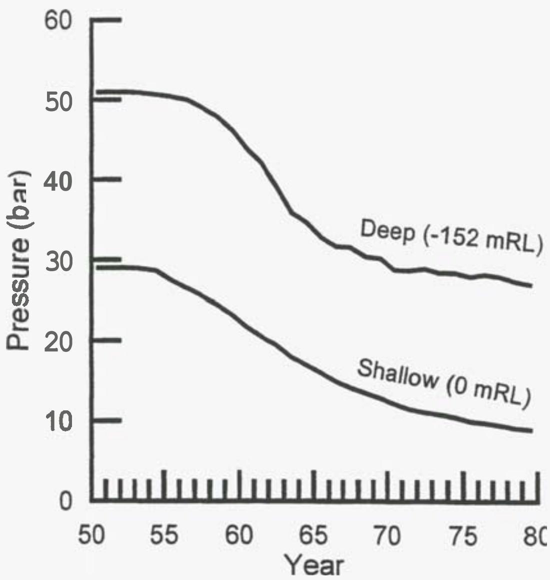

Fig. 3. Geothermal reservoir pressure-elevation relationship, **1950-1980,** in the Eastern Borefield (EB, Fig. **1).**

3. CESSATION OF SPRING FLOW

The dates for the cessation of flow in Geyser Valley springs can be estimated for 12 springs (Table 1) ficm recorded observations or measured flow rates. Springs SP29 and SP113 are at elevations greater than 388 m (Fig. 2) and were the first to cease flowing. However, flow cessation date is not simply related *to* spring elevation. For example, Spring SP55 at an elevation of 380.5 m ceased flowing between September 1957 and November 1958, but Spring 50 at 381 m continued to flow until sometime between May 1963 and January 1964. Spring SP59 (Wairakei Geyser) at 379.8 m elevation and located close to SP55, continued to flow until after 1965. Spring SP59 has no recorded date for the cessation of flow so is not included in Table 1 or Figure 2.

4. PREDICTIONS OF FLOW CESSATION USING THE MODEL FOR SP18

The model for SP18 predicted a geothermal feed elevation of -115 m (White and Hunt, 2000). This model uses a linear geothermal reservoir pressure - elevation relationship (Fig. 3) based on observations of shallow and deep pressures in the borefield. Flow from SP18 first ceased in late December 1955. The model for spring SP18 predicts that all the springs in Table 1 would have ceased flowing by 1958 and produces an estimate of the cessation of flow that is within two years of the observed cessation of flow for springs: SP18, SP29, SP55, SP113 and SP197 (Group A, Fig. 4). However, the model produces poor estimates of the date of cessation of flow for springs: SP37, SP50, SP54, SP65, SP97, SP180 and SP190 (Group B, Fig. 4). The marked separation of groups A and B on Figure 4 suggests that each group of springs has a different pressure regime where the spring feeder connects to the geothermal system.

The locations of the springs represented by these two groups do not appear to be clustered at the surface (Fig. 1).

5. SPRING FEED DEPTHS

The pressure-elevation relationship (Fig. 3) can be used to estimate the elevation of the spring feed point by assuming that the driving head (White and Hunt, 2000) is zero when a spring at a known ground elevation has ceased to flow. Interpretation of the pressure-elevation relation estimates feed elevations of between -90 mRL and -130 mRL for Group A springs (Table 2) in the Waiora Formation (Fig. 5). Extrapolation of the pressure-elevation relation is required to estimate the feeder elevation for Group B springs because the pressures required to sustain flow in theses springs until 1962-1963 is greater than estimated at -152 mRL (Fig. 3). This indicates that the source is deeper than -152 mRL. The model predicts feeder elevations in the range -350 mRL to -500 mRL for Group B springs (Table 2) in the Wairakei Ignimbrite (Fig. 5).

