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Regional Geothermal Geochemistry Monitoring Programme (REGEMP II)

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Abstract

Chemical characteristics of geothermal fluids provide useful information on the deep resource, as well as on the nature of heat and mass flow from source to the surface. A geothermal geochemical monitoring programme (REGEMP) for the Waikato region was first developed in 1996 (Huser & Jenkinson, 1996), but for various reasons of budget or staff availability, never implemented until now. This new version of REGEMP, REGEMP II, is adapted from the programme of Huser and Jenkinson, taking account of developments that have occurred in the intervening period in relation to policy development, understanding of the nature of the geothermal resource, and the availability of new methods of geochemical analysis.

In addition to springs in the Taupo volcanic zone, the 1996 programme sampled a limited number of small isolated springs. The 2005 programme has added significantly to the number of isolated springs sampled. These springs are increasingly being used for leisure bathing and in some cases for horticultural uses. It is necessary to sample them to establish a baseline for unused springs, and to monitor effects of several small takes on small geothermal systems. For this reason, all small geothermal systems that have springs or wells that are readily accessible are included in the current programme.

1 Introduction

1.1 Monitoring the Waikato regional geothermal resource

One of the Waikato Regional Council's statutory requirements, as set out in the Resource Management Act (1991) Section 35, is: "to gather information, monitor, and keep records on the state of the whole or any part of the environment of its region to effectively carry out its function". In conformity with that requirement a Regional Geothermal Geochemistry Monitoring Programme has been established.

Geothermal systems and their associated surface features constitute significant natural resources for the Waikato region, requiring the availability of data and information to ensure their sustainable use, development and protection. This programme has been designed to sample, analyse, and report on the geochemistry of a representative range of geothermal flowing springs and fumaroles throughout the Waikato region.

The Waikato region contains approximately 80 per cent of the nation's geothermal resources. The Waikato resource consists of 15 high-temperature geothermal systems and approximately 31 small geothermal systems. The high-temperature systems are found in the Taupo volcanic zone (TVZ), a band of active volcanism stretching from Mt Ruapehu north-east to White Island (Whakaari) and beyond. The small systems are found throughout the region, but particularly in the Waikato lowlands and along the base of the Kaimai ranges. There are some small systems in the TVZ (see Figure 1).

A geothermal geochemical monitoring programme (REGEMP) for the Waikato region was first developed in 1996 (Huser & Jenkinson, 1996), but for various reasons of budget or staff availability, never implemented until now. This new version of REGEMP, REGEMP II, is adapted from the programme of Huser and Jenkinson, taking account of developments that have occurred in the intervening period in relation to policy development, understanding of the nature of the geothermal resource, and the availability of new methods of geochemical analysis.

The geothermal chapters of the Waikato Regional Policy Statement (Environment Waikato, 2006a) and Proposed Waikato Regional Plan (Environment Waikato, 2006b) set out the management regime for geothermal resources. They identify the lack of geothermal information as one of the issues for the region, and contain objectives and policies for ensuring provision of appropriate information. Both documents emphasise the importance of adequate monitoring of the region's geothermal resources, and contain objectives and policies for ensuring provision of appropriate information.

Note that there needs to be a distinction made between consent monitoring and environmental monitoring.

(i) **Consent monitoring:** Monitoring undertaken by a consent applicant as part of their Assessment of Environmental Effects, and later, if a resource consent is granted, monitoring to assist in ensuring compliance with consent conditions, and to determine effects of the consented operation.

(ii) **Environmental monitoring:** This includes characterising geothermal features and other geothermal features, and carrying out baseline and trend monitoring. This is mainly carried out by the regional council, Crown Research Institutes, and universities.

As the former is generally the responsibility of the resource user, for example a developer of a geothermal system, we are primarily concerned with aspects of environmental monitoring in this programme. It is important, however, that information requirements and any data collected from resource users are coordinated to optimally complement the environmental monitoring programme.

The geothermal chapters of the Waikato Regional Policy Statement and Proposed Waikato Regional Plan divide the region's geothermal systems into five categories: four high-temperature system types and Small Geothermal Systems:

