HABITAT CHARACTERISTICS OF GEOTHERMALLY INFLUENCED WATERS IN THE WAIKATO

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REPORT CONTEXT AND OVERVIEW

The Waikato province contains almost 80% of New Zealand's geothermal systems (Environment Waikato 1998). Thus, this region represents an important resource in terms of the habitat associated with increased soil and water temperatures for both geothermal vegetation (Beadel & Bill 2000) and aquatic organisms (Parkyn & Boothroyd 2000; Duggan & Boothroyd 2001). Associated issues and values range from exploitative resource use, such as thermal energy extraction and the utilisation of mineralised fluids, to historical, amenity, cultural, spiritual, conservation and scientific values (Environment Waikato 1998; Merrett & Clarkson 1999). The environmental management objectives of Environment Waikato are derived from these. The objectives are to maintain the variety of characteristics and to achieve protection and efficient of the regional geothermal resource (Environment Waikato 1998).

The present report provides an inventory of the ecological and physical/chemical characteristics of geothermally influenced water in the Waikato province. The area was surveyed between April 10th and May 9th and assessments of habitat and in situ measurement of environmental parameters (eg DO, pH, conductivity, temperature) were used to determine habitat characteristics. The types of habitats included springs, streams, lakes, and rivers. Transects were used to determine environmental gradients at sites. Observations on habitat suitability or any local factors likely to be adversely impacting on the geothermal habitats were also recorded and all data appear in Appendix 1. The present survey provides relevant background data which will contribute to the development of protection and conservation strategies.

Geological Setting: The geothermal systems of the central North Island occur along a north northeast trending volcanic graben occupied by active volcanism. This reaches from the centre of the North Island to the Bay of Plenty and offshore into the Tong Kermadec Trench. Onshore this is known as the Taupo Volcanic Zone (TVZ) and is about 300 km long and up to 60 km wide. It contains several active and dormant volcanoes.

Most voluminous and widespread is rhyolitic volcanism and its caldera and dome landforms, which occur within the central TVZ. Residual magmas beneath these caldera centres provides the heat source which drives the overlying geothermal systems, together with the emission of volatile elements and gases given off by the cooling rhyolite magmas. About 15,000 km^3 of rhyolitic eruption products have been erupted from the TVZ in its c. 2 MY history (Wilson et al. 1995).

The northeast and southwest portions of the TVZ are characterised by andesitic cone building volcanoes. The eastern margin of the TVZ is a remarkably straight line but the western boundary is more subdued by successive overprinting and weathering. It lies in the southern and eastern section of a larger triangular shaped area of Cenozoic volcanism known as the Central Volcanic Zone (CVZ), which contains the Coromandel and Waikato volcanic landforms and products.

The CVZ-TVZ is regarded as being a consequence of the Pacific and Australian-Indian Plate tectonic regime, which is seen as a deep offshore trench known as the Hikurangi Trough or Margin, which lies about 250 km east of the TVZ. The trough is where the Pacific Plate is being obliquely subducted beneath the Australian Plate. The junction of this subduction zone is marked by a boundary of plunging crustal rocks into the underlying mantle and extends about 350 km westwards of the Hikurangi Margin to about 300 km depth, with its upper portion at about 70 km depth beneath the TVZ (Hunt et al. 1994). It is now believed that the partial melting of crustal rocks in the subduction zone and the consequent rising of magmatic fluids is the source of the high heatflow and volatile elemental emissions from the TVZ.

In the TVZ more than 20 geothermal systems are known and all are clearly associated with volcanism in the TVZ and magma bodies (>800 ^{o}C) in the earth's crust. It is considered that meteoric waters percolate downward some 3-10 km and interact with the magma bodies or extensive zones of heated brines and rocks, then buoyantly rise upwards again through fractures produced by the high rates of tectonic deformation associated with the plate margin subduction and rotation.

Active geothermal systems in the TVZ are mostly located in the central rhyolitic portions of the TVZ and are identified by a combination of geophysical (electrical resistivity, magnetic and gravity surveying), geological (alteration products) and chemical (isotope and magma derived volatile elements). The occurrence of thermal features on the ground surface is the most obvious manifestation of geothermal systems, although the size, type and number of these features does not relate at all to the size and deep temperatures of the underlying geothermal system.

Electrical resistivity soundings show steep gradients across boundaries of geothermal systems, where values of >500 ohmmetres occur outside of these systems but drops rapidly to <20 ohmmetres inside active geothermal systems. The very low readings are produced by highly conductive saline fluids at depth, although in a few places cold altered or mineralised ground may also produce low readings. Unaltered cold basement rocks are typified by very high readings.

Geothermal systems in the TVZ are all closely related to caldera structures, as they all lie within or beside calderas. Where calderas have a history of multiple eruptive episodes over 10 – 100s of thousands of years, that activity represents a long period of ongoing high heatflow from large magma bodies emplaced at shallow depths in the earth's crust. The high rate of tectonic deformation, crustal fracturing associated with caldera openings and the high permeability of highly brecciated and shattered volcanoclastic deposits are all conducive to good vertical permeability of meteoric waters to circulate.

Geothermal Features of the Waikato Region: The geothermal fields and warm outflow waters surveyed are a major proportion of all New Zealand's geothermally influenced waters. However, these sites are part of a continuum extending further northwards into the adjoining Environment Bay of Plenty (EBOP) region. As an indication of the geothermal features within the Environment Waikato (EW) region, the following numbers give an approximation of the percentages of geothermal feature types by area.

Type of Feature:		**Environment Waikato:**		**Environment BOP:**	
		No:	**%:**	**No:**	**%:**
Geysers		52	75	17	25
Alkaline springs:	Boiling	120	80	30	20
	Non boiling	90	67	45	33
Sinter deposition sites		60	70	25	30
Heated Streamways (km)		45	70	20	30

All geothermal fields have some unique features and characteristics associated with them. Only Orakeikorako contains excellent examples of all geothermal features, even though this field has been greatly modified by human activity; i.e. the construction and filling of Ohakuri Dam in February 1961. However, almost every geothermal field in the EW region has been changed by human activity, with perhaps Waiotapu and Te Kopia being the least modified of all, although Te Kopia is largely steam heated surface features with very little warm outflow.

It is therefore least susceptible to major change due to reduction of hot stream outflow, because those feature types are almost absent to begin with.

Waikite Valley geothermal features are presently in their largely natural condition, but extensive sinter terraces once occurred in the upper Puakohurea springs area and there is ~1 km^2 of intensely altered but now cold ground is also present there. Both these are possibly of prehistorical activity as there are no records to confirm their historical demise. However, the cessation of sinter terrace growth is a response to be expected to accompany the draining and clearing of marshy low lying stream flats along the upper Otamakokore Stream, which began in earnest during the 1940s and immediate post war years.

Geothermal springs and geysers: Sinter-depositing springs generally produce neutral to alkaline fluids at or near boiling temperature. Acidic springs can dissolve and deposit silica also, but these do not usually form extensive continuous sinters (Luketina et al. 2002). Recently, Luketina et al. (2002) have provided an extensive inventory of actively sinter-depositing springs and geysers in the Waikato region. Although most springs in the present study were alkaline (pH up to 9.3), 6 of the geothermal fields examined in the present report were found to have examples of acidic springs (Orakeikorako, Reporoa, Rotokawa, Te Kopia, Waimangu, and Waiotapu) with pH variations between 2.7 and 4.5. The temperature range for acidic springs (15.7 ºC at Rotokawa – 95.3 ºC at Waimangu) was similar to the range for alkaline springs (15.0 ºC at Wairaki – 99.4 ºC at Orakeikorako). In addition to the current report, chemical analyses of geothermal features are included in Huser & Jenkinson (1996). However, one problem identified by Luketina et al. (2002) is the accurate recording of names and locations of geothermal features. Accordingly, we used GPS readings (New Zealand map grid reference) to accurately record locations for all geothermal sites examined.

Geothermal biota: Beadel and Bill (2000) provide a thorough inventory of the distribution and extent of geothermal vegetation, and assessment of the relative significance of each site. They identified, mapped, and classified known areas (with an area of at least 1 ha.) of geothermally-influenced terrestrial and emergent wetland vegetation in the Waikato region. The work by Merrett and Clarkson (1999) also compiled an annotated bibliography of reports (using 32 published sources) relevant to geothermal vegetation occurring within the boundaries of the Waikato region. The spatial dynamics of algae and macroinvertebrates in the Taupo Volcanic Zone have been reported on by Duggan and Boothroyd (2001), and Parkyn and Boothroyd (2000) provided an annotated bibliography of aquatic biota of geothermal ecosystems. The main focus of these reports was to examine the responses of biota to environmental gradients in stream habitats and to identify any influences of habitat and environmental factors on the diversity and distribution of aquatic geothermal biota. Generally, temperature and pH were the dominant factors controlling community composition and abundance of macroinvertebrate species within and between geothermal fields (Duggan & Boothroyd 2001).

The present inventory when combined with these previous reports will provide comprehensive coverage of the significant features in geothermal ecosystems within the Waikato province. This will assist resource managers to focus conservation efforts on important environmental features of these systems, to measure changes in ecosystem health, and to develop appropriate tools and indicators for bio-monitoring.

GEOTHERMAL SITES

1. ATIAMURI

There are several hot springs known in this region, although many are now submerged after the filling of Lake Atiamuri in January 1961 (Luketina et al. 2002). Only two main springs are depositing sinter at present (Fig. 1).

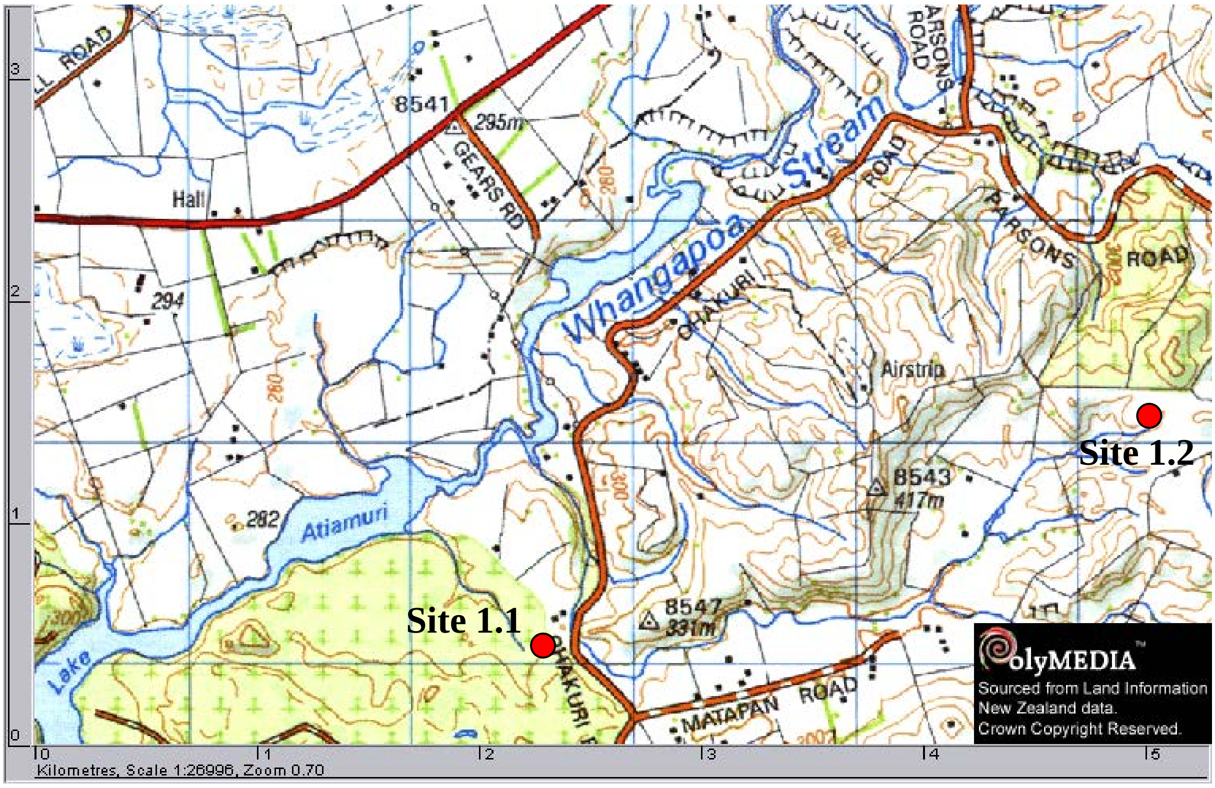

Figure 1. Site 1.1 and 1.2 locations in the Atiamuri geothermal region.

1.1 Whangapoa Springs

This site is located to the north of the Waikato River between Atiamuri and Ohakuri near the intersection of Ohakuri, Matapan, and Ngautuku Roads (Fig. 1) and accessed through a vehicle track about 100m off Ohakuri Road (Fig. 2). Two hot sinter-depositing springs drain artificially into a non-geothermal wetland. These springs have extensive pre-historic sinter deposits around them and could again grow sinters if their artificial outflows were blocked and the waters allowed to disperse naturally. This region was previously exotic pine forest but now has been converted to pasture. Erosion is a problem where vegetation is lacking. The two springs were gifted to DoC, who have fenced the small zone around the springs. In this zone pine trees have also been felled, but the existing vegetation is sufficient to maintain substrate stability.

Figure 2. Site access off Ohakuri Road, 100m along the farm access drive. The surrounding area used to be exotic forestry but has now been cleared for pastoral use. Steam from East Pool can be seen on the far right side of the photo.

Site 1: East Pool

Location: Grid reference: U16 2776601E, 6311058N, alt. 282m.
Description: A clear circular pool (12x10m) with vertical walls surrounded by pastoral/horticultural land (see Figs. 3, 4). Some attached algae was observed growing at the margins, however no obvious growth in or near pool. Hot (55-56ºC, see Table 1) sinter-depositing (spongy organic sinters) spring draining to a non-geothermal wetland (see Fig. 5).

Site 2: West Pool

Location: Grid reference: U16 2776587E, 6311132N, alt. 285m
Description: A clear pool (10x7m), with a single outflow (2m wide by 0.15m deep) located 20m north of East Pool. Attached algae in the pool was surrounded by geothermal ferns on overhanging vertical banks about 1.5m above the water level (Fig. 6). This is a hot (52-57ºC) sinter-depositing spring draining to the same non-geothermal wetland as East Pool (Table 1). The drain (Fig. 7) was excavated to form a trench (1.0x1.5m) to divert flows for a swimming pool in the 1970s (no longer present) (see Luketina et al. 2002). Exposed sinters show that extensive sinter sheets once grew over approximately 2 hectares (down to the wetland).

Figure 3. The vertical walls of East Pool (Site 1) are visible below the surface of the water. The pool is used for scalding fur and feathers off game near the platform on the far side of the spring.

Figure 4. Bacterial and algal growths can be seen on substrate within the pool.

Figure 5. Sinters and coloured algal mats growing along the outflow plume. The outflow heads west into a tributary of the Whangapoa Stream.

Figure 6. Attached algae in pool surrounded by geothermal ferns on overhanging vertical banks about 1.5m above the water level. It is doubtful that the spring would generate sinter again if the outlet channel was blocked because it may not have sufficient head to overcome the height. Also, sinter-deposition is quite weak now, indicating a reduction in silica over time (Luketina et al. 2002).

Table 1. Chemistry of the Atiamuri geothermal field. *Previous records from 1978 taken from Luketina et al. (2002).

Name	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp °C	Total dissolved solids (g/l)	Flow rate (m/s)	Salinity (ppt)
1.1 Whangapoa Springs							
Site 1: East Pool	8.1	2.37	2.92	55.8	1.5	0.2	0
Eastern spring*	8.7			69.0			
Site 2: West Pool	7.9	2.45	3.67	57.4	1.6	0.21	0
Western spring*	8.6			67.0			
1.2 Matapan Road Springs							
Site 1: source in cliff	7.3	0.709	0.46	69.4	0.45	0.22	0
Site 2: foot of cliff	8	0.442	6.83	42.6	0.28	0.11	0
Site 3: 40m downstream	8.5	0.443	9.27	33.8	0.29	0.16	0

Figure 7. Four metres below West Pool at the outflow, where measurements were taken.

1.2 Matapan Road Springs

Location: Grid reference: U16 2779214E, 6312036N, alt. 335m.
Description: Small spring seepage producing clear water from a fissure in the ignimbrite cliff (Fig. 8) but without any sinters at about 69ºC, and decreasing to 43ºC below seep, to 34ºC 40m downstream (see Table 1). Site is surrounded by pastoral/horticultural land. Some attached algae and bacterial growth in water channel (see Fig. 9). Three sites measured: 1) at seep; 2) at the bottom of the cliff; and 3) 40m downstream.

1.3 Ohakuri Road Springs

Warm springs in the stream immediately north of the intersection of Ohakuri and Parsons Roads. This site was examined but no evidence of any geothermally influenced waters was found.

Figure 8. Small spring seepage from a fissure in the ignimbrite cliff producing clear water with a small pool at the bottom of the cliff and flows into a stream 40m downstream.

Figure 9. Attached algae and bacterial growth in pool below cliff.