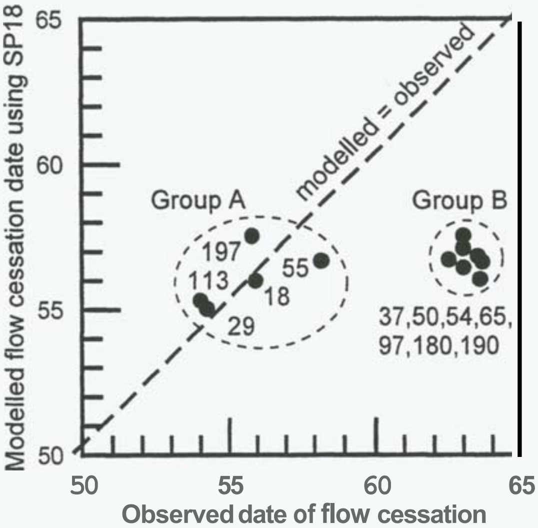

Fig. 4. Predicted spring flow cessation dates using the model for SP18 (White and Hunt, 2000) compared with observed spring flow cessation dates.

Spring-feeder pressures at the time of cessation of spring flow estimated fkom the pressure-elevation relationship (Table 2) were around 42 ±2 bars when Group A springs ceased flowing. Group B springs had a spring-feeder pressure of around 71 ±7 bars when flow ceased.

6. MODELS OF SPRING FEEDER PLUMBING

We now examine two possible models for the 'plumbing' of the spring feeder systems.

1. Each spring has a separate feeder to the reservoir. The Group A springs in this model would be fed from relatively shallow in the reservoir and Group B springs would be fed ficm relatively deep in the reservoir. In this model the pressure differences between the two groups are a result of changes in reservoir pressure with depth. This model is consistent with observed spring chloride chemistry.

2. All springs are fed ficm the same depth. This model would require a horizontal pressure gradient in the reservoir. However, this gradient would have to have been large and quite irregular to support spring flow in the Group B springs until 1962-1963 when the Group A springs ceased flowing by the end of 1958. For example, the reservoir pressure required to support flow in the Group B springs in 1962-1963 with a feeder elevation of -100 m is approximately 42 bar.

Table 1. Observations of the cessation of spring flow, Geyser Valley.

Spring	Reference	Last date when flow recorded	First date when zero flow recorded	Mid-point	Spring Elevation (m)
18	Glover and Hunt	19.12.55	29.12.55	55.98	384.7
29	Thompson	18.3.54	6.4.54	54.25	390
37	Data reports	10.3.63	14.1.64	63.61	384.3
50	Data reports	7.5.63	14.1.64	63.69	381
54	Data reports	18.1.62	15.1.63	62.54	380.1
55	Glover and Hunt	10.9.57	11.11.58	58.28	380.5
65	Data reports	18.1.62	15.1.64	63.04	382.3
97	Data reports	15.1.63	15.1.64	63.54	378.9
113	Thompson	11.1.54	21.1.54	54.04	388.6
180	Data reports	18.1.62	15.1.64	63.04	375.7
190	Data reports	18.1.62	15.1.64	63.04	373.1
197	Data reports	26.10.55	11.11.55	55.84	374.5

Table 2. Predicted spring feed elevations and pressures for Group A and Group B springs at the time of spring flow cessation.

Group	Spring	Predicted feed elevation RL(m)	Estimated error in feed elevation (m)	Predicted feed pressure (bars)	Estimated error in feed pressure (bars)
A	SP18	-115	10	43	2
A	SP29	-100	10	43	2
A	SP55	-130	10	44.5	2
A	SP113	-90	10	42	2
A	SP197	-90	10	40.5	2
B	SP37	-500	50	77	7
B	SP50	-500	50	77	7
B	SP54	-350	50	64	7
B	SP65	-400	50	68	7
B	SP97	-500	50	76	7
B	SP180	-400	50	68	7
B	SP190	-400	50	68	7

Table 3. Early chloride measurements made in the Geyser Valley Springs.