- **Development Geothermal Systems** are those where large-scale extractive uses are allowed. There are seven Development Geothermal Systems in the Waikato Region: Horohoro, Mangakino, Mokai, Ngatamariki, Rotokawa, Ohaaki, and Wairakei-Tauhara. Geothermal power stations are in operation at Mokai, Rotokawa, Ohaaki, and Wairakei-Tauhara, and the resource consent holders for these power stations are required to undertake geochemical monitoring, with the purpose of observing any changes to geothermal features and to the geothermal reservoir that are caused by large-scale extraction. While this monitoring is the major source of information on the geochemistry of each system, it is appropriate that some monitoring be undertaken directly by Waikato Regional Council to act as a cross-check. It is also important that the information gathered by the users is collated into a regional information network. In the undeveloped systems, it is necessary for baseline monitoring so that effects on the system can be quantified more accurately when development occurs.
- **Limited Development Geothermal Systems** are those where small-scale development is allowed as long as it does not adversely affect geothermal features that have been classified by the policy documents as Significant Geothermal Features. There are two Limited Development Geothermal Systems; Atiamuri and Tokaanu-Waihi-Hipaua. There are some small extractive uses already occurring at Tokaanu-Waihi-Hipaua, and there have been marked changes in the activity of geothermal features over the last 100 years. A cause and effect relationship has not been determined conclusively because of a lack of monitoring data. There are few extractive uses at Atiamuri, other than modifications to one of the Whangapoa Springs to enable bathing in the outflow, and some farm wells. For these systems, as with the Development Geothermal Systems, it is necessary to establish the current baseline before any further development occurs, and also to determine the natural characteristics of the resource for policy development and implementation.
- **Research Geothermal Systems** are those where not enough is known about the system to put it in one of the other three categories. Reporoa is the only known system in this category. There may be undiscovered systems that have no identifying surface outflow. Reporoa system adjoins Waikite-Waiotapu-Waimangu, a Protected Geothermal System. A geochemical monitoring programme will both assist in determining the characteristics of the system and provide some baseline data for if it is later classified as Development or Limited Development.
- **Protected Geothermal Systems** are those where only very small-scale extractive uses are allowed, in order to protect the large number of vulnerable Significant Geothermal Features in these systems. The systems in this category are Orakeikorako, Te Kopia, Tongariro and Waikite-Waiotapu-Waimangu. There is variability in the activity of geothermal features, from both natural and artificial changes. Unknown system dynamics and external factors such as climate and, at Orakeikorako, water level changes in Lake Ohakuri can affect the geothermal features. It is necessary to determine the natural range of variability in geothermal features in order to determine more fully the effects of other natural and artificial events such as earthquakes, volcanic eruptions, and climate variations. In addition Waikite-Waiotapu-Waimangu is adjoined by the Research Geothermal System Reporoa, which may be hydrologically linked to it. Geochemical monitoring of these two systems can assist in determining whether they are linked.
- **Small Geothermal Systems:** Very little is known about the 31 identified Small Geothermal Systems in the Waikato Region. Some of these systems are remnants of ancient large geothermal systems, which have left behind a large volume of residual hot water at medium depths of 500 metres to a kilometre, with some springs providing a surface expression. Waikare, Te Aroha, and Hot Water Beach may fall into this category. Very high mercury concentrations have been found in the sediment surrounding the Lake Waikare springs, and there are sinter deposits near

the springs. Both factors indicate a hot, deep resource. Other springs are of a tectonic nature, with fissures and faults providing a conduit for water heated by the natural geothermal gradient to find its way to the surface. Some small systems may be linked to others, particularly those on the Coromandel Peninsula and those at the base of the Kaimai Ranges. Some of the systems support small-scale uses, such as commercial, domestic, or informal bathing facilities. These small systems have not been studied in any great detail because they are unlikely to provide a substantial economic resource. In most cases, the capacity of each system to support any, or further uses, is unknown, as is the source and nature of the fluids produced by each system. Geochemical monitoring of a representative set of springs would aid understanding of the nature of the Region’s warm-water resource.

Figure 1: Map of geothermal resources of the Waikato region

2 Design of monitoring programme

2.1 What do we need to monitor?

Geothermal resources have a variety of characteristics that may require monitoring, including:

- **physical-chemical** (such as heat, flow, enthalpy, pressure and geochemistry)
- **biological** (such as terrestrial and aquatic vegetation, flora and fauna, thermophilic bacteria and other microorganisms, rare and endangered species)
- **amenity values** (such as landscape, appearance, uniqueness and recreation/tourism)
- **traditional, cultural and spiritual values** (Maori taonga).

Chemical characteristics of geothermal fluids provide useful information on the deep resource, as well as on the nature of heat and mass flow from source to the surface.

It is proposed to determine the chemical composition of geothermal liquids and gases from hot springs, wells, and fumaroles for this programme.

Other characteristics are studied as part of specific monitoring programmes. In addition to reports generated by such entities as Crown Research Institutes and universities, the following reports have either been completed in recent years by or for Environment Waikato or are currently in press.