2. HOROHORO SPRINGS

Region approximately 15km SW of Rotorua (Fig. 10) is known for minor hot springs with associated sinter deposits and small hydrothermal explosion craters. Most of the springs in this geothermal system have very extensive extinct sinters, dried-up spring basins and big explosion craters (Hedenquist 1984). In recent historical time there has been no boiling or geysering known here. We examined two hot springs with pools about 1km SW of Haparangi Mountain.

2.1 Horohoro Springs

Site 1: Horohoro South Spring
Location: Grid reference: U16 2788088E, 6322910N, alt. 365m.
Description: Spring influenced stream at the base of a steep slope in a swampy gully producing clear water (dark sulphite peaty walls and substrate) (see Fig. 11) surrounded by a stand of treeferns and pines. However, the dominate land-use is pastoral. This is a hot spring (82ºC) decreasing to 23ºC 40m downstream (Table 2). It has white sinters depositing as thin, sparse rinds with some filamentous algae and bacterial growth in the spring. Four sites

measured: 1) at spring source; 2) 10m downstream; 3) 20m downstream; and 4) 40m downstream.

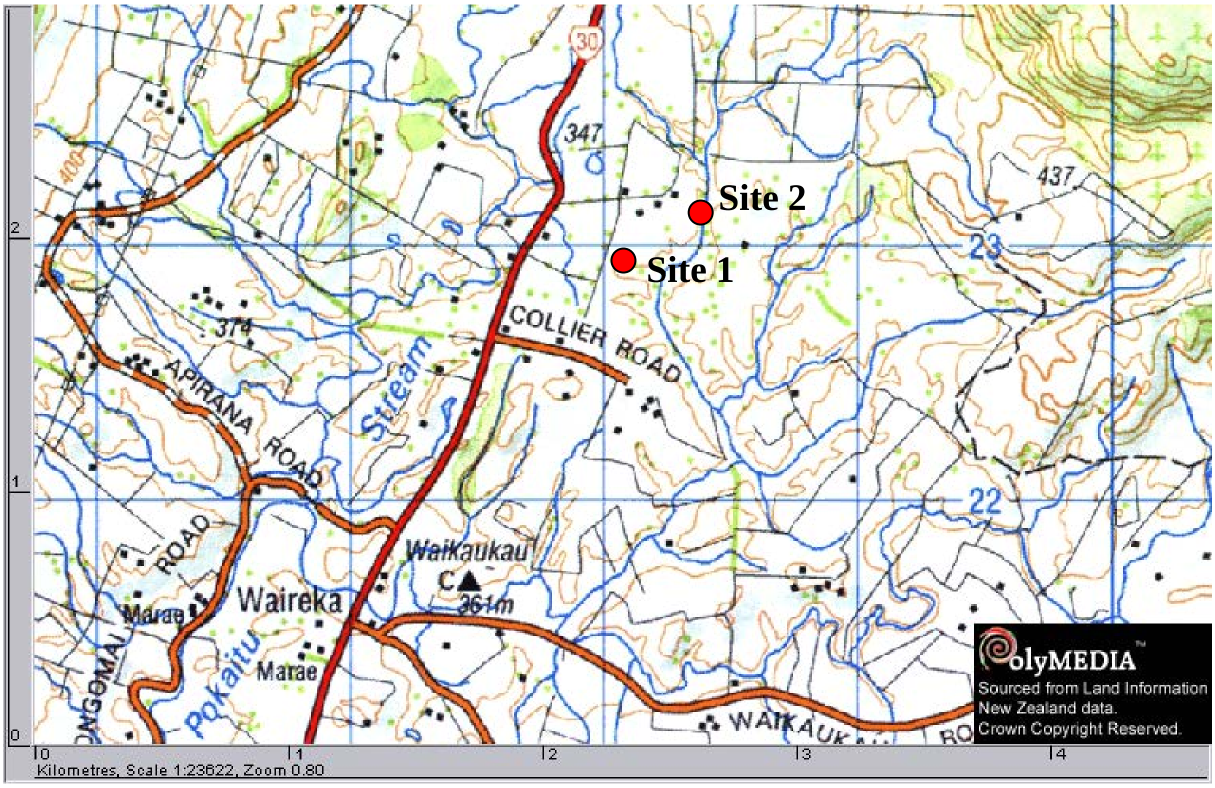

Figure 10. Site 1 (Horohoro South Spring) and Site 2 (Waipupumahana Spring) locations in the Horohora geothermal region.

Figure 11. Location at the Horohoro South Spring (Site 1).

Site 2: Waipupumahana Spring
Location: Grid reference: U16 2788386E, 6323144N, alt. 352m.
Description: This is the largest active feature in the Horohoro region. Sinter (silica) depositing spring with an outflow to a stream in pastorally-dominated land-use area (Fig. 12). Hot spring (51ºC) decreasing to 37ºC where the geothermal water meets the stream (Table 2). The pool (15x12m) has vertical sinter walls on the eastern half where the silica deposits are damming the lower edge of the pool (except for a channel excavated by local Maori). Some algal mat growth in the upper-side of pool is present (see Fig. 13). Four sites measured: 1) at source (pool); 2) between pool and stream; 3) two water sources meet; and 4) 10m downstream.

Figure 12. Waipupumahana Spring. The silica deposits damming the lower edge of the pool can be seen where a channel has been excavated by local Maori to fill baths. A log in the northern side of the pool is known as the pool's caretaker "Korowhakatipua" (Maxwell 1990).

Figure 13. Algal mat growth in the upper-side of pool.

Table 2. Chemistry of the Horohoro geothermal field. *Previous records from 1984 taken from Luketina et al. (2002).

Name	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp ºC	Total dissolved solids (g/l)	Flow rate (m/s)	Salinity (ppt)
2.1 Horohoro Springs							
Site 1: Horohoro South Spring	7.8	1.16	0.22	81.8	0.7	0.02	0
Gully spring*	8.5			81.5			
Site 2: 10m downstream	8.7	1.09	6.09	38.8	0.7	0.02	0
Site 3: 20m downstream	8.6	0.812	7.89	26	0.52	0.01	0
Site 4: 40m downstream	8.2	0.771	8.1	23.2	0.49	0.02	0
Site 5: Waipupumahana Spring	8.6	1.11	4.94	50.9	0.7	0.09	0
Waipupumahana spring*	8.4			49.4			
Site 6: mid-way between spring and stream	8.5	1.1	5.42	48.7	0.7	0.25	0
Site 7: at stream	8.8	1.18	7.65	37.4	0.7	0.12	0
Site 8: 10m downstream	8.2	0.115	13.49	16.2	0.07	0.32	0

3. MOKAI

3.1 Mulberry Road, Waipapa Stream

Site located 20 km NW of Taupo in pine forest, near where the Waipapa Stream comes to Mulberry Road (private forest road off Tram Road from SH1) (Fig. 14). The site is located 4.7km along Mulberry Road. The region is known for mudpools, warm and steaming ground, collapsed pits, and numerous hot springs. At this site a track leads down off the main forestry track to hot springs and steam vents draining into the Waipapa Stream along approximately a 200-300 m length of the stream.

Site 1

Location: Grid reference: T17 2767817E, 6300938N, alt. 340m.
Description: Extensive algal mats at Site 1, although none were present in the flow channel (see Figs. 15 and 16) and the temperature would not prevent growth (see Table 3).

Site 2

Location: Grid reference: T17 2767871E, 6300938N, alt. 354m.
Description: The site is in the Waipapa Stream (Figs. 17, 18) with a small geothermal influence (23.7°C).

Site 3

Location: Grid reference: T17 2767847E, 6300938N, alt. 301m.
Description: The site is also in the Waipapa Stream (Fig. 19), although the temperature would indicate an additional geothermal influence (29.7°C) compared to Site 2.

Figure 14. Mulberry Road, Waipapa Stream (Site 3.1) location in the Mokai geothermal region. A total of three sites were examined in the Waipapa Stream, including a fourth spring site located between the stream and Mulberry Road.

Figure 15. Spring source at Site 1. Note the lack of algae in the channel.

Figure 16. Immediately downstream from Site 1, in a tributary of the Waipapa Stream.

Figure 17. Upstream of Site 3, looking at Site 2-right side, Site 1-upper left side.

Site 4
Location: Grid reference: T17 2767864E, 6300954N, alt. 303m.
Description: The site is a separate spring above the height of the Waipapa Stream (Fig. 20). The site is located along the foot track between the Waipapa Stream and Mulberry Road.

Table 3. Chemistry of the Mokai geothermal field. *Previous record from 1978 taken from Luketina et al. (2002).

Name	**pH**	**Conductivity (ms/cm)**	**Dissolved Oxygen (mg/l)**	**Temp ºC**	**Total dissolved solids (g/l)**	**Flow rate (m/s)**	**Salinity (ppt)**
3.1 Mulberry Road, Waipapa Stream							
North Mokai*	6.6			58.0			
Site 1	7.8	2.11	2.68	60.0	1.2	0.16	0.1
Site 2	8.1	0.409	13.06	23.7	0.26	0.36	0
Site 3	7.7	0.612	9.47	29.7	0.35	0.57	0
Site 4	7.1	2.45	4.18	53.1	1.4	0	0.1

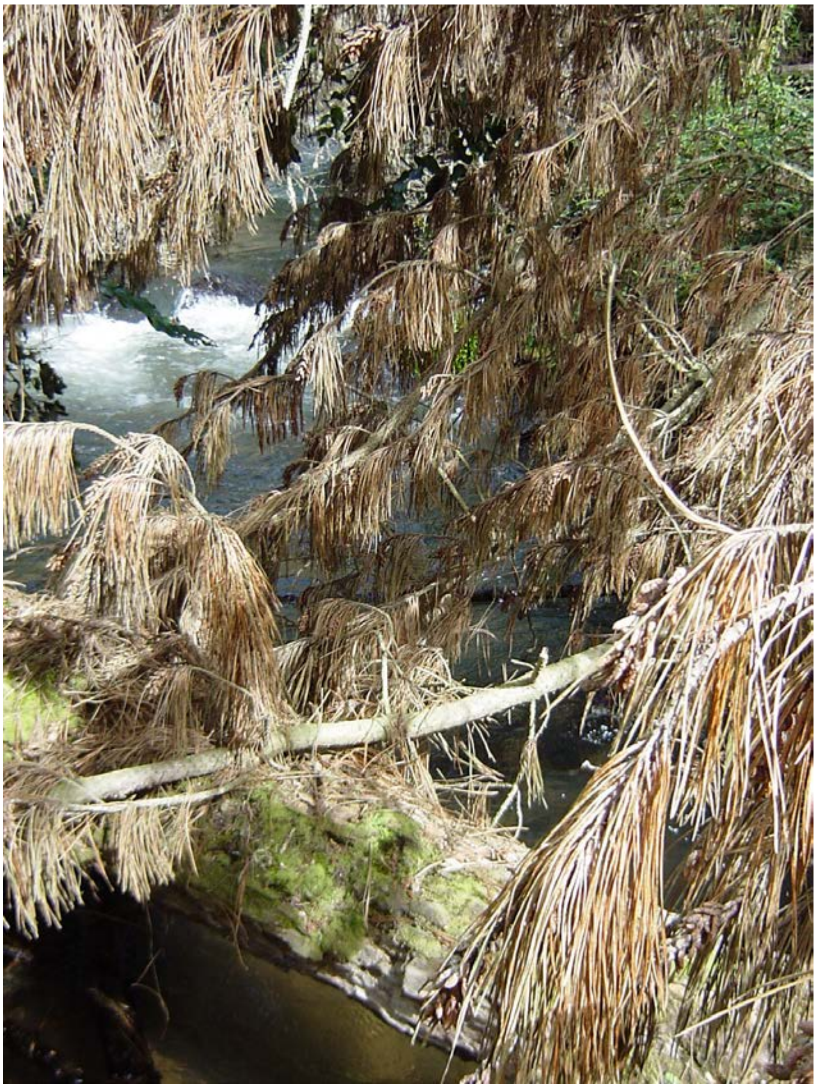

Figure 18. Measurements at Site 2 were taken from the log in the Waipapa Stream.

Figure 19. Site 3 is located in an area where the Waipapa Stream is diverged from the main stream channel for 20-30m.

Figure 20. Site 4, separate thermal pool on right side of stream but above the stream height.

4. TE NGATAMARIKI

The thermal springs are located 5km south of Orakeikorako, 20 km NNE of Taupo on the banks of the Orakonui Stream (Fig. 21). A number of hot pools, springs, and seepages are located along the Orakanui Stream in the Tahorakuri Forest. Currently five sets of features actively depositing calcite sinters and one actively depositing silica sinters. One of these occupies a hydrothermal explosion crater which formed about 1950.

4.1 Northern Springs

This area of the Orakonui Stream (bank) is active over 50x100m. A total of four sites were measured in the Northern Springs area (see Table 4).

Site 1
Location: Grid reference: U17 2786781E, 6292194N, alt. 304m.
Description: Main spring area, upwelling occurs 4m upstream (Fig. 22).

Site 2
Location: Grid reference: U17 2786741E, 6292198N, alt. 306m
Description: Near-boiling spring outflow (Fig. 23), runs into stream. The vegetation type in this area is predominantly native with some pines.

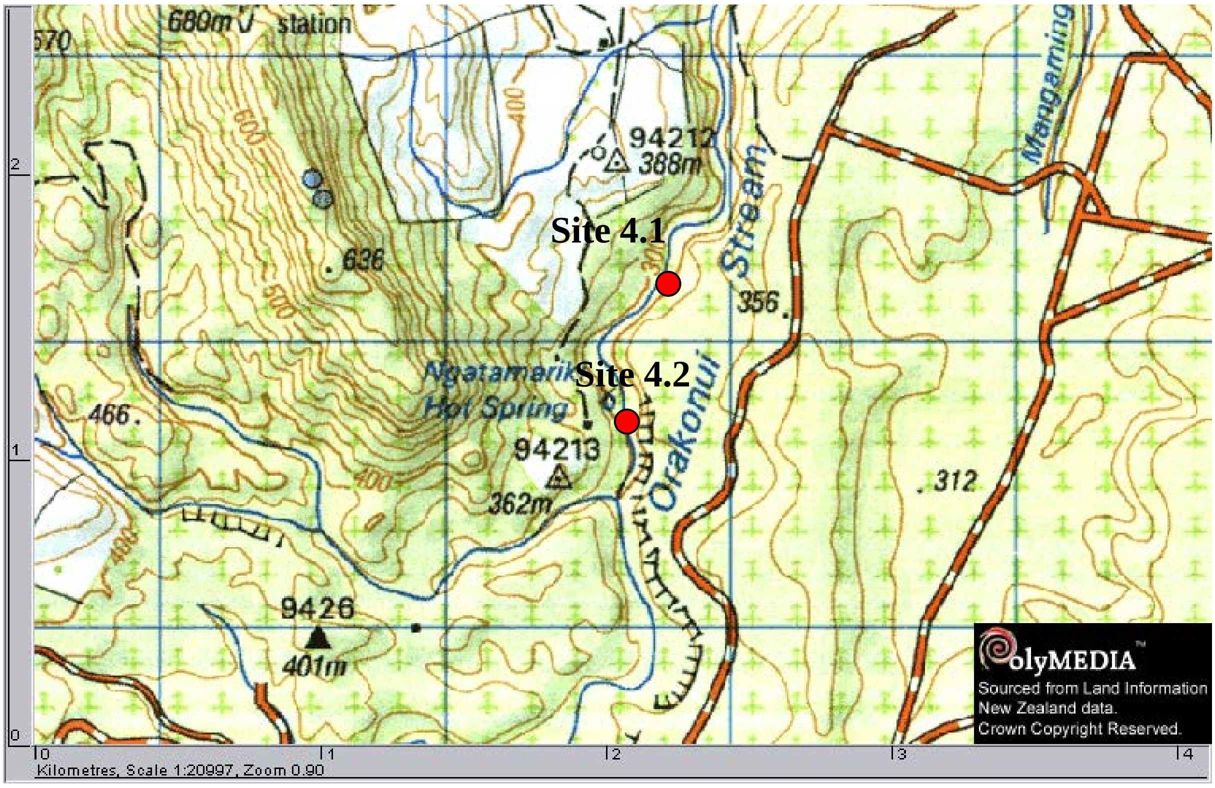

Figure 21. Te Ngatamariki geothermal region along the Orakonui Stream showing the locations for the Northern Springs (4.1) and Southern Springs (4.2).

Figure 22. Extensive sinters present at Site 1, with coloured algae and gelatinous masses of microbial growths over a 10x30m area. Arrow indicates present spring source for the stream which flows to the left of the photo towards the Orakonui Stream.

Figure 23. Site 2 hot spring with filamentous bacterial growths.

Site 3
Location: Grid reference: U17 2786742E, 6292174N, alt. 310m.
Description: Stream next to Site 2 (Fig. 24).

Site 4
Location: Grid reference: U17 2786779E, 6292209N, alt. 312m.
Description: Downstream from Site 1 (Fig. 25).

Figure 24. Site 3 was location in the stream next to Site 2.

Figure 25. Site 4, where measurements were taken at this site downstream from site 1.