Group	Spring	Chloride measurements (ppm)		
		1886[1]	1951[2]	January 1962[3]
A	SP18	-	1803	567 (not flowing)
A	SP29	-	-	-
A	SP55	-	1556	617 (not flowing)
A	SP113	-	1624	-
A	SP197	-	1531	355 (not flowing)
B	SP37	1205		478
B	SP50	-		64
B	SP54	-		248
B	SP65	-	-	376
B	SP97	1743	1739	1110
B	SP180	-	-	1319
B	SP 190	1720	-	1596

[1] Glover (1977)
[2] Thompson (1960)
[3] Walker (1965)

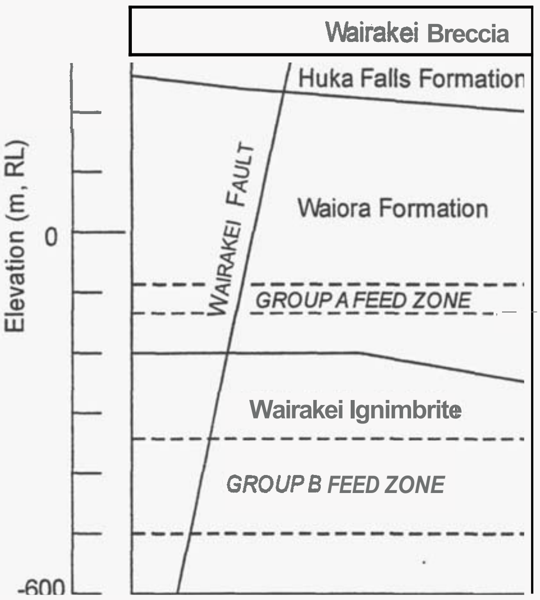

Fig. 5. Geological section through the area of Geyser Valley shown in Fig. 1. From C.P. Wood (pers.comm.).

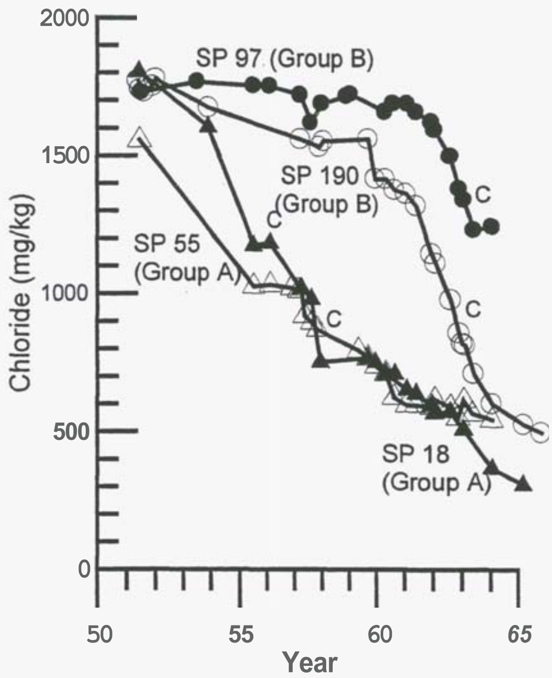

Fig. 6. Variation of chloride content with time. C marks the approximate time of cessation of flow; subsequent measurements were of the non-overflowing pool.

At this time it is estimated that the pressure at the base of the Group A spring feeders was about 32 bar. A pressure gradient of about 10 bar across spring feeders in relatively close proximity would possibly lead to interference effects such as Group B springs recharging Group A springs and this was not observed.

7. SPRING CHLORIDE CHEMISTRY

Chloride concentration in the Group A and Group B springs (Table 3) were all typical of a deep geothermal source in 1886 and 1951. Thompson (1960) records Group A springs SP18, SP55, SP113 and SP197 all declining from 1400-1800 ppm in 1951 to be 0-900 ppm chloride by 1959 (Fig. 6). Two Group B springs (SP97 and SP190), however, remained between 1500 ppm and 1800 ppm chloride between 1951 and 1959 (Fig. 6). By 1962 the chloride concentrations in SP97, SP180 and SP190 were still above 1110 ppm (Fig. 6, Table 3), indicating significant input of deep geothermal reservoir water. Chloride concentrations in other Group B springs were becoming influenced by cold groundwater inflows in 1962, reflected by the relatively low chloride levels. These spring chloride measurements are consistent with the Group A and Group B wells having different elevations for the feeds.