- **Aquatic Biota Bibliography**: S. Parkyn and I. Boothroyd (2000): *Aquatic biota of geothermal ecosystems: annotated bibliography of biodiversity, distribution and environmental significance*. Hamilton, NIWA: 23.
- **Aquatic Biota in Flowing Waters:** I. Duggan and I. Boothroyd (2001): *The distribution of biota from some geothermally influenced waters in the Taupo Volcanic Zone*. Hamilton, NIWA: 31.
- **Aquatic Biota in Standing Waters:** I. Duggan and I. Boothroyd (2002): *The distribution of biota from some geothermally influenced standing waters in the Taupo Volcanic Zone*. Hamilton, NIWA: 38.
- **Aquatic Habitat:** M.I. Stevens, A.D. Cody, and I.D. Hogg (2003): *Habitat Characteristics of Geothermally Influenced Waters in the Waikato Region*. This maps all known aquatic geothermal habitat in the Waikato Region and describes the important habitat parameters of each site.
- **Earth Science Bibliography:** W.A. Hampton, K.A. Rogers, and P.R.L. Browne (2001): *Geothermal Activity (Past and Present) in the Environment Waikato Region: an Annotated Bibliography*, 2001. This is a full bibliography of all documents, published and unpublished on the Regional geothermal resource that the authors could find.
- **Vegetation:** Wildland Consultants Ltd (2004): *Geothermal Vegetation of the Waikato Region: Revised 2004*. This provides a comprehensive survey of all geothermal vegetation sites in the Waikato Region over one hectare in area, and some smaller than one hectare. A later document, Wildland Consultants Ltd (2006b): *Field Evaluations of Five Geothermal Sites, Waikato Region, June 2006,* provides updated information on five sites. Wildland Consultants Ltd (2007) describes geothermal information on 8 previously unstudied sites, and an update on one other. Wildland Consultants Ltd (2006a): *Priorities for Pest Plant and Animal Control, and Fencing at Geothermal Sites in the Waikato Region* prioritises all geothermal vegetation sites for protective intervention.
- **Sinter Springs:** A.D. Cody, R.F. Keam, K.M. Luketina, and D. Speirs (2007, in press): *Sinter-depositing Springs and Geysers in the Waikato Region*. This is an

inventory of all sinter-depositing springs and geysers, giving description, histories, and photos for each spring.

- **Significant Geothermal Features:** R.F. Keam, K.M. Luketina and L.Z. Pipe (2007, in press): *Definition and Listing of Significant Geothermal Features in the Waikato Region*. This defines and identifies the type of Significant Geothermal Features in the Waikato Region and determines the significance of each type based on rarity and vulnerability.
- **Hydrothermal Eruption Craters:** Bridget Y. Lynne, (2007): *Hydrothermal Eruption Craters within the Horohoro Thermal Area and Tauhara.* This reports on field examinations of eruption breccia to determine the true nature of landforms previously identified as hydrothermal eruption craters.
- **Behaviour of Springs:** From 1999 to 2005 Ashley Cody (Cody, 2000, 2001, 2002, 2003, 2004, 2005) monitored the behaviour geothermal springs in the Waikato Region for the Waikato Regional Council, and produced annual reports on his observations. From 2007 that role has been resumed by Bridget Lynne.
- **Location of Springs:** In January 2007 Environment Waikato monitoring staff visited geothermal springs and streams in 9 locations to describe and map the features (Holwerda and Blair, 2007).

Other monitoring methods and techniques include:

- aerial photography (b/w, colour, infrared)
- remote sensing – satellite/video imagery (such as SPOT, Landsat and Geoscan)
- heat surveys (thermal infrared).

These have also been used and continue to be investigated for their potential and most useful applications. The data obtained from the Regional Geothermal Monitoring Programme can be combined with surface feature mapping (detailing location and access), and photo/video documentation taken at fixed photo points to provide comprehensive information on geothermal features over time.

2.2 Sources of fluid

There are two potential types of sources of fluid for geothermal monitoring:

- wells, which, depending on depth, access either the deep or shallow aquifers
- natural surface features.

For the study of the characteristics of the geothermal resources *per se*, use of wells for monitoring would be preferable. However, most wells are privately owned and may not be available for sampling because of issues to do with obtaining legal or physical access to the well head, or whether the configuration of the wellhead permits sampling. In addition, wells are not available for sampling when they are being pumped, and the fluid extracted from them is not representative for some time after pumping ceases.

Natural surface features, e.g. hot springs and fumaroles, are the manifestations of the deep geothermal resources, and as such representative of a particular system or area. Hot springs and fumaroles are more practicable to monitor than wells since, in general, they are fairly accessible. It is therefore proposed to focus on natural features for this programme, except in situations where there are either no natural discharging features or they are not easily accessible.

2.3 Important considerations

The following factors need to be considered when designing a geochemical monitoring programme of geothermal features.

Representativeness
It is important to choose a range of features that cover:

- a comprehensive geographical spread
- all important geothermal fields in the region
- all features with unusual chemistry.

Influences
The following chemical characteristics need to be considered in choosing features for sampling. Chemical analysis over time can determine the extent of these parameters:

- influence by surface flows of cold meteoric waters
- human influences such as agricultural contaminants.

Natural variability
The discharge from a feature may vary depending on such short-term factors as rainfall, atmospheric pressure, or ground water levels. Seasonal rainfall changes may take years to propagate. Changes in characteristics of the geothermal aquifer or feed zones may affect the feature, and geochemical monitoring may be the only way to observe such changes.

Determinands
A decision need to be made about whether it is necessary to test all features for the same chemical species, or if the analytical suite should be determined on a case-by-case basis.

Logistics of sampling and analysis
Considerations relating to the logistics and safety of sampling include the following.