4.2 Southern Springs

Orakanui Stream runs through this area. The region is active over 50x100m. Five sites were measured in this area including a newly formed boiling pool (Table 4). The instability of this region is obvious. The area use to be a lake until 2 years ago when the bank collapsed filling with pumas, now water seeps through and the landscape is always changing with collapse of the ground and new pools developing.

Site 1 (South Spring)
Location: Grid reference: U17 2786634E, 6291724N, alt. 300m.
Description: The banks are supported by rotten logs and the area is quite variable. Measurements were taken (Table 4) under fallen pine in the outflow (Fig. 27).

Figure 26. The steam from Site 1 can be seen. Orakanui Stream is located approximately 30m to the right of Site 1.

Table 4. Chemistry of the Te Ngatamariki geothermal field. *Previous records from 1974 taken from Luketina et al. (2002).

Name	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp ºC	Total dissolved solids (g/l)	Flow rate (m/s)	Salinity (ppt)
Northern Springs							
Northern springs*	7.5			96.0			
Main Lakelet*	7.3			68.0			
Site 1: Main spring	7.1	1.53	1.92	66.3	1	0.27	0.1
Site 2: spring seepage	7.4	2.21	0	94.1	1.4	0.2	0.1
Site 3: stream	9.1	0.168	18.65	16.4	0.11	0.38	0
Site 4: downstream	8.1	0.304	7.15	32.4	0.2	0.24	0
Southern Springs							
Site 1: South Spring	7.4	3.44	0	79.5	2.2	0.09	0.2
Site 2: lake outlet	7.5	1.93	5.43	54.3	1.2	0.26	0.1
Site 3: Nor-west Spring	7.9	2.73	6.94	49.6	1.7	0	0.1
Site 4: Calcite Spring	7.8	3.51	2.44	70	1.9	0.08	0.2
Site 5: new spring	8.1	4.23	0	80.3	2.3	0.02	0.2

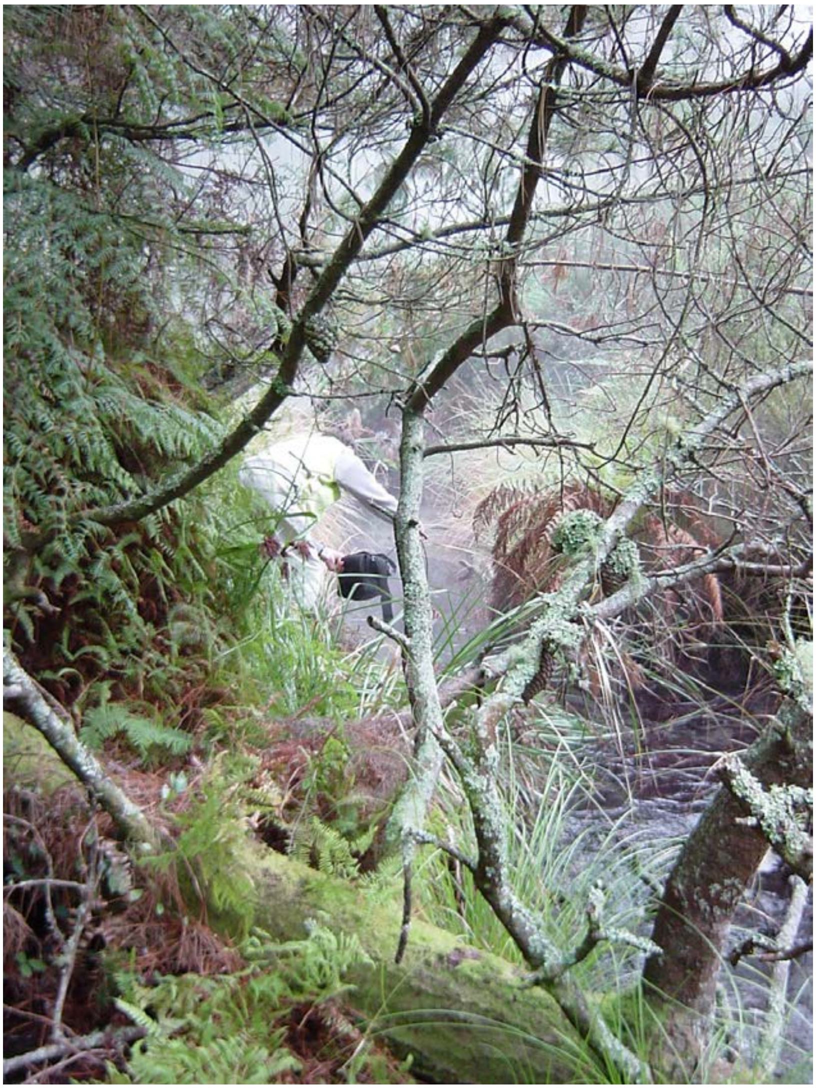

Figure 27. Measurements at the outlet at Site 1. The flow from this outlet joins the Orakanui Stream.

Site 2
Location: Grid reference: U17 2786609E, 6291782N, alt. 311m
Description: This area was once a large pool about 2 years ago (now filled by a land-slide), here measurements (Table 4) were taken at an outlet from water that remains below the filled area (see Figs. 29-30). There is a high percentage of pumas (40%) with mud/silt (60%) in the soil.

Figure 28. Site 1 measurements in the main upwelling pool. The upwelling area can be seen under the dead branches at the tip of the fallen pine.

Figure 29. One of us (ADC) takes measurements at the outflow of the lake.

Figure 30. Sunken bank with boiling water below ground often causing the ground to subside near Site 2. Algal mats growing on surface in the stream.

Site 3 (Nor-west Spring)
Location: Grid reference: U17 2786596E, 6291838N, alt. 307m.
Description: Cooler pool than other pools/springs in the immediate area due to a cool inflow from the opposite side of the pool (see Fig. 31, Table 4).

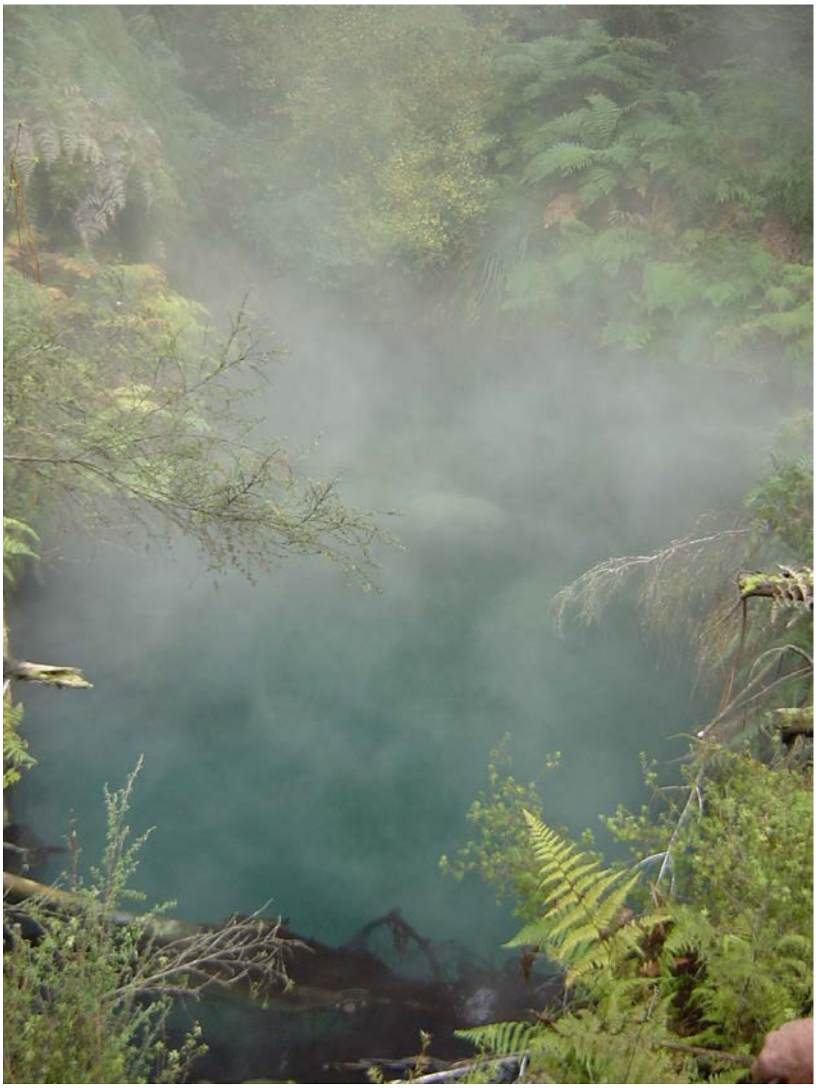

Figure 31. Nor-west pool.

Site 4 (Calcite Spring)
Location: Grid reference: U17 2786625E, 6291876N, alt. 306m.
Description: A clear and calm spring located on the west bank, approximately 10m from the Orakonui Stream (Fig. 32). On the margins sinter deposits are approximately 10-50mm wide, these white sinters are extensive over the outflow channel spillway (Figs. 32-33). The site contains filamentous and gelatinous microbial masses seen in Figures 32 and 33.

Figure 32. Calcite Spring (Site 4) is a clear and calm spring with brilliant white sinters around the lip.

Figure 33. Calcite spring (Site 4) showing the outflow channel spillway (2-3m wide, 8m long). The outflow contains filamentous and gelatinous microbial masses which continue towards Orakonui Stream.

Site 5 (new spring)
Location: Grid reference: U17 2786611E, 6291774N, alt. 311m
Description: A newly formed (since February 2003) boiling spring (Table 4). Sinter deposits around edge on the water level (Figs. 34-35).

Figure 34. Photo showing the new boiling pool (lower pool) where measurements were obtained (Site 5, see Table 4). Sinter deposits already obvious around the level of the water.

Figure 35. The upper pool of Site 4 seen in the foreground (see Fig. 34).

5. ORAKEIKORAKO

On the Waikato River, 37 km SSW of Rotorua (Fig. 36). New Zealand's most extensive sinter deposits, deposited from the silical-bearing discharge of a spectacular array of hot springs and geysers. Seventy five percent of the hot springs were submerged in 1961, by construction of Ohakuri hydro-dam and the resulting lake which raised the level of Waikato River by 18m (Lloyd 1972). This area also contains mudpools and hydrothermal explosion craters. The field has a surface area of 1.8 square km and has three main attributes: 1) Only known chalcedonic sinter in the volcanic region; 2) Prolific blue-green algae which inhabit the cooled thermal waters; 3) Large collapse feature known as Ruatapu. There are around 100 or more sinter-depositing springs in this region, here we examine some of the main sites (Fig. 36).

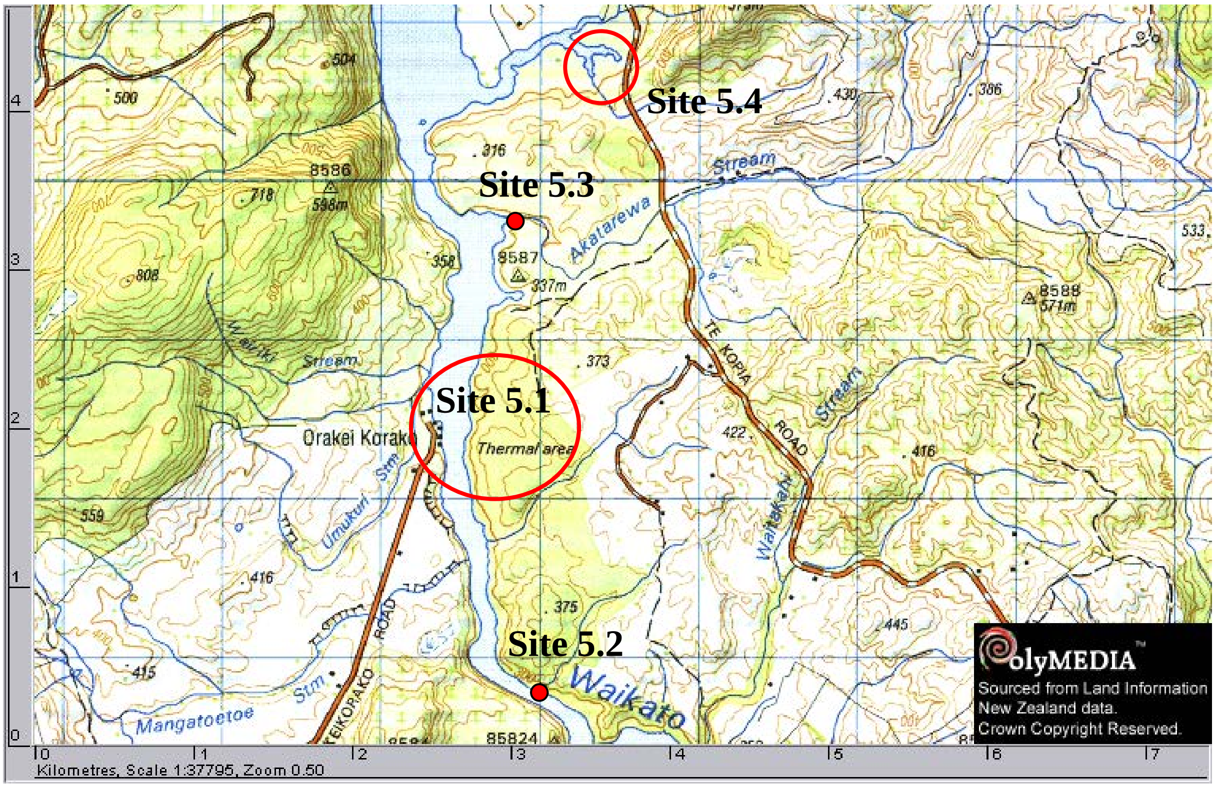

Figure 36. Location of main sites throughout the Orakeikorako geothermal region along the Waikato River.

5.1 Te Kapua (Waipapa Valley)

This is a small valley approximately 0.5km by 0.2km on the east bank of the Waikato River. This is the main tourist area and has many hot flowing springs and geysers (30+ geysers; 20+ boiling springs). Extensive sinter terraces lead to the Waikato River in the Orakeikorako tourist area (see Fig. 37). Eight sites were examined here (one site was located on the western side of Waikato River).

Site 1 Waiwhaakata (cave)
Location: Grid reference: U17 2784835E, 6298425N, alt. 308m.
Description: A large cave with two chambers, formed by collapse, containing pools of acidic sulphate water (Fig. 38; Table 5).

Figure 37. Overall site of the Hidden Valley tourist area at Waipapa Valley.

Figure 38. Acid spring at Waiwhaakata (cave), Site 1.

Site 2 "Cauldren" (S124)
Location: Grid reference: U17 2784766E, 6298519N, alt. 320m
A calm hot spring (see Table 5) about 4m in diameter at the base of the Golden Fleece fault scarp. The spring is actively depositing silica sinter (Figs. 39-40).

Figure 39. "Cauldren", measurements carefully obtained by one of us (ADC) at this hot boiling spring that has been known to geyser regularly until recently.

Figure 40. Gelatinous masses present at the "Cauldren" spring.

Site 3 Manganese Pool (S120)
Location: Grid reference: U17 2784751E, 6298523N, alt. 320m.
Description: Hot spring actively depositing silica sinter at the western end of Golden Fleece terrace (Fig. 41). A clear calm spring about 2m diameter, usually the water level is below the overflow. However, the spring was flowing at this time.

Figure 41. Manganese Pool with a small outflow to the right. The massive dense sinters coat the walls and the surrounding terrace.

Site 4 Fred & Maggie Pools (S119)
Location: Grid reference: U17 2784752E, 6298548N, alt. 311m.
Description: Boiling spring actively depositing silica sinter (Fig. 42). This is a boiling (Table 5), flowing spring on the central Golden Fleece terrace. The basin is about 2m in diameter, but of an irregular shape. Dense sinters coat the walls and the outflow channel (Fig. 42).

Site 5 "Devils Throat" (S1007)
Location: Grid reference: U17 2784702E, 6298569N, alt. 307m.
Description: A noisy boiling and flowing spring which geysers occasionally to 1m. The spring lies within an area of recent crumbling collapse on the fault scarp itself and now deposits silica sinter at the base of Rainbow Fault scarp (Figs. 43-44).

Figure 42. Fred & Maggie Pools. This is a boiling, flowing spring located on the central Golden Fleece terrace. The dense sinters coat the walls and the outflow channel which flows from the boiling point where one of us (ADC) takes measurements.

Figure 43. “Devils Throat” at the top of the Rainbow Fault scarp (arrow indicates location of spring).

Figure 44. “Devils Throat” (top photo) where we found invertebrates (bottom photo) under sinter deposits.

Site 6 "Map of Africa"
Location: Grid reference: U17 2784676E, 6298553N, alt. 313m
Description: In the Rainbow Fault terrace area, one of many hot springs depositing silica sinters and contributing to a coalescing mass of sinter terracing (Figs. 45-46).

Figure 45. Sampling at "Map of Africa".

Figure 46. Starlings (indicated by arrow) feeding on algal mat above "Map of Africa".