8. DISCUSSION

In this analysis it has been assumed that there was a linear pressure-elevation relationship, associated with complete hydrostatic conditions in and above the reservoir. Pressure- elevation data show that hydrostatic conditions prevailed beneath the Eastern Borefield up until about 1957 (Grant & Horne, 1980). However, subsequent production from the field caused dryout in the upper part of the 2-phase zone beneath the Eastern Borefield resulting in formation of a vapour-dominated steam zone which was about 100m thick by 1962. It is not known if such conditions extended beneath Geyser Valley. Temperatures at about 150 m depth (top of the reservoir) in well Wk 33 (450 m deep), situated about 1km north-east of the Eastern Borefield and 1 km east of Geyser Valley, rose by about 15°C between Nov. 1959 and June 1962, and a further 50°C by Sept. 1966 (Allis, 1982). These temperature increases may have been the result of steam-heating, and suggest that non-hydrostatic conditions may have developed beneath Geyser Valley in the early 1960's. If this had occurred then our assumption of Darcy flow may have been incorrect for the Group B springs and further modelling may be required.

A puzzling result of this analysis is that springs which are close together at the surface, and of similar elevation, may have significantly different feed depths (e.g. SP54 and SP55). The most likely explanation for this is that the spring feeders were independent of each other and this is supported by the lack of any systematic variation in cessation date with elevation.

9. CONCLUSIONS

1. The date of cessation of spring flow is an important parameter in understanding the hydrological changes that occurred.

2. Dates for cessation of flow were not simply related to spring elevation.

3. The springs fall into two groups based on dates of cessation of flow, but are not spatially clustered at the surface.

4. Modelling suggests that one group had feed depths of -90 to -130 mRL in the Waiora Formation, the other fed fiom depths of -350 to -500 mRL in the Wairakei Ignimbrite.

10. ACKNOWLEDGEMENTS

We acknowledge the former DSIR staff who made the historic measurements and thank C. Bromley for information and comments. Funding was provided by the New Zealand Foundation for Research, Science & Technology Contract CO5X0004.

11. REFERENCES

Allis, R.G., 1982. Geologic controls on shallow hydrologic changes at Wairakei Field. *Proc. 4th NZ Geothermal Workshop:* 139-144.

Glover, RB., 1977. Chemical and physical changes at Geyser Valley, Wairakei, and their relationship to changes in borefield performance. *NZ* DSIR *Bulletin 218:* 19-26.

Glover, RB., Hunt, T.M., 1996. Precursory changes to natural thexmal features during testing of the Wairakei and Broadlands-Ohaaki fields. Proc. *18th NZ Geothermal Workshop:* 69-76.

Grant, M.A., Horne, RN., 1980. The initial state and response to exploitation of Wairakei Geothermal Field. *GRC Transactions 4:* 333-336.

Thompson, G.E.K., 1960. Recent variations of chloride content and spring activity at Wairakei Geyser Valley. *NZ Journal of Geology and Geophysics 3:* 265-270.

Walker, I.K., 1965. Changes in the Wairakei Geyser Valley Springs 1962-1965. Unpublished letter fiom Chemistry Division DSIR to the Geothermal Co-ordinator, DSIR 26p.

White, P., Hunt, T.M. 2000. Simple models for changes in geothermal spring flows during early development at Wairakei. *Proc. 22nd NZ Geothermal Workshop:* 203-208.

Wilson, S.H. 1976. Possible conflict between the interests of tourism and geothermal power development. *Proc. 2nd UN Symposium on Development and Use of Geothermal Resources:* 2457-2466.