- Geographical or legal accessibility.
- Physical risks involved in accessing the feature and in working with hot steam and water in areas where ground may be unstable. This may require an experienced operator and in almost all cases a team of at least two.
- Particular equipment and techniques must be employed in taking samples, and the correct sample bottles used. Some field measurements such as temperature must also be taken for input into the laboratory analysis.

Data storage and querying/analysis

Systems need to be in place to ensure that new observations and monitoring results are appropriately archived. In terms of previous data, a VAX-based database exists at IGNS, but may require updating. This database contains only data collected prior to 1983 (except some newer Wairakei information). There is still a lot of early data, mainly in various field/notebooks and files, which should be entered onto the database.

IGNS are developing a new web-based database, currently located at http://data.gns.cri.nz/gww/index.jsp.

Data from this monitoring programme will need be entered into the appropriate Environment Waikato information management systems such as LOCATED. A system for ensuring this needs to be developed.

2.4 Schedule of previous work

Huser and Jenkinson (1996) undertook the following schedule of activities for the design of the Regional Geothermal Monitoring Programme.

1 **Compilation** of available information, including preparation of a ‘master list’ of geothermal systems/areas, including relevant bibliographic details and location maps (see Appendix I, Huser and Jenkinson, 1996).

2 **Investigation** of the short term variability in chemical characteristics (from existing data) to assist in design of the programme (for example, suitable determinands, trend detection power, sampling frequency), (see Section 2.3, Huser and Jenkinson, 1996).

3 **Selection** of representative features for sampling (see Section 2.2: Tables 1 and 2, Huser and Jenkinson, 1996), determinands to measure, and sampling frequency:

   a. development of operational plans and procedures

   b. development of data storage system and data analysis procedures, and performance measures.

4 **Geochemical sampling** of the features in 1993 and 1994 (see Table 3, Huser and Jenkinson, 1996).

5 **A detailed description** of all sites, including location, directions for access, photographic documentation, hazards, and other observations (see Appendix 1, Huser and Jenkinson, 1996).

3 Collection and analysis

Since 1996 there have been changes to analysis techniques and their availability, and costs of analysis have decreased for many chemical species. In addition, elements can be detected to much lower limits. Because of these developments, and because of the length of time that has elapsed since the last analysis, it is considered appropriate to do a full analysis of all springs and fumaroles on every occasion, rather than a full analysis some years and a partial analysis most years.

Water samples will be collected by Environment Waikato staff and contractors. Spring water is to be analysed by Hill Laboratories, who are IANZ-accredited. They have a strong relationship with Environment Waikato, and do most of Environment Waikato's analytical chemistry. Consequently there are in place well-tested standardised receipt and reporting procedures, and their proximity to the Environment Waikato Hamilton office enables easy transfer of samples. Most trace level analyses will be done using ICP-MS instruments.

Gas samples will be collected and analysed by GNS Science, Wairakei, who are experienced in gas collection and analysis, and who have the appropriate equipment.

Isotopes will be measured by Isotrace, a commercial arm of Otago University, who are the only laboratory in New Zealand capable of doing this.

Because costs are lower, new chemical species are able to be analysed, and full analysis carried out each year.

3.1 Analysis of waters

The full analysis for geothermal waters will now consist of pH, conductivity, and the following chemical determinands.

- **Major or significant anions and related species:** bicarbonate (HCO_3^-), silica ($SiO_2(OH)_2^{2-}$ / $SiO(OH)^{3-}$ / $Si(OH)_4$) and total dissolved silicon (Si), chloride (Cl^-), sulphate (SO_4^{2-}), fluoride (F^-), sulphide and un-ionised hydrogen sulphide (S^{2-} and dissolved H_2S). Un-ionised hydrogen sulphide is estimated from sulphide, by a method that also requires source temperature and salinity.
- **Major or significant cations:** dissolved sodium (Na^+), potassium (K^+), lithium (Li^+) calcium (Ca^{2+}), magnesium (Mg^{2+}), iron ($Fe^{2+/3+}$), total ammoniacal-nitrogen (nominally NH_4^+).
- **Other trace elements:** dissolved aluminium (Al), antimony (Sb), arsenic (As), boron (B), bromine (Br), caesium (Cs), mercury (Hg), rubidium (Rb) and thallium (Tl).

3.2 Rationale for analysis of waters

- **Sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and silica** (approximated as SiO_2) are geothermometers. Silica increases with temperature and its concentration in the deep fluid is controlled by quartz solubility. Sodium and potassium are subject to mineral solubility controls that result in the value of the sodium/potassium ratio having an inverse relation to temperature.
- **Calcium** also has mineral solubility constraints. Usually the proportions of the three cations (sodium, potassium and calcium) are different in the three basic types of water (deep geothermal, shallow steam-heated, and cold near-surface or ground water). Thus their ratios can be used to identify these components in the discharged water.
- **Magnesium** (Mg^{2+}) indicates more or less mixing with low-temperature surface water. In deep hot geothermal fluids, it is present only in small concentrations due to solubility considerations.