Site 7 Diamond Geyser (S95)
Location: Grid reference: U17 2784887E, 6296887N, alt. 296m.
Description: An active geyser at the western base of Rainbow Fault scarp. The irregular sinter-lined basin is enclosed by massive sinter deposits on the west, and is 1.7 m by 1.6 m at the surface and 3.7 m deep (Fig. 47). Its eruptions are irregular, lasting from a few minutes to several hours, and can eject water up to 3 m, although occasionally jets reach a height of 9 m. The outflow fans across the southeast portion of Rainbow terrace, where green and orange masses of algae flourish.

Figure 47. Diamond Geyser. This geyser only flows during an eruption.

Site 8 "Map of Australia" (Papakainga-S25)
Location: Grid reference: U17 2784264E, 6298537N, alt. 308m.
Description: A hot spring actively depositing silica sinter located along the west side of the river near the main tourist reception and accommodation. The spring is a clear alkaline (see Table 5) flowing spring approximately 10x5m area. It has dense silica sinter walls and outflow channel deposits (Fig. 48).

Figure 48. A 10x5m upwelling spring (Map of Australia) on the western side of Waikato River.

5.2 Red Hills

This area is up river and south of the main tourist area Boiling springs and geysers are along the riverbanks building sinters. There are two boiling springs alongside the east bank of Waikato River. The site has not been recently visited.

Site 1 Stream site
Location: Grid reference: U17 2785008E, 6296814N, alt. 278m.
Description: Stream flowing into Waikato River (Fig. 49).

Site 2 Boiling pool
Location: 30m above Site 1.
Description: Boiling pool with massive silica sinter deposits, geysers occasionally (Fig. 50). The pool flows into the stream (Site 1).

Site 3
Location: Grid reference: U17 2784946E, 6296755N, alt. 293m.
Description: In centre of river, opposite Site 1 (Fig. 51).

Site 4
Location: Grid reference: U17 2784757E, 6297093N, alt. 305m.
Description: Boiling pool 2m from river, outflow into river. Sinter deposits and moss around lip (Fig. 52).

Figure 49. Stream at Site 1, upstream beyond tourist area.

Figure 50. Boiling pool (Site 2) 30m above Site 1. The spring geysers occasionally.

Figure 51. Site 3 in the centre of the Waikato River, opposite Site 1 (indicated by arrow).

Table 5. Chemistry of the Orakeikorako geothermal field. *Previous records taken from Luketina et al. (2002).

Name	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp ºC	Total dissolved solids (g/l)	Flow rate (m/s)	Salinity (ppt)
Te Kapua (Waipapa Valley)							
Site 1: Waiwhaakata	3.2	2.26	7.02	38.7	1.8	0	0.1
Site 2: Cauldren	7	2.39	0	88.8	1.4	0	0.1
Site 3: Mn Pool	7.7	2.33	0	98.8	1.4	0.28	0.1
Site 4: Fred & Maggie Pools	7.5	2.3	0	97.8	1.4	0.22	0.1
Site 5: Devils Throat	9	2.1	7.72	48.7	1.3	0.09	0.1
Site 6: Map of Africa	8.7	1.96	5.05	55.4	1.3	0	0.1
Site 7: Diamond Geyser (S95)	8.2	2.48	0	97.5	1.7	0.2	0.1
Diamond Geyser*	8.7			99.0			
Site 8: Map of Australia	7.8	1.99	0	83.9	1.3	0	0.1
Map of Australia*	8.5			72.0			
Red Hills							
Site 1: Waitakahi	8.8	0.472	6.33	34.3	0.31	0.17	0
Site 2: Boiling pool	8.9	2.56	0	97.5	1.05	0	0.1
Site 3: centre of river	5.6	0.255	12.4	17	0.16	0	0
Site 4: Boiling pool	8.2	2.12	0	99.4	1.2	0.13	0.1
Akatarewa	8.5	0.606	6.14	30.4	0.38	0.01	0
Waihunuhunu Stream							
Site 1: at culvert	6.6	0.701	1.76	54.2	0.45	1.45	0
Site 2: West inlet	7.6	0.449	6.98	24.7	0.29	0	0
Site 3: upstream of site 2 at source	8.4	1.05	2.68	62.8	0.7	0.25	0
Site 4: right arm	5.9	0.447	9.67	22.9	0.28	0	0

Figure 52. Boiling pool (Site 4) 2m from river, outflow into Waikato River.

5.3 Akatarewa

Location: Grid reference: U17 27848848E, 6299754N, alt. 294m.
Description: Active geysers and boiling flowing springs (not accessible) about 10m above a freshwater stream (Akatarewa Stream) flowing into the Waikato River (Fig. 53).

Figure 53. Upstream 200m in the Akatarewa Stream looking towards Waikato River.

5.4 Waihunuhunu Stream

Hot springs in an arm of Lake Ohakuri. More than 5 boiling springs depositing sinters have been recorded here but with the flooding of Lake Ohakuri in January 1961 the state of any sinter-depositing springs was unclear.

Site 1
Location: Grid reference: U17 2785529E, 6300774N, alt. 294m.
Description: Waihunuhunu Stream at the culvert into Lake Ohakuri. Ferns surround the outflow.

Site 2 Waihunuhunu West Inlet
Location: Grid reference: U17 2785339E, 6300630N, alt. 292m.
Description: West Inlet into Lake Ohakuri where hot water (see Table 5) moves over the top of the cool lake water below.

Site 3
Location: 20m upstream from Site 2.
Description: This stream (Fig. 56) is fed by a boiling spring further upstream (not easily accessed). Represents one of the few remaining boiling springs in the Waihunuhunu area.

Site 4
Location: Grid reference: U17 2785247E, 6300833N, alt. 291m.
Description: Measurements taken in Lake Ohakuri, where the water would be influenced by both Sites 1 and 3.

Figure 54. Waihunuhunu Stream at the culvert into Lake Ohakuri (Site 1). Tropical ferns dominate the banks near the culvert.

Figure 55. Waihunuhunu west inlet (Site 2). At this site, hot water moves across the cool lake water. The hot stream is located behind the fallen tree.

Figure 56. A stream (Site 3) fed by one of the few boiling springs that remain in this region.

6. REPOROA

Hydrothermal activity consists of large hot pools, minor areas of steaming ground and mudpools, and seepages of hot water into drainage channels. There are four main regions located around Reporoa, 30 km south of Rotorua City (Fig. 57).

6.1 Longview Road/Loop Road

Boiling sinter-depositing spring, pools, and warm drains (algal sinters). Just east of the intersection of Longview Road and Loop Road (see Fig. 57). The thermal ground has prostrate kanuka and associated vegetation on the margins with a sinter apron and springs in the centre. These springs were significant for the types of silica deposition occurring but no longer actively form due to the surrounding land having been drained by the owner for farming purposes. Because the area is surrounded by pastoral land and has been altered by drainage to reclaim land there is an ongoing destruction of hot spring habitat occurring.

Site 1 Largest pool in this group (Fig. 58)
Location: Grid reference: U17 2803580E, 6304456N, alt. 306m.

Site 2 (Fig. 59)
Location: Grid reference: U17 2803642E, 6304570N, alt. 311m.

Site 3 (Fig. 60)
Location: Grid reference: U17 2803677E, 6304571N, alt. 310m.

Site 4 Vent pool (Fig. 61)
Location: Grid reference: U17 2803601E, 6304534N, alt. 306m.

Site 5 Mud pool (Fig. 62)
Location: Grid reference: U17 2803553E, 6304483N, alt. 311m.

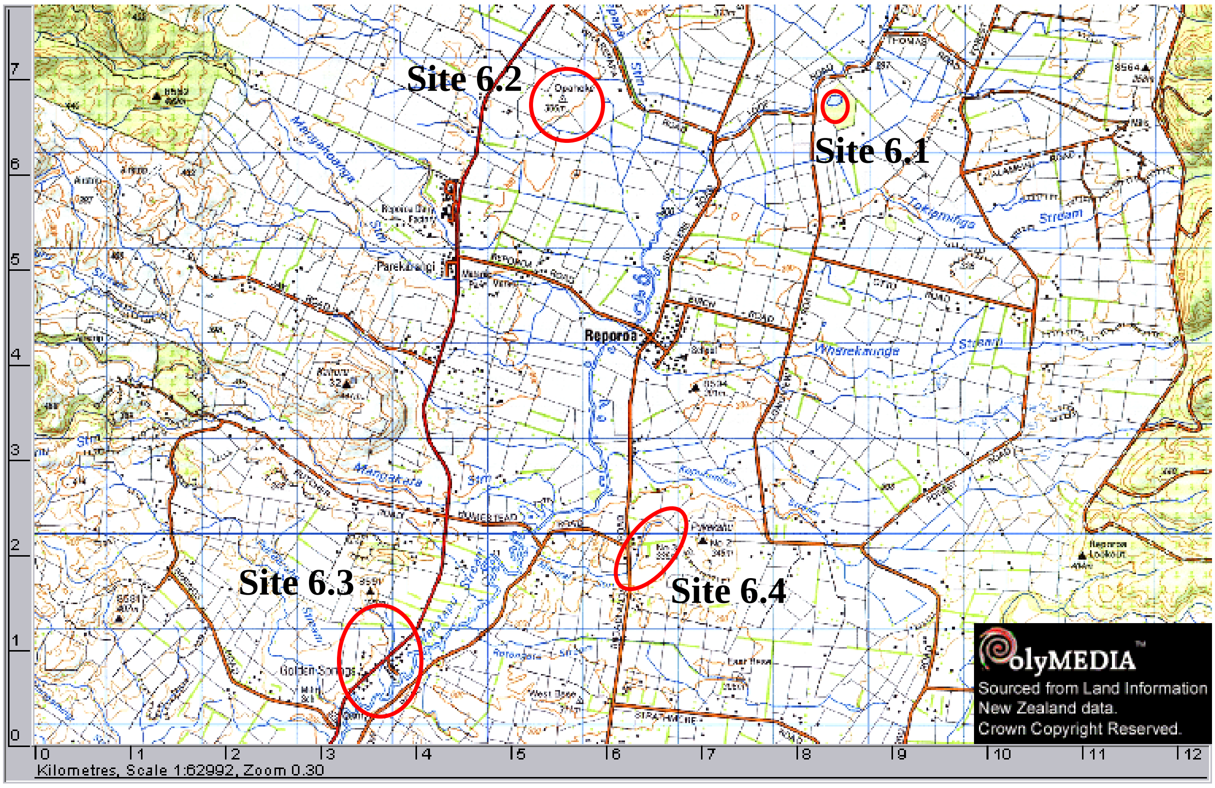

Figure 57. Location of main sites throughout the Reporoa geothermal region.

Figure 58. Main large pool (Site 1).

Figure 59. Site 2. This pool has an opaque colour and the surrounding substrate is very unstable.

Figure 60. The surface around Site 3 was particularly unstable.

Figure 61. Vent pool (Site 4). Heated by steam also (see Table 6), but water present.

Figure 62. Mud pool (Site 5).

6.2 Opaheke

Boiling sinter-depositing springs (Maori (North) Spring). Two of these hot pools surrounded by farmland (Southeast Spring) with drains (Sites 1-2), the other three are located among native vegetation (Sites 3-5). Most are actively depositing silica sinter, with algal and bacterial masses present. Access on SW side of Wharepapa Road half way between SH5 and Settlers Road (see Fig. 57).

Site 1 Main spring SE
Site 2 Outflow of Main spring SE (Site 1)
Location: Grid reference: U17 2800947E, 6304318N, alt. 309m.
Description: This is a large circular hot spring about 8m in diameter with clear calm alkaline water (see Fig. 63; Table 6). The surrounding landscape has been drained for pastoral land-use. Where the spring once flowed naturally into marshy peats and swamp with thin sinter deposits, it is now directed into a channel.

Figure 63. Main Spring SE (Site 1) with channel outflow (Site 2).

Site 3 South Spring (Figs. 64-65)
Location: Grid reference: U17 2800875E, 6304390N, alt. 311m.

Site 4 Maori Spring (North)
Location: Grid reference: U17 2800902E, 6304606N, alt. 312m.
Description: A clear boiling alkaline spring actively depositing silica sinter (Figs. 66-67). The spring has large, algal sinter, marshy surrounds with peripheral manuka scrub (Fig. 67). The sinter deposits around the spring are raised dense crenulated masses, with dense flat laminar deposits along the outflow zone (Fig. 66).

Site 5 March 1987 (name given to the spring when it formed) (Figs. 68-69)
Location: Grid reference: U17 2801239E, 6304557N, alt. 314m

Site 6 Clear pool (Figs. 70-71)
Location: Grid reference: U17 2801211E, 6304732N, alt. 316m.

Figure 64. South Spring (Site 3).

Figure 65. Silica sinters and moss around South Spring.

Figure 66. Constant boiling sinter depositing spring with extensive silica deposits around the main spring (Site 4-Maori Spring) with a single overflow channel.

Figure 67. Algae and bacterial masses on surface with a large stand of manuka surrounding Site 4.

Figure 68. Vent pool (Site 4-March 1987).

Figure 69. Measurements taken at the edge of the pool at Site 4.

Figure 70. Scolding spring (Site 6).

Figure 71. Small outlet, not flowing at present from Site 6.

6.3 Golden Springs

Site 1 West Pool (Fig. 72)
Site 2 Outflow from the pool (Fig. 73)
Location: Grid reference: U17 2798921E, 6299017N, alt. 310m
Description: One of the two main pools in the Golden Springs Recreation Reserve.

Figure 72. West Pool (Site 1).

Site 3 East Pool (Fig. 74)
Site 4 Outflow from the pool (Fig. 75)
Location: Grid reference: U17 2798958E, 6298944N, alt. 307m
Description: One of the two main pools in the Golden Springs Recreation Reserve.

Site 5 Golden springs Motorcamp
Location: Grid reference: U17 2798958E, 6298411N, alt. 300m
Description: Warm springs feeding a stream in the grounds of the Golden springs Motorcamp on SH5. The stream is highly modified and the vegetation includes a mix of exotic and native species (Fig. 76).

Figure 73. Outflow from West Pool (Site 2).

Figure 74. East Pool (Site 3).

Figure 75. Outflow from West Pool (Site 4). Algae dominates the channel.

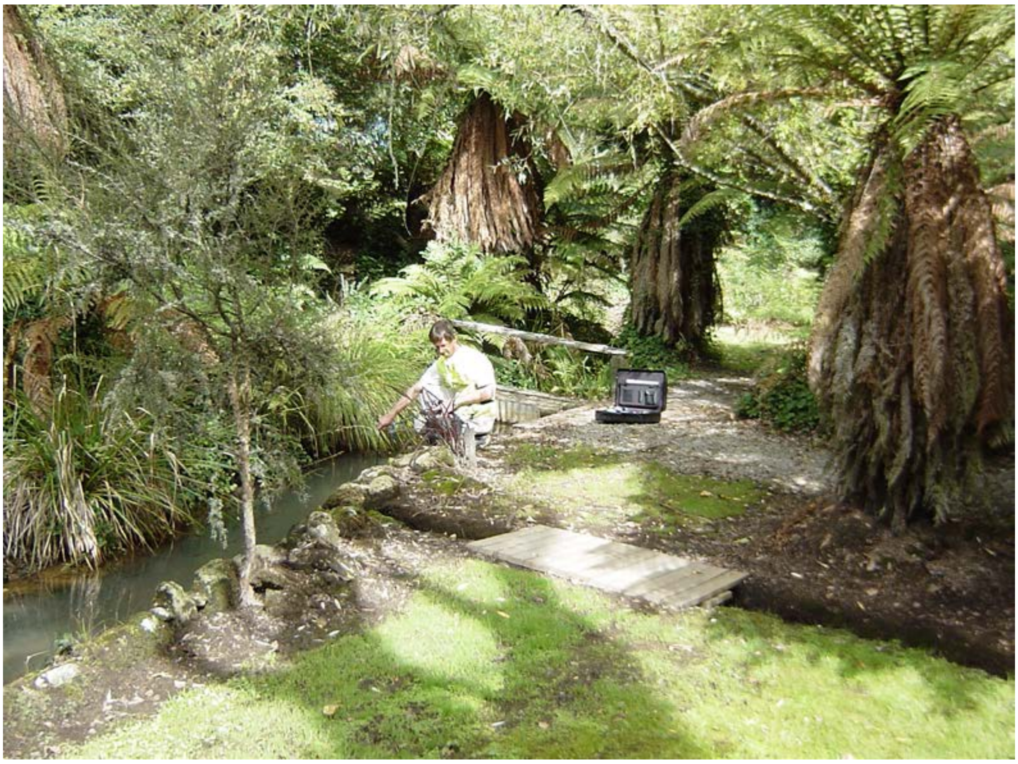

Figure 76. Stream located at the Golden Springs Motorcamp (Site 5).

6.4 Butcher Pool Stream

Site 1 Stream under Homestead Road (Fig. 77)
Location: Grid reference: U17 2801477E, 6299584N, alt. 309m.

Site 2 Butcher Pool (Fig. 78)
Location: Grid reference: U17 2801819E, 6300122N, alt. 301m.

Figure 77. Site 1 located where the stream drains under Homestead Road.

Figure 78. Butcher Pool (Site 2).

Table 6. Chemistry of the Reporoa geothermal field. *Previous records taken from Luketina et al. (2002).

Name	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp ºC	Total dissolved solids (g/l)	Flow rate (m/s)	Salinity (ppt)
Longview Road/Luke Road							
Site 1	3.3	2.41	9.55	26.6	1.5	0	0.1
Site 2	4.5	2.7	3.02	56.6	2.1	0	0.2
Site 3	6.4	2.52	0.7	74.9	1.8	0	0.1
Site 4	7.1	1.88	0	93.9	1.1	0	0
Site 5	2.9	4.05	11.43	21.7	5.1	0	0.4
Opaheke							
Site 1: Main spring SE	7.5	3.19	0	93.4	2.1	0.17	0.2
Southeast Spring*	8.5			88.0			
Site 2: outlet	8	3.22	0	86.1	2.1	0.22	0.2
Site 3: South spring	7.7	3.55	0	91.2	2.3	0	0.2
Site 4 Maori Spring	7.4	4.01	0	97.1	2.5	0	0.2
Maori Spring (North)*	7.8			99.0			
Site 5: March 1987	5.1	5.36	0.37	74.1	3.6	0	0.3
Site 6: Clear pool	8.4	3.95	0.1	79.7	2.5	0	0.2
Golden Springs							
Site 1: West Pool	6.2	1.3	2.9	48.9	0.8	0	0.1
Site 2: West pool outflow	7.3	1.16	5.39	43.5	0.7	0.16	0.1
Site 3: East Pool	7	1.19	4.04	41.7	0.8	0	0.1
Site 4: East pool outflow	6.8	1.19	2.68	41.3	0.8	0.04	0.1
Site 5: Campground	8	1.1	6.18	35.7	0.7	0.31	0
Butcher Pool Stream							
Site 1: stream under road	7.8	1.01	6.92	35.1	0.6	0.19	0
Site 2: pool	7.8	0.99	5.12	39.7	0.6	0.36	0

7. ROTOKAWA

7.1 Lake Rotokawa – Parariki Stream

Activity consists of steaming ground, mudpools, hot springs and collapsed pits with associated hydrothermal alteration and sulphur deposits. The discharge features feed shallow acidic Lake Rotokawa, ponded on a hydrothermal explosion crater. There are several generations of explosion craters in this region. Lake Rotokawa is a large acidic lake with one main outflow – the hot Parariki Stream which drains into the Waikato River (Fig. 79). The lake has a pH of around 2 (see Table 7), and a unique variety of the leech *Helobdella* sp. has been recorded there (Beadel and Bill 2000).

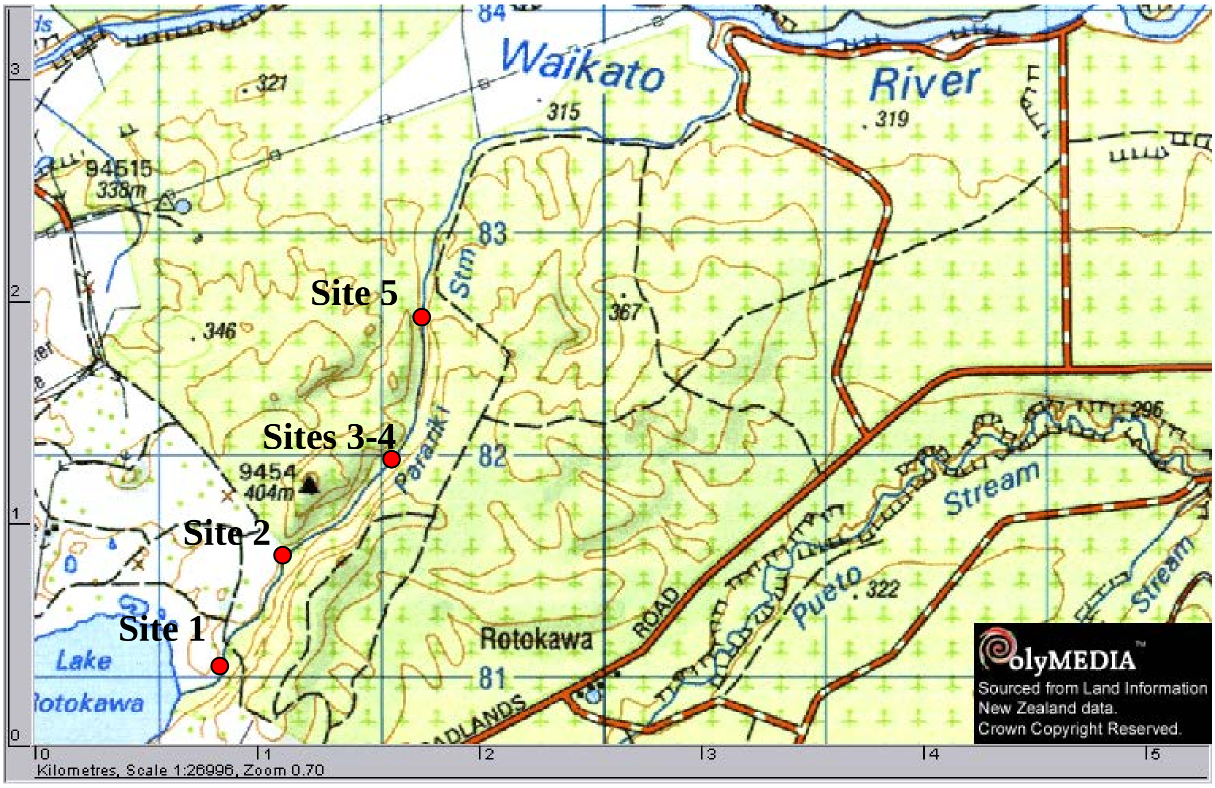

Figure 79. Location of sites along Parariki Stream, between Lake Rotokawa and Waikato River.

Site 1
Location: Grid reference: U17 2788297E, 6281033N, alt. 352m.
Description: Measurements (Table 7) obtained at the collapsed log bridge, approximately 100m from Lake Rotokawa (Figs. 80-81).

Site 2 Further downstream, thermal activity along the banks (Fig. 82)
Location: Grid reference: U17 2788582E, 6281568N, alt. 330m.

Site 3 Stream site (Fig. 83)
Site 4 Boiling pool near Site 3 (Fig. 84)
Location: Grid reference: U17 2789106E, 6282050N, alt. 308m.

Site 5
Location: Grid reference: U17 2789181E, 6282611N.
Description: Downstream site along Parariki Stream towards Waikato River, measurements were obtained next to a small wooden bridge across the stream (Fig. 85).

Figure 80. Parariki Stream Site 1, about 100m from Lake Rotokawa. Sampling was carried out next to the collapsed log bridge.

Table 7. Chemistry of the Reporoa geothermal field.

Name	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp ºC	Total dissolved solids (g/l)	Flow rate (m/s)	Salinity (ppt)
7.1 Lake Rotokawa – Parariki Stream							
Site 1	2.9	7.91	8.03	15.7	5.6	0.19	0.4
Site 2	2.7	11.5	4.64	37.6	7	0.21	0.5
Site 3	2.7	9.06	5.15	41.8	4.3	0.52	0.6
Site 4	6.3	3.93	0	85.5	2.5	0	0.2
Site 5	2.7	9.92	4.64	38.2	4.4	0.32	0.6

Figure 81. View towards Lake Rotokawa from Site 1 in the Parariki Stream.

Figure 82. Site 2 further downstream along the Parariki Stream.

Figure 83. Site 3 in the Parariki Stream where measurements were taken by one of us (MIS), with a spring actively depositing silica sinters in the background (Site 4).

Figure 84. One of us (ADC) taking measurements in the boiling pool (Site 4) above the stream (Site 3).

Figure 85. Site 5 further downstream along Parariki Stream towards Waikato River.

8. TAUHARA (WAIRAKEI)

This system had many geysers and sinter-depositing springs pre-development. The system is recognised as having two fields, with the Waikato River forming the boundary between them. The Wairakei field had many sinter-depositing springs in the area known as Geyser Valley in the north of the field, as well as steam features in the Waiora, Te Kiri O Hinekei, and Karapiti areas (see also Sites 8.1, 8.4 and 8.5 below). The Tauhara field is recognised has having two separate upflows (Site 8.2 and 8.3) which were examined here.

8.1 Broadlands Road

Previous records indicate steaming ground, fumaroles and geothermal ponds in this area, and the gully has been recorded as being geothermally influenced. However, this area is quite dynamic and although the geothermal area extends across Broadlands Road into Landcorp land only steaming ground was found with no surface water present.

8.2 Otumuheke Stream

Several hot streams originating on the east side of Centennial Drive that merge and flow to the Waikato River (see Fig. 86). Some springs are located within AC Baths grounds (Site 2). Several of the springs have stopped flowing in recent years. In this area we examined three sites.

Site 1
Location: Grid reference: U18 2779045E, 6276718N, alt. 390m.
Description: By spa hotel, 100m upstream of EW gauge under the foot bridge (Fig. 87).

Site 2
Location: Grid reference: U18 2779335E, 6276114N, alt. 412m.
Description: AC Baths, one of two main sources for Site 1 (Fig. 88).

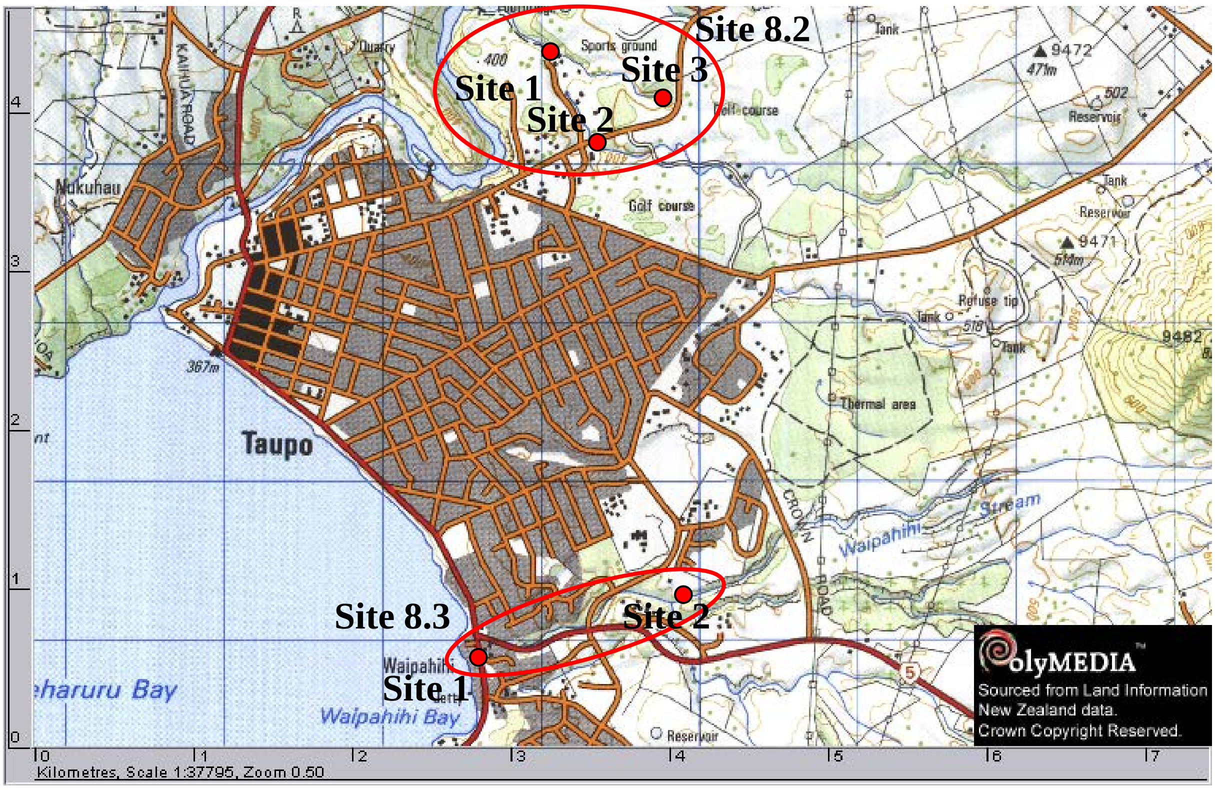

Figure 86. Location of sites with surface waters (Sites 8.2 and 8.3) in the Tauhara geothermal region.

Figure 87. 100m upstream of EW gauge under the foot bridge where measurements were obtained for Site 1.

Figure 88. Site 2 at the outflow from AC baths on Centennial Drive. This is one of two main sources for Site 1.

Site 3
Location: Grid reference: U18 2779784E, 6276393N, alt. 397m.
Description: Otumuheke Stream at main source, steam heated clear shallow water (Fig. 89). The spring is at the head of a deep gully where native vegetation dominates (Figs. 89-91). It is the only remaining sinter-depositing spring along this valley. Great care is necessary at this site, the sinter crust is thin and falling through would cause severe scalding.

Figure 89. Otumuheke Stream at main source (Site 3), steam heated clear shallow water.

Figure 90. View down the deep gully from above Site 3.

Figure 91. View from above Site 3.

8.3 Waipahihi Valley

Hot stream (Onekeneke Stream) flowing through Waipahihi Valley to Lake Taupo. Site 2 accessed above De Bretts Hotel.

Site 1
Location: Grid reference: U18 2778605E, 6272899N, alt. 378m.
Description: Clear warm water (see Table 8) with dark green algae attached. 1m wide stream with weak silica deposits on the algae.

Figure 92. View of Site 1 from SH1/5 in Taupo (Lake Taupo in background).

Site 2 Waipahihi Source Spring (Terraces Spring No. 6)
Location: Grid reference: U18 2779873E, 6273255N, alt. 419m
Description: Waipahihi source spring (3x3m) (Fig. 93). This is a hot flowing clear spring in the bottom of a deep gully. It now flows steadily (see Table 8) and has thin sinter margins on soft marshy substrate (also found were weak silica deposits on the algae). It is the only remaining sinter-depositing spring along this valley, although in the 1890s-1900s several more pools existed.

Figure 93. Waipahihi source spring. The thin sinters can be seen around the margins of the spring.

8.4 Crown Park Reserve

Location: Grid reference: U18 2779899E, 6274341N, alt. 446m.
Description: In head of gully, we recorded 99ºC in the steam vent but no surface waters were present (Fig. 94).

8.5 SH5 roadside seeps

Location: Grid reference: U18 2782993E, 6272069N, alt. 556m.
Description: No surface water present, steaming ground only (96ºC) (Fig. 95).

Figure 94. Crown Park Reserve (Site 8.4) in the head of the gully where we recorded 99ºC in a steam vent but no surface waters were present.

Table 8. Chemistry of the Tauhara (Wairakei) geothermal field.

Name	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp ºC	Total dissolved solids (g/l)	Flow rate (m/s)	Salinity (ppt)
Otumuheke Stream							
Site 1-Spa Hotel	7.9	0.87	3.9	52.4	0.53	0.26	0
Site 2-AC Baths	7.7	1.55	6.04	40.6	1	0.28	0.1
Site 3-Source	7	1.07	0	88.5	0.7	0.13	0
Waipahihi Valley							
Site 1	8.3	2.09	5.17	45.6	1.3	0.14	0.1
Site 2: Waipahihi source spring	8.1	2.28	2.86	63.5	1.3	0.09	0.1

Figure 95. SH5 roadside seeps (Site 8.5). Here we found steaming ground only (96ºC) with no surface waters.

9. TE KOPIA

9.1 Te Kopia – Acid Spring

Steaming cliffs and ground, hydrothermal explosion craters, mud geyser, hot springs and fumaroles 20 km South of Rotorua near the scarp of the Paeroa Fault (Fig. 96). This area has geothermal lakes, hot ground, and fumaroles. The region is accessed along the base of the Paeroa Range in farmland to the west of Te Kopia Road (on side of Mangatete Stream) (Fig. 97). Two main sites were examined.

Site 1
Location: Grid reference: U17 2790846E, 6306445N, alt. 401m.
Description: Acid Spring Site 1 within the gully system (Fig. 98).

Site 2
Location: Grid reference: U17 2790834E, 6306452N, alt. 402m
Description: Downstream 25m second spring (Fig. 99), further down (10m) another spring with weak silica deposits on rocks (95.5ºC) but only 43.2ºC before outlet at Site 2 (Table 9).