- **Chloride** (Cl^-) is a basic component used to determine dilution or contribution of deep thermal water that has high chloride content.
- **Sulphate** (SO_4^{2-}) indicates contribution of shallow steam heated waters. It is formed by the oxidation of sulphide (S^{2-}).
- **pH** varies with the proportion of deep to shallow components, increasing with an increase in the deeper, more mineralised, component of the spring flow.
- **Conductivity** can be used as a simple general indication of bulk change in the total concentrations of dissolved cations and anions.
- **Bicarbonate** (HCO_3^-) increases with greater ground water components in the spring. Together with chloride and sulphate it helps distinguish deep, steam heated, and ground water components.
- **Rubidium (Rb^+), caesium (Cs^+), ammonia (NH_4^+), and hydrogen sulphide (H_2S)** can also be used to characterise the fluid. The presence of rubidium and caesium are associated with deep fluids whilst the ammonia and hydrogen sulphide are indicators of possible steam heating. They are also liable to large concentration changes over time.
- **Lithium (Li^+) and boron** ($B(OH)_4^-$, $B(OH)_3$, $B_3O_3(OH)_4^-$ and various other polyborate species) indicate whether the same or different aquifers are supplying different springs. Lithium is also an indicator of the presence of deep geothermal water.
- Other constituents listed above, i.e. **arsenic (As), fluoride (F^-), iron (Fe), aluminium (Al), and mercury (Hg)**, are normally analysed if environmental effects of the discharge are to be considered. Iron may also be a useful indicator of reduction and oxidation potential of the source waters, as high concentrations of dissolved iron occur in groundwater as a result of reducing conditions.

3.3 Analysis of gases

The full analysis for geothermal gases will now consist of:

Carbon dioxide (CO_2), hydrogen sulphide (H_2S), oxygen (O_2), nitrogen (N_2), methane (CH_4), argon (Ar), ammonia (NH_3), water (H_2O), hydrogen (H_2) and helium (He).

3.4 Rationale for analysis of gases

- **Carbon dioxide** (CO_2) and hydrogen sulphide (H_2S) are the major geothermal gases.
- Elevated concentrations of **helium** (He) indicate a mantle component.
- **Hydrogen** (H_2) varies with the temperature of the source.
- **Oxygen** (O_2) is not present in deep geothermal fluids and its presence is used to check on whether air has contaminated the sample. Air is approximately 20 per cent oxygen and 80 per cent nitrogen. Nitrogen (N_2) together with argon (Ar) show the presence of deep fluid, or atmospheric gases/gases exsolved from ground water.
- **Methane** (CH_4), although present in geothermal fluids, can also indicate shallow organic decomposition.

All gases may vary as the pressure and temperature of the steam supplying the fumarole changes.

3.5 Isotope analysis of gases and waters

The isotopes to be analysed are the same as in REGEMP (Huser and Jenkinson, 1996): deuterium (^{2}H) and oxygen-18 (^{18}O).

3.6 Rationale for isotope analysis

Deuterium and oxygen-18 in water are used to investigate the source of the deep water by comparing the deuterium content of the geothermal water with those of local meteoric waters. They can also reveal processes such as evaporation and dilution of the deep water by ground water in the system.

4 Current monitoring programme

4.1 Springs and fumaroles to be sampled

Small geothermal systems

The 1996 programme sampled a limited number of small isolated springs. The 2005 programme has added significantly to the number of springs sampled. These springs are increasingly being used for leisure bathing and in some cases for horticultural uses. It is necessary to sample them to establish a baseline for unused springs, and to monitor effects of several small takes on small geothermal systems. For this reason, all small geothermal systems that have springs or wells that are readily accessible are included in the current programme. Locations added are: Buffalo Beach (Taputapu), Ngatea, Okoroire, Lake Waikare, and Whangairorohea.

At Hot Water Beach, on the advice of the 1996 report, the motorcamp bore is to be sampled rather than the beach seeps.

Springs and wells in large geothermal systems

The only changes to these relative to the 1996 programme have been the removal of the northern Tauhara springs (Kathleen Spring, A.C. Spring, and Spa Spring) that have stopped flowing. The spring named in the 1996 report as Upper Atiamuri is now known as one of the Whangapoa springs in the Atiamuri geothermal system.

Fumaroles in large geothermal systems

It would be beneficial to sample a fumarole at Hipaua, as the Tokaanu-Waihi-Hipaua system did not have any fumaroles being monitored. However, access has been denied by the land owners.

4.2 Sites

The new set of sampling sites and proposed monitoring schedule is listed in Tables 1 - 3 overleaf.

Previous results from Huser and Jenkinson (1996) are shown in Tables 4 – 6.

In each table, ‘QUALARC number’ refers to the feature’s identifier in the Environment Waikato monitoring database.