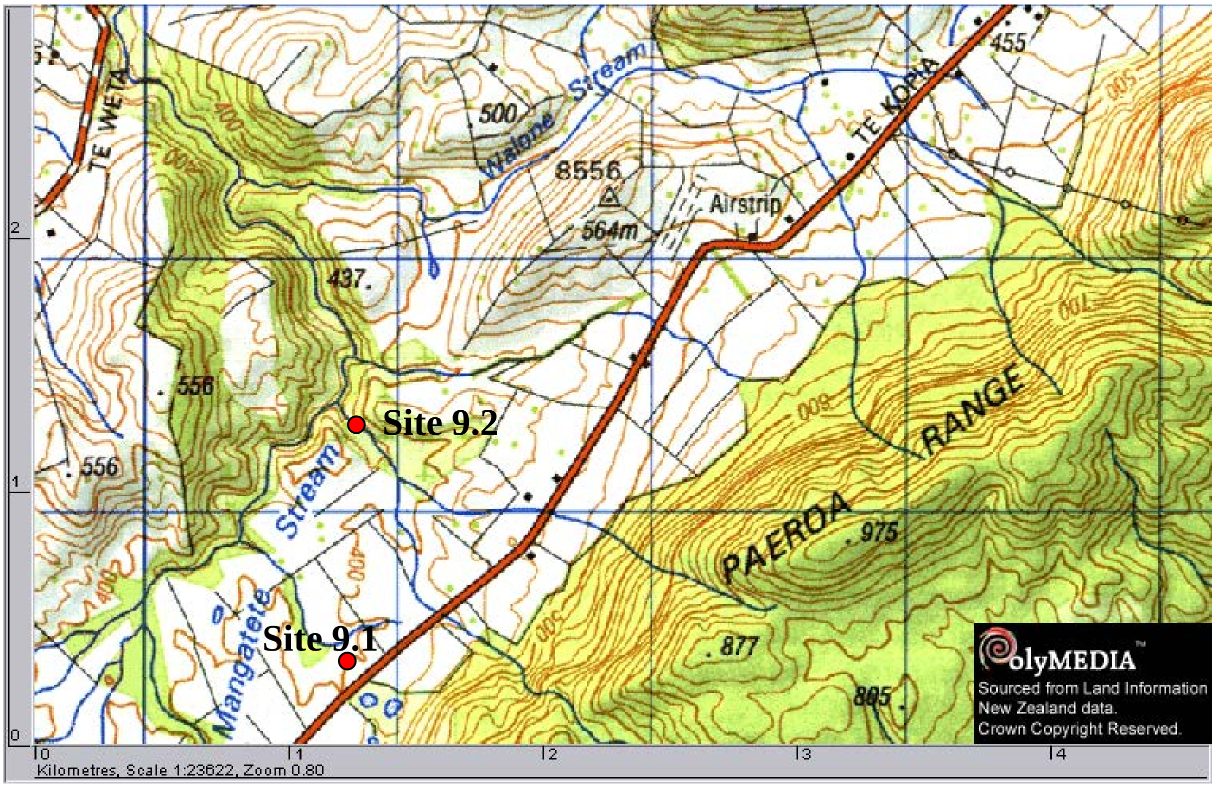

Figure 96. Location of Acid Spring (Site 9.1) and Murphy's Gully Spring (Site 9.2) in the Te Kopia geothermal region.

Figure 97. Te Kopia Springs are accessed along the base of the Paeroa Range (seen in this photo) where we examined two main sites.

Figure 98. Acid Spring Site 1 within the gully system.

Table 9. Chemistry of the Te Kopia geothermal field.

Name	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp ºC	Total dissolved solids (g/l)	Flow rate (m/s)	Salinity (ppt)
9.1 Te Kopia – Acid Spring							
Site 1	3.9	0.881	1.83	77.7	1.9	0	0.1
Site 2	3.7	0.666	4	57	0.44	0.16	0
9.2 Murphy's Gully Springs							
Site 1	9.1	0.498	3.42	53.7	0.32	0.21	0
Site 2	7.9	0.531	3.4	59.2	0.34	0.13	0

Figure 99. Acid Spring Site 2 within the gully system at Te Kopia.

9.2 Murphy's Gully Springs

Three hot springs weakly depositing silica sinter. This site is in farmland to the west of Te Kopia Road (on side of Mangatete Stream), on the north wall of the gully about 1 km north-west from the house (Fig. 96). The springs are clear alkaline hot flowing springs (see Table 9) with insignificant sinters (in mass and extent) (see Fig. 100). The sinters in this area have been damaged by stock crushing them (fencing appears to limit their access now), but the area is now planted (pines) and logging work will severely damage the springs.

Site 1
Location: Grid reference: U17 2790852E, 6307348N, alt. 405m.
Description: Mostly native vegetation around seep, 30m above stream gully on southern facing slope. Insect larvae were evident in the algal sheets which cover all of the substrate (Fig. 100).

Figure 100. Invertebrate larvae evident in algae sheets which cover all the substrate at Site 1, Murphy's Gully Springs.

Site 2 (Fig. 101)
Location: Grid reference: U17 2790874E, 6307322N, alt. 404m.

Figure 101. Site 2 at Murphy's Gully Springs. Measurements were taken by one of us (ADC) at the outlet for the stream, 10m below the source.

10. TOKAANU

10.1 Tokaanu

Southern end of Lake Taupo at the foot of Kakaramea-Tihia volcanoes (Fig. 102). Numerous hot springs, pools and ephemeral geysers (eg Taumatapuhipuhi) in Tokaanu Thermal Reserve. Also hot springs at Waihi village and fumaroles and steaming ground on the hill above the village. Area has many hot pools and springs draining into Tokaanu Stream which is hot for some of its length. Also present are geothermally influenced wetlands. Almost all of the geysers and sinter-depositing springs on this field have had drainage channels dug or have been otherwise modified in order to use their heat or water for traditional uses. Five sites were examined, most in the Tokaanu Domain, on private land or on the marae grounds (Fig. 102).

Site 1 Taumatapuhipuhi
Location: Grid reference: U18 2749631E, 6244798N, alt. 385m.
Description: This spring geysers regularly to about 1m. Silica sinter splash zone has developed with bacterial growth in the pool (Fig. 103). The sinter apron is degrading because the dug channel does not allow the water to flow over it and rejuvenate it.

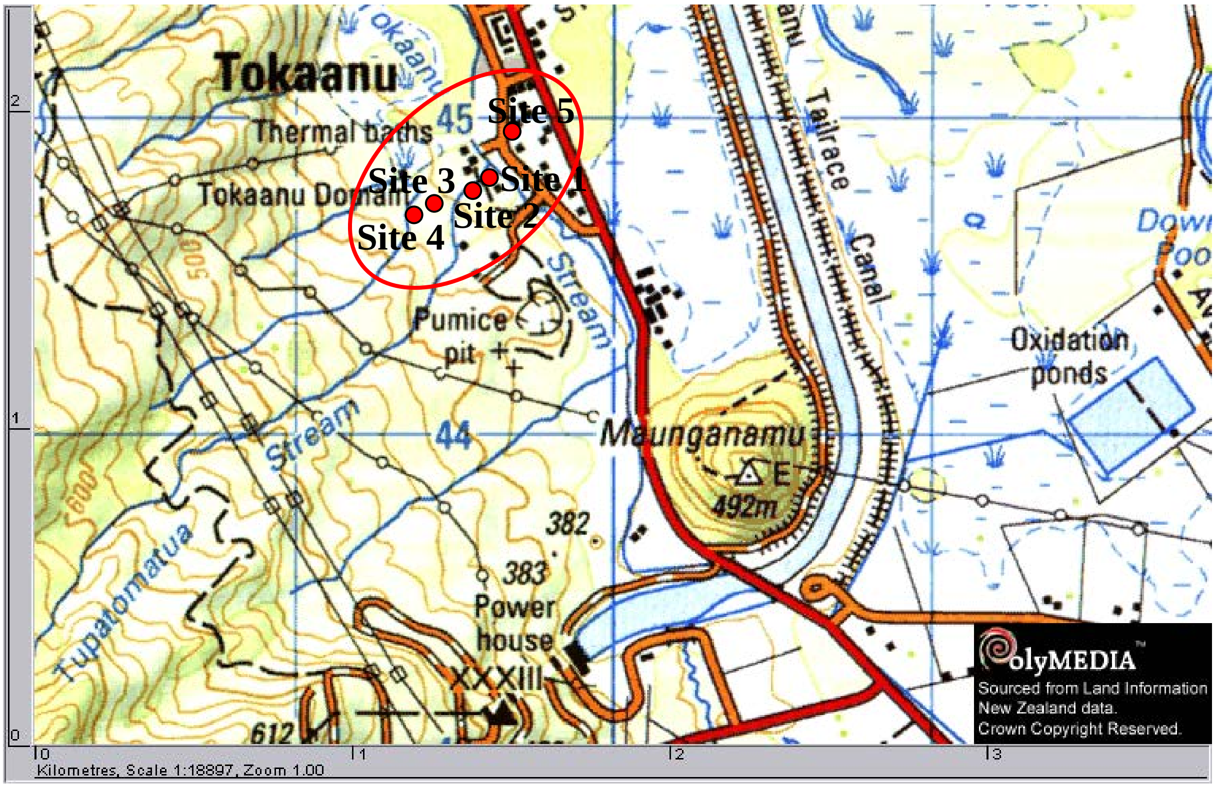

Figure 102. Location of the Tokaanu geothermal region and the five sites examined.

Figure 103. Taumatapuhipuhi (a 0.5x1.5m pool at Site 1) that geysers regularly.

Site 2 Matewai (main pool)
Location: Grid reference: U18 2749590E, 6244773N, alt. 371m.
Description: Slightly cloudy pool (5x6m pool) with no recent eruptions (Fig. 104). The walls and surfaces are sinter with an outflow into the Hoani basin. Silica deposits as highly porous coral-like masses typical of algal sinters.

Figure 104. Matewai (main pool at Site 2).

Site 3 Takarea #6
Location: Grid reference: U18 2749457E, 6244732N, alt. 372m.
Description: Clear water with dead plant material observed in pool (5x5m pool) surrounded by tall kanuka scrub (Fig. 105). Cooler than other pools (see Table 10) with abundant algal growths. No activity (boiling/gas eruptions) observed while at this site. The spring has sinter walls and margins with a small outflow.

Site 4 Paureni #16
Location: Grid reference: U18 2749398E, 6244692N, alt. 370m.
Description: Three springs in sinter basins. Algal growth more extensive than at Site 3 with vegetation to the edge of the pool (Fig. 106).

Site 5 Tauwhare
Location: Grid reference: U18 2749693E, 6244938N, alt. 372m.
Description: Inactive geyser actively depositing silica sinter (Fig. 107). This is a hot clear spring (6x15m) at the south-east end of the Marae. The walls of the spring are sinter but no surface outflow occurs.

Figure 105. Takarea #6 (Site 3). Although this pool was cooler than other pools and had algal growths there was a large amount of dead plant material observed in the pool (Fig. 105).

Figure 106. Paureni #16 (20x40m pool) (Site 4).

Table 10. Chemistry of the Tokaanu geothermal field. *Previous records from 1966 taken from Luketina et al. (2002).

Name	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp ºC	Total dissolved solids (g/l)	Flow rate (m/s)	Salinity (ppt)
10. Tokaanu							
Site 1: Taumatapuhipuhi	8.2	9.44	0	97.9	5.9	0	0.5
Taumatapuhipuhi*	7.8			98.0			
Site 2: Matewai	7.6	7.6	0	84.2	4.9	0.02	0.4
Matewai*	7.0			67.0			
Site 3: Takarea #6	7.1	13.6	1.84	68.1	8	0	0.8
Takarea*	6.9			67.0			
Site 4: Paureni #16	7.0	5.19	3.6	57.1	3.2	0	0.3
Paureni*	7.0			62.0			
Site 5: Tauwhare	7.1	8.13	0	91.3	5.2	0	0.4
Tauwhare*	7.4			83.0			

Figure 107. Tauwhare Spring (Site 5). Located next to the Marae.

11. TONGARIRO

11.1 Ketetahi

This is New Zealand's only region of high-altitude geothermal springs. The springs are acidic and feed into a hot stream. A unique midge has previously been recorded here. Fumeroles, hot ground, and hot springs at Ketetahi, fumeroles and hot ground at Red Crater, and Te Mari Craters. On the basis of resistivity data, the field covers 25 square km on Tongariro – the only vapour-dominated geothermal system in New Zealand.

Ketetahi Springs: Activity is confined mainly to the head waters of Mangatpua Stream, and in the upper valleys of its eastern and western tributaries. Numerous fumaroles and hot springs occur in an area of 0.5 square km.
Red Crater: Numerous fumaroles and areas of steaming ground in and on the flanks of Red Crater and around the Emerald Lakes.
Te Mari Craters: Weak fumaroles and warm ground located around the upper and lower (Sulphur Lagoon) Te Mari craters.

Permission was sought through the Ketetahi kaitiakito to access this site (via Katherine Luketina) but permission was not granted.

12. WAIKITE

Northern side of Waikite Valley Road, west of Waiotapu. Hot and boiling springs occur along the base of the Paeroa Fault scarp (Fig. 108). Sinter deposition contains some calcite. No geysers have been active in recent years, although Ht geyser (S5651) used to geyser many times daily 5-8m high during the early 1980s.

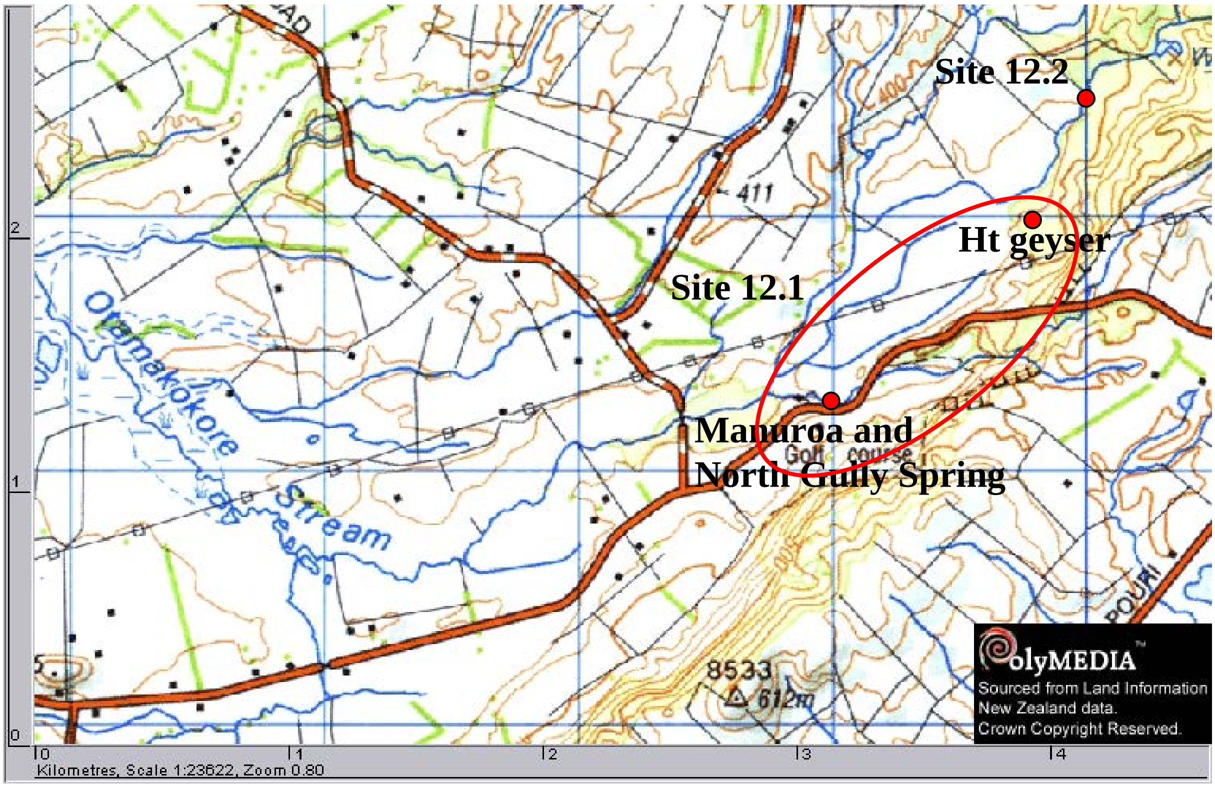

Figure 108. Location of the sites examined in the Waikite geothermal region.

12.1 Waikite Valley

Boiling sinter-depositing springs and geothermal streams located in the Waikite Valley (Fig. 109). Many are calcite bearing sinters which are rare.

Figure 109. Waikite Valley with pools at Site 1 and 2.

Site 1 Manuroa Spring
Location: Grid reference: U16 2799024E, 6314268N, alt. 379m.
Description: Silica/calcite spring unique in this region (Fig. 110). This represents one of the largest boiling water springs in New Zealand.

Site 2 North Gully Spring (S5580) (Fig. 111)
Location: Grid reference: U16 2799063E, 6314262N, alt. 376m.

Site 3
Location: Grid reference: U16 2798392E, 6314196N, alt. 358m.
Description: At Corbett Road, downstream from Sites 1 and 2 (Fig. 112).

Figure 110. Manuroa Spring (Site 1). This is one of the largest boiling water springs in New Zealand.

Figure 111. North Gully Spring. Massive sinter deposits form the walls and margins of the spring.

Figure 112. Corbett Road, downstream from Sites 1 and 2.

Site 4 Ht Geyser (S5651)
Location: Grid reference: U16 2799808E, 6315007N, alt. 392m.
Description: Surrounding area covered by moss and manuka and tropical ferns, extensive sinter deposits throughout the area.

Figure 113. Ht Geyser (S5651). Extensive sinter deposits throughout the area.

Figure 114. Ht Geyser pool in background. Surrounding area covered by moss and manuka and tropical ferns.

Table 11. Chemistry of the Waikite Valley geothermal field. *Previous records from 1991-1992 taken from Luketina et al. (2002).