Table 1: Selected monitoring features – springs in small systems

Small system	Feature	QUALARC number	Grid ref	Monitoring source	Rationale	Comment
Buffalo Beach (Taputapu)	Bore Seawater			Hopping bore	Most northern spring, may be linked to Hot Water Beach	
Hot Water Beach	Bore Seawater	??	T11:621-756	Motorcamp bore?	Being used, may be linked to Buffalo Beach	Sample motorcamp bore at low tide, sample sea water
Kawhia	Seepage Seawater	2687	R15:663-470	None	OO	Sample at low tide, sample sea water
Lake Waikare	Hot spring on islet in lake Lake water				High mercury content in surrounding sediment and presence of sinter on island	Island spring
Miranda	Bath source	2690	S12:171-411	Some from consent	HS	Some analysis every five years by consent holder
Ngakuru	Spring			None	Small system in midst of TVZ	
Ngatea	Rock Shop Well					
Okauia	Opal Springs	2684	T14:602-755	None	LF,HS?	
Okoroire	Hotel Bore			None	Southernmost Kaimai spring	Hotel spring – will need to liaise with hotel
Te Aroha	Mokena Geyser (#1)	2685	T13:504-029	None	HD,LF	
Naike (Te Maire)	Main Spring	2689	R13:820-098	None	LF,HD	Maybe change spring
Waingaro	Baths bore (trapdoor)	2688	R14:866-881	Consent?	OO	
Waitoa	Hapai Rd, Elstow (Suisted)	2683	T13:387-073	None	HS	
Whangairorohea	Spring			None	Small system in midst of TVZ	

Table 2: Selected monitoring features – springs in high-temperature systems

Field	Feature	QUALARC number	Grid ref	Monitoring source	Rationale	Comment
Atiamuri	Upper Atiamuri	53	U16:766-111	None	LF	
Horohoro	Horohoro pool	862	U16:876-227	None	OO	Bore Consent had full analysis in 1997, 2002
Mokai	North Mokai #29 (Mulberry Rd)	2681	T17:678-009	Quarterly	CS,GS	
	South Mokai, #1 (Parekiri)	2680	T17:664-929	Quarterly	GS	
Ngatamariki	New Feature	2668	U17:867-918	None	HS	
Ohaaki	Mihi	2669	U17:983-964	Contact Energy Ltd	OO	
Orakeikorako	Waihunuhunu (#674) Map of Australia, EFL 25) Manganese Pool (#120)	2678 2679	U17:853-010 2784250 – 6298600 U17:847-986	None None None	GS,HD GS GS,HD	
	Red Hills					
Reporoa	Opaheke	94	U17:012-043	None	LF,HD	
Rotokawa	#4B (Eastern Pool) #10 #22 (adj. Parariki Stm) #4 A (Western Pool)	2670 2671 2672 2673	U17:879-813 U17:884-821 U17:886-816 U17:879-814	 Yes Yes yes	EW-MP EW-MP,HD EW-MP,HD EW-MP,HD	

Field	Feature	QUALARC number	Grid ref	Monitoring source	Rationale	Comment
Tauhara	Terraces Spring Taharepa Spring Lake Front Spring	109 928 695	U18:787-727 U18:783-735 U18:783-732	Contact Energy Ltd Contact Energy Ltd Contact Energy Ltd	EW-MP,HD EW-MP,HD EW-MP,HD	
Te Kopia	Murphy's Farm	2677	U17:909-066	None	CS	Ensure correct feature
Tokaanu Waihi	#47 (Whakatara)	2675	T19:479-468	None	LF,HD	
	Old Bath House Spring	1267	T19:494-449	None	LF,HD	
Tongariro	*Black Cauldron *Iron Spring	TI 1004 TI 1009	T19:391-295 T19:390-294	IGNS IGNS	LF,HD LF,HD	
	Lower Emerald Lake Blue Lake	TI 1001 TI 1000	T19:398-268 T19:400-277	IGNS IGNS	CS CS	
Waikite	#6 (WE1031) (Manuroa)	2676	U16:991-143	None	LF	Consent source spring full, 1997, 2002
Waimangu	Rainbow Mountain		U17:855-008	None		
Waiotapu	Champagne Pool #24 (Frying Pan Flat)	2665 2666	U16:046-105 U16:045-102	None None	LF,HD GS	 May require full annually
Wairakei	Totara Gut	2674	U17:790-802	Contact Energy Ltd	00	

Table 3: Selected monitoring features – fumaroles

Field	Feature	ID number	Grid reference	Monitoring source	Rationale	Comment
Hipaua				None		
Mokai				None		
Ohaaki				None		
Orakeikorako				None		
Reporoa				None		
Rotokawa	#14	RK 1006	U17:885-825	Rotokawa Joint Venture	EW-MP, HD	
Tauhara	Pony Club	TH 1015	U18:807-758	Contact Energy Ltd	HD, GS	
	Hell's Gate	TH1016/ TH1022	U18:788-762/??	Contact Energy Ltd	HD, GS	
Te Kopia	Te Kopia Fumarole	TK 1001	U17:913-052	None	LF	
Tongariro	*Ketetahi #2	TI 1012	T19:391-298	IGNS	LF, HD	Get results from GNS
	*Emerald Lake Fumarole	TI 1018	T19:395-266	IGNS	HD, GS	Get results from GNS
	*Red Crater	TI 1019	T19:392-264	IGNS	GS	Get results from GNS
	*TNP Central Crater	TI 1017	T19:391-268	IGNS	GS	Get results from GNS
Waikite	Foot of Waikite Scarp	WE 1010	U16:998-149	None	OO	
Waimangu				None		
Waiotapu	Maungaongaonga	WT 1066	U16:026-133	None	OO	
Wairakei	Thermal Valley (opp. Spring #97)	WK 1054	U17:7850-8305	Contact Energy Ltd	HD, LF	
	Karapiti (KP18)	WK1045	U18:77166-79794	Contact Energy Ltd	HD	
	Karapiti (KP22)	WK 1047	U18:77026-79315	Contact Energy Ltd	HD	

Abbreviations for rationale:

GS	=	Geographical Spread
HD	=	Historical Data
LF	=	Largest Feature (Size and/or flow and/or temperature)
OO	=	Only Feature
HS	=	Hottest Spring
CS	=	Chloride Spring in area of mostly steam heated acid features
EW-MP	=	Environment Waikato monitoring programme (existing)

Table 4: Small geothermal systems: water analyses

(Huser and Jenkinson, 1996)