Name	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp ºC	Total dissolved solids (g/l)	Flow rate (m/s)	Salinity (ppt)
12.1 Waikite Valley							
Site 1: Manuroa Spring	9.8	1.4	0	97.4	0.8	0	0.1
Manuroa (S5586) *	7.8			99.5			
Site 2: North Gully Spring	8.5	1.51	0	95.8	0.9	0	0.1
North Gully (S5580) *	7.9			97.5			
Site 3: Corbett Road	8.7	0.974	5.14	50.7	0.62	0.97	0
Site 4: Ht Geyser	8.7	1.78	1.78	97.6	1.1	1.1	0.1
Ht Geyser (S5651) *	8.1			98.4			
12.2 Otamakokore Stream							
Site 1	8.8	0.477	7.4	39.3	0.31	0.31	0
Site 2 (S5644)	7.9	1.98	0	87.6	1.3	0	0.1
Scalding Spring (S5644) *	7.9			89.2			

12.2 Otamakokore Stream

Location: Grid reference: U16 2799928E, 6315369N, alt. 391m.
Description: Geothermal stream immediately north of Corbett Road at the base of the scarp. Numerous hot springs along the base of the scarp, three warm lakelets, with extensive old sinter aprons and a geyser that was active between 1973-1988. The area is dominated by a sinter base, possibly organic material (not a strong base). Two sites were measured (see Table

11), Site 1 was in the Otamakokore Stream (Figs. 115-116) where it meets the outflow from Scalding Spring (S5644) (Site 2) (Figs. 115, 117).

Figure 115. One of us (ADC) taking measurements in Otamakokore Stream (Site 1). Scalding Spring (S5644) (Site 2) is fenced off in the background (15m from the stream).

Figure 116. Otamakokore Stream (Site 1). View upstream towards source (in valley).

Figure 117. Scalding Spring (S5644). Silica sinters line the walls and margins of the spring.

13. WAIMANGU

Located 20 km SE of Rotorua City, extending to SW of Lake Rotomahana. Activity is associated with craters opened during the 1886 Tarawera eruption. Two hot acid-sulphate crater lakes with sympathetic variations in outflow and level respectively have been recorded. There are numerous boiling alkaline-chloride springs, both within and outside these and other craters throughout the region.

13.1 Maungakakaramea – Rotowhero

Rotowhero is a geothermally influenced lake in an eruption crater near Rainbow Mountain (see Fig. 118). The side opposite the road is very active with sheer sides (10m) in most places with a valley with what appears to be the source for a weak sinter terrace that protrudes out into the lake. The lake is acidic (Table 12) and the surrounding margins are very soft and unstable, most is not suitable for foot exploration (Fig. 119). We examined five sites throughout the lake.

Site 1
Location: Grid reference: U16 2805143E, 6314618N, alt. 406m.
Description: Stream from spring, outflow through manuka and mingi mingi (Fig. 120). No silica deposits. Algal growths were present throughout the lake but stop near outflow of spring.

Site 2 Spring at edge of lake (Figs. 121-122)
Location: Grid reference: U16 2805202E, 6314527N, alt. 399m.

Site 3 Spring at edge of lake (Figs. 123-124)
Location: Grid reference: U16 2805199E, 6314453N, alt. 393m.

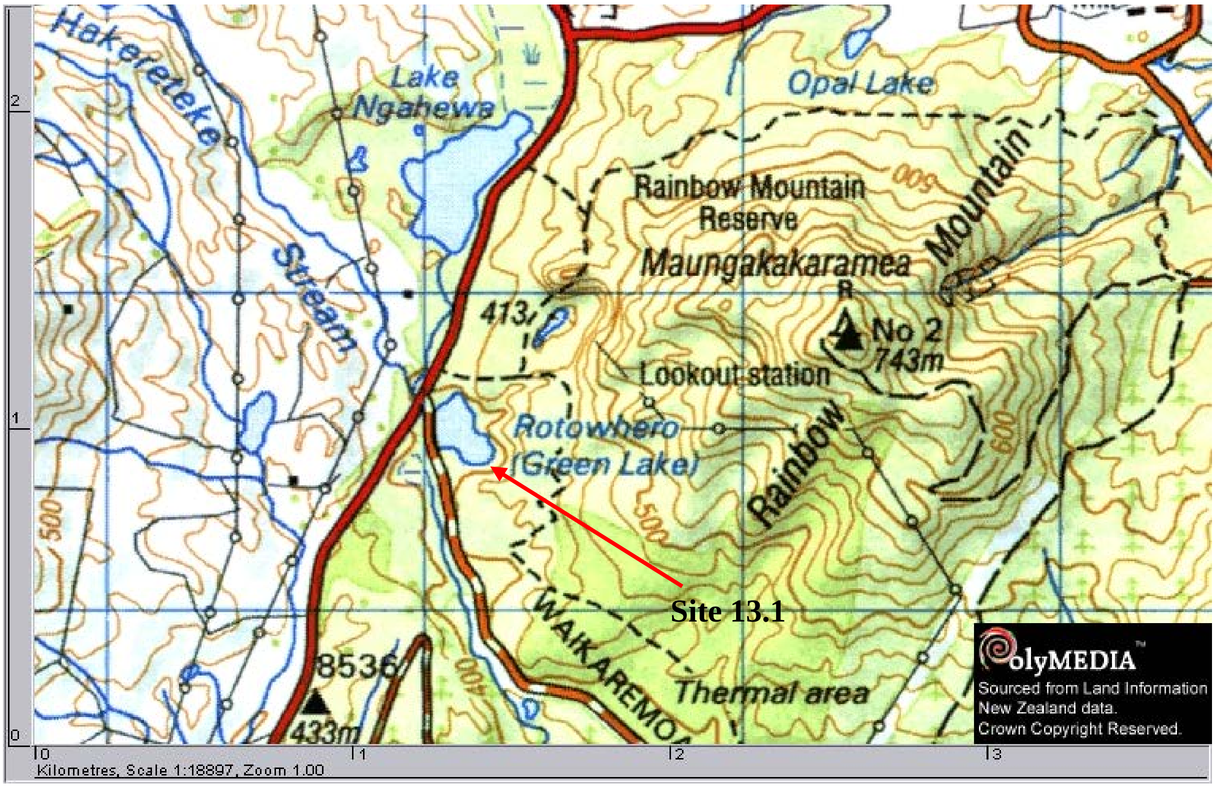

Figure 118. Location of Rotowhero in the Waimangu geothermal region.

Figure 119. Site 1 located on the left side of the silica terrace. The silica terrace seen here is very soft and unstable with boiling substrate below the surface.

Figure 120. Stream (Site 1) from spring (seen 10m upstream), outflow through manuka and mingi mingi.

Table 12. Chemistry of the Maungakakaramea – Rotowhero geothermal lake.

Name	**pH**	**Conductivity (ms/cm)**	**Dissolved Oxygen (mg/l)**	**Temp ºC**	**Total dissolved solids (g/l)**	**Flow rate (m/s)**	**Salinity (ppt)**
Maungakakaramea – Rotowhero							
Site 1-spring 1	3.4	1.71	4.14	45.7	1.1	0.07	0.1
Site 2-spring 2	3.5	2.51	0	95.3	1.5	0.18	0.1
Site 3-spring 3	3.3	4.84	6.06	38.9	4.9	0	0.4
Site 4-centre of lake	3.2	13.0	8.36	30.3	1.2	0	0.1
Site 5-carpark side	3.3	3.02	7.37	30.1	1.4	0	0.1

Site 4 At centre of lake
Location: Grid reference: U16 2805077E, 6314577N, alt. 402m.

Site 5 Far side of lake near car-park
Location: Grid reference: U16 2805020E, 6314527N

Figure 121. Site 2 (arrow) located at the lake edge.

Figure 122. A boiling actively sinter-depositing spring (Site 2) at the lake edge.

Figure 123. The active spring was not accessible here (3m from lake edge) but in the foreshore were 3 holes (Site 3) in the lake substrate that presumably remain clear of sediment through gradual convection.

Figure 124. Site 3 measurements taken from inside the convection hole. The green algae staining the water is evident throughout the lake.

14. WAIOTAPU

North end of Reporoa Valley, 23 km SSE of Rotorua City (Fig. 125). A major intense system once characterised by more extensive discharge of fluid. Extensive features including mud volcanoes, geysers, collapsed holes, fumeroles, hydrothermal eruption breccias, warm and boiling springs, steaming ground, silica, sulphur and sulphide deposits, and acid altered ground. The region is known to have more than 5 geysers and 15 boiling springs.

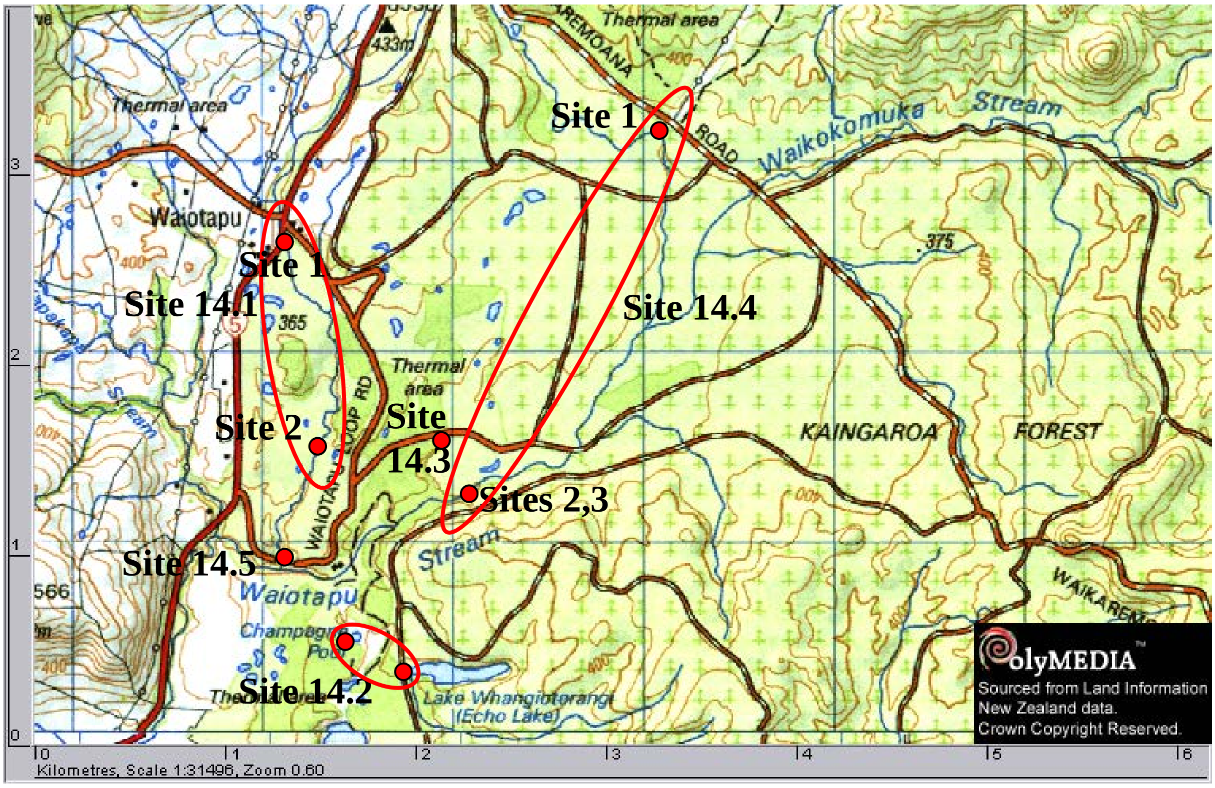

Figure 125. Location of the sites examined in the Waiotapu geothermal region.

14.1 Maungaongaonga (previously Ngapouri)

Geothermal stream (see Table 13) to the north and south of SH5 and Waikite Valley Road.

Site 1
Location: Grid reference: U16 2804114E, 6312617N, alt. 371m.
Description: Next to SH5, Pub Stream, water through drain under road.

Site 2
Location: Grid reference: U16 2804273E, 6311484N, alt. 371m.
Description: Midway along Pub Stream.

Figure 126. Unnamed geothermal stream Site 1 (14.1), this site is also referred to as the Pub Stream.

Figure 127. Site 2 downstream along Pub Stream.

Figure 128. The sampling location at Site 2.

14.2 Waiotapu 1 – Main tourist area and Echo Lake (Whangiotrangi)

Geothermal warm lakes, geothermally influenced cool lakes, wetlands and streams.

Site 1 Echo Lake
Site 2 Echo Lake outlet
Location: Grid reference: U17 2804740E, 6310328N, alt. 355m
Description: Surrounding countryside. Two sites measured: Site 1 in Echo Lake, and Site 2 at the outlet of a pipe running under Rotorohe Road from the lake (Table 13; Figs. 129-130). A 500x100m lake stirred by gas bubbles (turbid/cloudy). Surrounded mostly by exotic forestry (pines). Measurements taken at Rotorohe Road side of the lake, and at the pipe outlet on the opposite side of the road from the lake (a 25 m deep, 5 ha, warm acidic lake, occupying an explosion crater fed by hot springs – native sulphur globules frequently rise in the lake).

Figure 129. Echo Lake sampling site (marked by arrow) (Site 1).

Figure 130. Outlet of Echo Lake (Site 2) on the opposite side of Rotorohe Road.

Site 3 Champagne Pool (S64)
Location: Grid reference: U16 2804464E, 6310475N, alt. 348m.
Description: Located in the main visitor area (Wai-o-tapu thermal wonderland). This is the largest spring at Waiotapu (about 30m diameter). Occupying a sinter lined 900 year old (formed in AD 1350) explosion crater (Fig. 131). This pool actively grows a silica sinter terrace of about 2 hectares. The 2000 square metre pool discharges carbon dioxide rich alkaline chloride water and has a temperature of around 74 ºC (Table 13; Fig. 132).

Figure 131. Champagne Pool (Site 3) in main visitor area.

14.3 Waiotapu 2

Geothermal warm lakes and geothermal streams to the north of the main Waiotapu tourist area.

Location: Grid reference: U16 2804935E, 6311515N, alt. 364m.
Description: Hidden WF pool (Fig. 133). Separate stream system to 14.1, fine black mud/silt with stone substrate and plant material. Algae less prominent in stream, mostly filamentous bacteria.

Figure 132. Champagne Pool (Site 3) in main visitor area. The pool discharges carbon dioxide rich alkaline chloride water. The spring margins are spectacularly brightly coloured due to the presence of heavy metal sulphides.

Figure 133. Hidden WF pool.

14.4 Hakareteke Stream (Kerosine Creek)

Three sites measured along Hakareteke Stream: 1) upstream; 2) downstream; and 3) a geothermally active site near Site 2.

Site 1
Location: Grid reference: U16 2806072E, 6313137N, alt. 378m.
Description: A 2m wide acidic geothermal stream in a mostly native vegetated area (Manuka, Cabbage trees, ferns and Caryx, but pines present also) just west of the intersection of Volcano and Waikaremoana Roads (Figs. 134-136). Currently a popular bathing area with many hot spring influences along the stream length.

Figure 134. Hakareteke Stream (Kerosine Creek) (view upstream from where measurements taken at Site 1).

Figure 135. Hakareteke Stream (Kerosine Creek) (view downstream from where measurements taken at Site 1).

Figure 136. Hakareteke Stream (Kerosine Creek) (overall site shot) showing the location of Site 1.

Site 2
Location: Grid reference: U16 2805054E, 6311234N, alt. 339m
Description: Stream among a mix of manuka and pines. Stream has less thermal influence than Site 1 with a temperature of 22ºC (see Table 13). The substrate is a mix of silica and gravel covered with periphyton (Figs. 137-138).

Figure 137. Site 2 along Hakareteke Stream (Kerosine Creek) (measurements at stream).

Table 13. Chemistry of the Waiotapu geothermal lake. *Previous records taken from Luketina et al. (2002).

Name	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp ºC	Total dissolved solids (g/l)	Flow rate (m/s)	Salinity (ppt)
Maungaongaonga (previously Ngapouri)							
Site 1: Pub Stream	5.2	0.93	5.59	42.7	0.6	0.19	0
Site 2: midway Pub Stream	5.2	1.47	7.37	41.3	0.9	0.34	0.1
Waiotapu 1: main tourist area and Echo Lake							
Site 1: Echo Lake	3.5	3.51	6.12	25.4	2.3	0	0.2
Site 2: Echo Lake outflow	2.9	3.66	6.7	25.4	2.3	0.28	0.2
Site 3: Champagne Pool	5.3	6.95	0.13	76.4	4.6	0	0.4
Champagne Pool*	6.5			75.0			
Waiotapu 2							
Hidden WF pool	3.1	3.5	5.41	39.4	5.7	0.39	0.2
Hakareteke Stream (Kerosine Creek)							
Site 1	3.7	0.919	5.6	36.6	0.59	0.58	0
Site 2	4.9	0.385	10.4	21.8	0.25	1.06	0
Site 3	2.9	2.99	0.05	80-90	2	0	0.2
Unnamed Waiotapu Stream	4.8	1.79	5.13	42.5	1.1	0.22	0.1

Figure 138. The view towards silica sinter terrace from the active geothermal pool/stream (Site 3) next to Site 2 at Hakareteke Stream.

Site 3
Location: Grid reference: U16 2805094E, 6311200N, alt. 338m
Description: Sinter (silica) depositing spring flowing towards Hakareteke Stream (Figs. 138, 139).

Figure 139. Sinter (silica) depositing spring (Site 3) flowing towards Hakareteke Stream (Site 2).

14.5 Unnamed Waiotapu Stream

Location: Grid reference: U16 2804102E, 6310871N, alt. 335m.
Description: Lower downstream from 14.1, flows into Waiotapu Stream 30m below bridge at southern end of Waiotapu Loop Road.

Figure 140. Unnamed stream (Site 14.5) that flows into Waiotapu Stream 30m below the bridge crossing Waiotapu Loop Road.

15. WAIRAKEI

Before the development of the Wairakei Geothermal Power Station two major areas of chloride springs and geysers were active, 1) at Geyser Valley and the Spa, an area of mixed and acidic waters at Waiora Valley; and 2) fumaroles and mudpools at Karapiti. However, drilling and exploitation of the field has resulted in a dramatic decrease in the discharge of the springs and all the geysers have ceased. An increase in the extent of steaming ground and fumarolic activity has occurred at Karapiti (now called Craters of the Moon). Springs and areas of steaming ground are present 3 km north of Taupo in the area referred to as the Tauhara Geothermal Field (see section 8), south of Wairakei. Hydrothermal eruptions have occurred both at Karapiti and Tauhara subsequent to the Wairakei geothermal development (see Fig. 141 for locations examined here).

15.1 Waiora Lakes and Alum Lakes (no access permission)

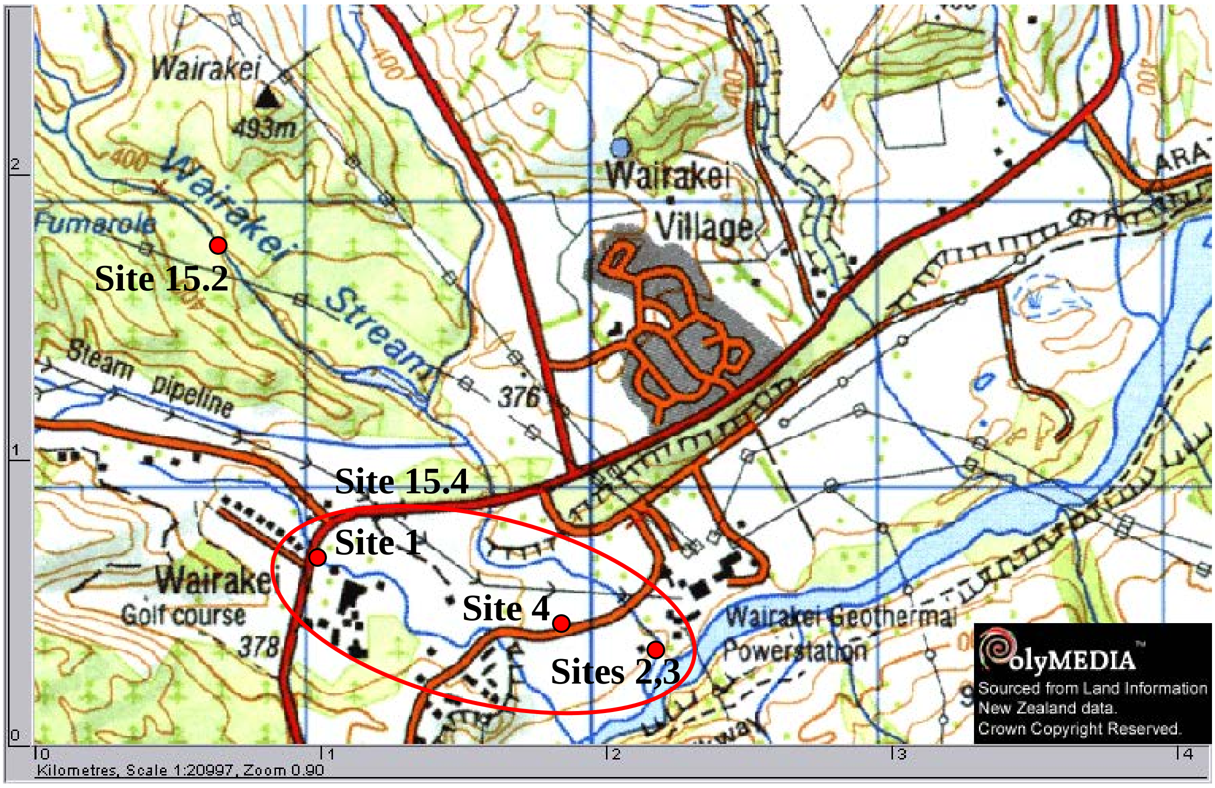

Figure 141. Location of the sites examined in the Wairakei geothermal field.

15.2 Geyser Valley

Location: Grid reference: U17 2778709E, 6282837N, alt. 379m.
Description: This site was accessed through Geyser Valley tearooms campground to reach the Wairakei Stream located in a deep gully (Fig. 142). The site was immediately upstream of an old flume (flow gauge) structure in the stream (Fig. 143).

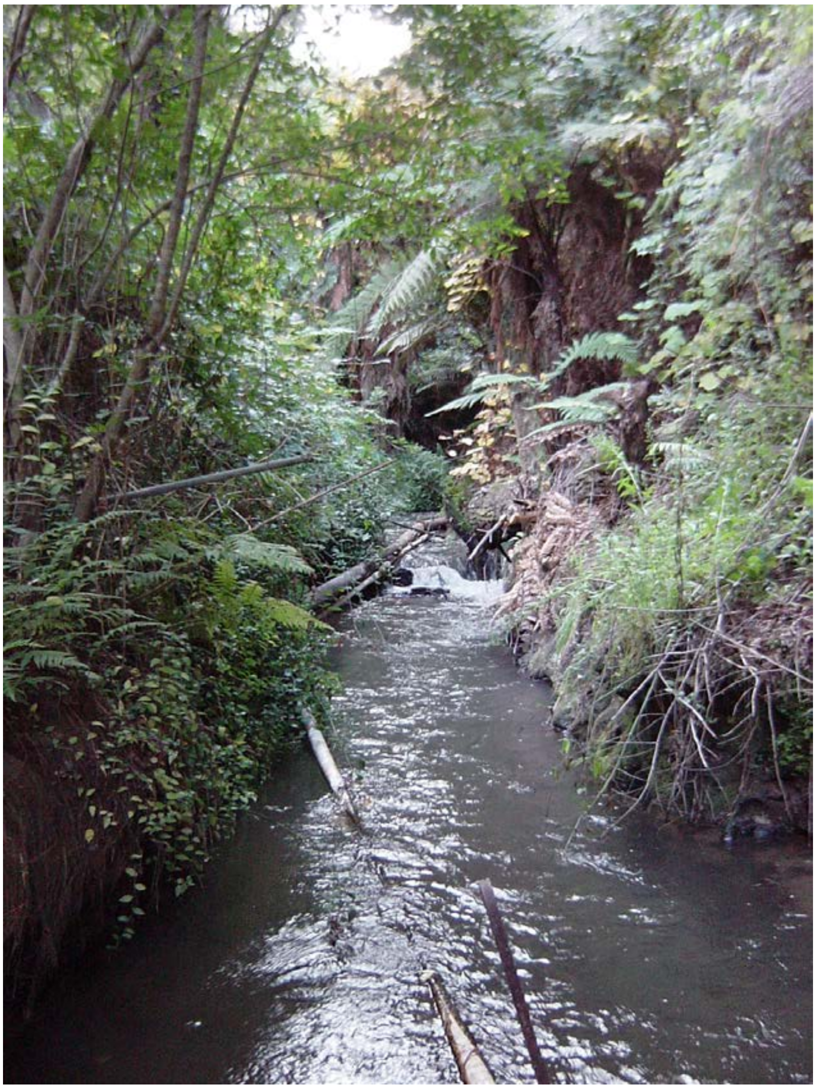

Figure 142. Upstream view from Site 15.2 in the Wairakei Stream.

Figure 143. Downstream view towards the flume structure at Site 15.2 in the Wairakei Stream.

15.3 Hall of Fame Stream

Geothermal stream infested with blackberry crossing SH1/5 and draining to the Waikato River. This section of the Kiriohineki Stream has been heavily modified as a drain for effluent from the Power Station with high barbed wire fencing and concrete substrate. Sampling was not undertaken at this location. However, sampling was carried out further downstream (along Kiriohineki Stream).

15.4 Wairakei Stream & Kiriohineki Stream

Heavily modified geothermal streams originating in the Contact borefield and draining to the Waikato River through the Contact power station site and Prawn Park.

Site 1
Location: Grid reference: U17 2779055E, 6281734N, alt. 351m.
Description: Effluent from Power Station (water sourced from Kiriohineki Stream for the power station) under SH1/5 opposite side to BP station. Unnatural silica deposits (well head condensates-no surface waters) throughout stream (see Fig. 144).

Figure 144. Water for this stream (Site 1) probably sourced from Kiriohineki Stream for the power station (see also Fig. 141). Unnatural silica deposits (well head condensates-no surface waters) are present throughout the stream.

Site 2
Location: Grid reference: U17 2780216E, 6281429N, alt. 347m.
Description: Wairaki Stream near Waikato River at Prawn Farm (Fig. 145).

Site 3
Location: Grid reference: U17 2780216E, 6281429N, alt. 347m.
Description: Prawn pool (water sourced from stream at Site 4) empties into the Wairaki Stream at Prawn Farm (Fig. 146).

Site 4
Location: Grid reference: U17 2779965E, 6281499N, alt. 355m.
Description: Kiriohineki Stream (or sourced from), pre-prawn farm. Algae encrusted with silica (colloidal silica-milky blue turbidity) (Fig. 147).

Figure 145. Wairaki Stream near Waikato River at Prawn Farm.

Figure 146. Prawn pool (water sourced from the same stream as Site 4) empties into Wairaki Stream at Prawn Farm.

Figure 147. Algae encrusted with silica (colloidal silica causing the milky blue turbidity) at Site 4.

15.5 Te Rautehuia Stream
Previous records indicate that the stream has geothermal inputs in three places but it is a deeply incised gully with extensive blackberry. The site is now inaccessible.

15.6 Waipouwerawera Stream

The stream once had a large geothermal input immediately upstream of the hay shed on McLachlan land on the left of Tukairangi Road. This site has not been active for around 2 years. Two sites were measured along the stream, which indicate that the stream still has some geothermal input (see Table 14) but its source is unknown.

Site 1
Location: Grid reference: U17 2776336E, 6279403N, alt. 419m.
Description: Waipouwerawera Stream at Poihipi Road culvert (Fig. 148).

Site 2
Location: Grid reference: U17 2775505E, 6279854N, alt. 459m.
Description: Waipouwerawera Stream (upstream of Site 1, downstream of old active site near the hay shed).

Figure 148. Waipouwerawera Stream at Poihipi Road culvert. Measurements at Site 1 and Site 2 indicate that there is geothermal input into the stream between the two sites.

Table 14. Chemistry of the Wairaki geothermal lake.

Name	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp ºC	Total dissolved solids (g/l)	Flow rate (m/s)	Salinity (ppt)
Geyser Valley	6.7	0.245	10.11	18.9	0.16	0.57	0
Wairakei Stream & Kiriohineki Stream							
Site 1: Kiriohineki Stream	8.4	7.69	3.97	50.9	4.9	0.77	0.4
Site 2: Wairaki Stream	8.6	5.86	5.32	44.7	3.7	0.61	0.3
Site 3: Prawn pool (Kiriohineki Stream)	8.7	7.08	4.5	35.5	4.5	0	0.4
Site 4: Kiriohineki Stream, pre-prawn farm	8.7	7.55	6.56	38.4	4.8	0.51	0.4
Waipouwerawera Stream							
Site 1: Waipouwerawera Stream at Poihipi Road culvert	9.3	0.182	9.14	18.7	0.11	0.52	0
Site 2: Waipouwerawera Stream	9.2	0.187	7.85	15	0.11	0.35	0

16. WHANGAIROROHEA

16.1 Whangairorohea Spring

Location: Grid reference: U17 2793078E, 6294716N, alt. 312m.
Description: Five km downstream from Mihi on the Whangairorohea Stream (Fig. 149). This is a circular lake of about 40m diameter in a recently planted pine forest (Fig. 150-151). This geothermally influenced lake is a warm lake of neutral pH, fed by a seepage in the lakes bottom (weak bubbles/convection seen throughout the lake) (see Table 15). With the clearing of forestry trees the river bank alongside the lake is susceptible to washing out and thus the lake may eventually be lost (Figs. 152-153). Springs along the Waikato River in the vicinity were not found and probably pre-date the dam and subsequent flooding of the Waikato River valley.

Figure 149. Location of the Whangairorohea Spring next to Whangairorohea Stream.

Table 15. Chemistry of the Whangairorohea Spring.

Name	pH	Conductivity (ms/cm)	Dissolved Oxygen (mg/l)	Temp ºC	Total dissolved solids (g/l)	Flow rate (m/s)	Salinity (ppt)
Whangairorohea Spring	6.5	1.72	7.24	35.7	1.1	0	0.1

Figure 150. This is a circular lake of about 40m diameter in a recently planted pine forest. This geothermally influenced lake is a warm lake of neutral pH, fed by a seepage in the lakes bottom (weak bubbles/convection seen throughout the lake).

Figure 151. Algae dominates the water in this lake.

Figure 152. This photo shows the close proximity of the lake to the deep gully (lake on the left).

Figure 153. With the clearing of ‘all’ forestry trees the river bank alongside the lake is susceptible to washing out and the lake may be eventually lost.

GLOSSARY

Types of Geothermal Activity

Surface geothermal activity can be grouped according to the types of processes that are occurring and the nature of deposits and landforms which result from them. Surface manifestations of geothermal activity are caused by the effects of two extreme end member processes: deep geothermal waters reaching the land surface, and by steam and gases boiling off from a deep aquifer. A continuum of intermingling between these two end member processes also occurs, which produces many intermediate forms of surface effects and features.

Groundwater availability and mixing, or its absence, greatly alters forms and appearances of surface features, which occur because of the addition of water and dissolved oxygen contained in it. Air entrainment allows oxidation of sulphides within exsolved gases and geothermal fluids, which in turn produce strong acid attack on most rock forming minerals. To assist with classification of surface geothermal features, the following list describes what constitutes each class and form. This also allows uniformity when discussing these features.

Generally, below about 73^{o}C photosynthetic algae ("blue-green algae" or cyanobacteria) can grow in waters containing sulphides and of alkaline, neutral or weakly acidic pH. Above that temperature photosynthetic algae do not grow and filamentous white to grey algae grow instead. Pools with only weak upflows of geothermal fluids or steam and gases are generally clear waters above about 73^{o}C, but below that temperature these waters are usually opaque or cloudy white, due to colloidal sulphur produced from the sulphide oxidation metabolism by bacteria. Above ~73^{o}C sulphur does not form but sulphates occur instead, so waters tend to remain clear.

Fumaroles: Dry steam and gas vents without water droplets, usually discharging under pressure with audible noise of steam ejection. Most commonly found in active volcano craters and less commonly in geothermal systems.

Solfatara: Areas of hot barren ground boiling to the surface, which are typified by sulphur deposition, with exfoliating and heaving or buckling of the ground surface due to oxidation of sulphide to sulphur (or sometimes by sublimation of sulphur), which grows sulphur crystals in voids to heave ground apart in prominent mounds of sulphur cemented sediments. Associated with boiling conditions extending from the geothermal aquifer to the ground surface. Uncommon in New Zealand; best examples being within White Island Crater and at the Puarenga Stream delta in Sulphur Bay, Rotorua.

Mud Pool: A viscous muddy pond that may build up mounds or ridges of mud as the pond dries out in dry or warm weather. Rainfall may dilute these muds to temporarily form a turbid muddy pool. Formed by steam and gas heating of surface ground; the acidic by-products attack the surrounding soil and materials to break these down into suspended solids. May be discoloured by small additions of sulphides, or creamy white if free of sulphides or sulphur.

Mud Cones (Mud Volcanoes): Steam and gas heated and altered ground with very little free water available to form pools or mud ponds. Highly viscous muds can then spatter away from gas vents to build up stiff mounds or cones. May break down in wet weather conditions, but rebuild in drier weather once more. Mud cones are a rare form of surface feature, although boiling geothermal ground is common.

Turbid Pools, Lakelets: Groundwater pools with significant amounts of gas and steam entering them to oxidise sulphides and produce acids, which attack and break down surrounding ground. Colloidal sulphur suspension produces turbid water and black sulphur or sulphides may produce a variety of colours. Usually these are warm, tepid, or even cold water pools. Above about 65°C these waters are clear, due to oxidation of sulphur to colourless and soluble sulphates.

Craters and Dolines: Circular or oval depressions forming distinct craters may form by either collapse or eruption. Collapse craters form by subsurface chemical and physical (tunnel) erosion of materials so that ultimately the ground surface falls into a void. Eruptions form craters by sudden production of steam to violently expand and throw open a crater, accompanied with production of airborne debris. These are called hydrothermal eruptions, which are driven by physical changes of form (usually hot water to steam); they do not involve any chemical release of energy, as occurs in true explosions.

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