Field	Feature	Date	Sample	CT	AT	pH	Li	Na	K	Ca	Mg	Rb	Cs	Cl	SO_4	B	SiO_2	NH_3	Tot HCO_3	Tot H_2S	F	Cond	Fe	As	^{18}O	^{2}H
				°C	°C	pH	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mS/m	mg/L	mg/L	°/oo	°/oo
HOT WATER BEACH	Hot Water Beach	**4/06/1994**	**7323/23**	**51.6**	**22**	**7.45**	**7.3**	**3100**	**127**	**181**	**209**	**0.75**	**0.91**	**5536**	**514**	**2**	**68**	**1.8**	**246**		**1.7**	**1644**	**<0.3**	**0.064**	**-4.4**	**-23.8**
		15/12/1983	5658	50	26	8.11	6.04	3726	193	334	215.3	0.89	0.84	6585	670	2.1	45	0.3	236	2						
		30/01/1981	4891/24		21	7.85	7.6	1587	98	177	58	0.83	0.62	2759	146	1.4	56		211							
	Hot Water Beach Well	17/06/1973	MI40	50		6.7	8.6	1035	96	151	2.3	0.87	0.87	1924	2.3	1.53	75		186		1.4					
	Hot Water Beach Spring	17/06/1973	MI39	63		7.6	8.6	1253	99	242	18	0.76	0.76	2240	31	1.63	66		254		1.2					
KAWHIA	Kawhia	**7/06/1994**	**7323/25**	**46**	**22**	**7.75**	**2.5**	**4096**	**90**	**2050**	**339**	**0.17**	**<0.05**	**10140**	**584**	**7.3**	**39**	**3.3**	**49**		**0.58**	**3214**	**1.2**	**0.017**	**-3.62**	**-20.2**
		28/01/1981	4891/48		18	7.41	1.6	4290	174	2360	350	<0.1	0.42	11540	603	9.34	43		93							
MIRANDA	Miranda-Bath Source	**20/04/1994**	**7323/3**	**55.3**	**15**	**6.21**	**0.19**	**133**	**1.8**	**2.8**	**0.02**	**<0.05**	**<0.05**	**151**	**11**	**4.9**	**55**	**0.45**	**54**	**<1**	**0.96**	**64.6**		**<0.001**	**-6.01**	**-35.3**
		5/08/1993	**7190/3**	**53.1**	**21**	**9.15**	**0.18**	**127**	**1.4**	**2.6**	**0.01**	**<0.05**	**<0.05**	**150**	**7**	**5.1**	**56**	**0.38**	**56**	**<1**	**0.86**	**65.4**	**<0.25**	**<0.001**		
	Miranda HS	7/12/1984	5963/6	56.5	22	8.93	0.2	80	<5	3.9	<0.02	<0.05	0.05	151	22	<5	52									
OKAUIA	Opal Springs	**4/06/1994**	**7323/24**	**39**	**22**	**7.32**	**0.2**	**110**	**11.3**	**16**	**9.9**	**<0.05**	**<0.05**	**15**	**<5**	**1**	**78**	**0.19**	**414**		**0.25**	**60.3**	**<0.3**	**0.013**	**-5.78**	**-35.3**
		29/01/1981	4891/46		20	7.65	0.2	97	10.4	23.5	11.1			17	6	0.89	77		402							
TE AROHA	Te Aroha Mokena	**20/04/1994**	**7323/4**	**77.3**	**15**	**8.17**	**1.9**	**3190**	**69**	**4.2**	**3.7**	**0.31**	**0.27**	**570**	**374**	**156**	**118**	**2.5**	**6450**	**<1**	**2**	**1034**	**<0.3**	**1.1**	**-2.28**	**-34**
		5/08/1993	**7190/5**	**72.9**	**21**	**8.18**	**2**	**3100**	**68**	**4.1**	**3.6**	**0.3**	**0.28**	**571**	**394**	**157**	**116**	**5.19**	**6300**	**<1**	**1.8**	**1257**	**<0.25**	**1.2**		
		1986				8.4	1.9	3310	78	4.8	4.1			567	1260	170	123		7100							
		29/01/1981	4891/31		19	8.7	2	3120	70	3.4	3.8	0.42	0.36	575	417	151	114		6880							
		1979				7.8	1.8	2920	67	6.8	3.9			540	472	161	138		6830							
		1958				7.5	2	4675	108	8.2	4			582	321	161	120		7000							
		1956												596		114			5960							
		1938						3162	40	8	4			581	388	132			6860							
TE MAIRE (NAIKE)	Te Maire Naike	**20/04/1994**	**7323/2**	**46.9**	**15**	**9.3**	**0.11**	**150**	**1.7**	**2.9**	**0.02**	**<0.05**	**<0.05**	**153**	**10**	**12.2**	**66**	**0.46**	**35**	**<1**	**11**	**70**	**<0.3**	**<0.001**	**-5.42**	**-32.1**
		5/08/1993	**7190/2**	**44**	**21**	**9.29**	**0.1**	**145**	**1.3**	**2.7**	**0.03**	**<0.05**	**<0.05**	**151**	**10**	**12.6**	**66**	**0.43**	**37**	**<1**	**14**	**72**	**<0.25**	**<0.001**		
	Te Maire Spring #1	08/83		64		9.7	0.2	155	2.1	5.2	0.01			160	5	12.3	48									
	Te Maire S	28/01/1981	4891/45		20	8.88	0.1	158	1.6	2.9	0.007			159	10	11.7	63		51							
	Te Maire Bath	27/01/1981	4891/28		18	9.17	<0.1	149	1.6	2.9	0.05			159	10	12.6	74		46							
	Te Maire N	27/01/1981	4891/27		18	8.94	0.1	144	1.6	2.9	0.01			161	10	12.8	64		59							
	Te Maire HS	19/12/1969	M49			9.15	1.8	150	2.5	2.6	7.9			159	4	11.9	70		34		9.1					
WAINGARO	Waingaro Bore	**20/04/1994**	**7323/1**	**53.8**	**15**	**9.59**	**0.06**	**86**	**0.62**	**1.3**	**0.02**	**<0.05**	**<0.05**	**50**	**11**	**5.1**	**58**	**0.42**	**61**	**<1**	**3.5**	**37.9**	**<0.3**	**<0.001**	**0.2**	**-29.2**
		5/08/1993	**7190/1**	**53.3**	**21**	**9.59**	**0.06**	**84**	**0.96**	**1.2**	**0.02**	**<0.05**	**<0.05**	**49**	**6**	**5.1**	**61**	**0.35**	**67**	**<1**	**3.7**	**39.4**	**<0.25**	**<0.002**		
	Waingaro HS	27/01/1981	4891/30		18	9.33	<0.1	35	0.6	16	<.005			52	11	5	64		76							
WAITOA	Waitoa	**20/04/1994**	**7323/5**	**50.7**	**18**	**7.22**	**0.28**	**246**	**47**	**31**	**16**	**0.12**	**<0.05**	**47**	**6**	**4.5**	**174**	**0.81**	**885**	**<1**	**0.22**	**130**	**1.3**	**0.013**	**-6**	**-36**
		5/08/1993	**7190/4**	**50.2**	**21**	**6.88**	**0.26**	**244**	**47**	**31**	**16.2**	**0.12**	**<0.05**	**48**	**7**	**5**	**176**	**<0.10**	**1063**	**<1**	**0.22**	**132**	**1.2**	**0.011**		
		29/01/1981	**4891/29**		18	8.83	0.3	206	48	16.9	16.5	0.23	0.13	51	10	4.5	148		676							

NB: samples taken as part of the 1996 Regional Geothermal Monitoring Programme have shaded sample dates and references

Abbreviations:

CT - Collection Temperature	**Na - Sodium**	**Rb - Rubidium**	**B - Boron**	**NH_3 - Ammonia**	**As - Arsenic**	**mg/L - Milligrams per litre**
AT - Analysis Temperature	**K - Potassium**	**Cs - Caesium**	**SiO_2 - Silica**	**F - Fluoride**	**^{18}O - Oxygen 18 isotope**	**mS/m - Millisiemens per metre**
pH - per Hydrogen	**Ca - Calcium**	**Cl - Chloride**	**Tot HCO_3 - Total bicarbonate**	**Cond - Conductivity**	**^{2}H - Deuterium**	**°/oo - permil**
Li - Lithium	**Mg - Magnesium**	**SO_4 - Sulphate**	**Tot H_2S - Total hydrogen sulphide**	**Fe - Iron**	**epm - Equivalents per million**	**°C - degrees Celsius**

Taken from EXCEL spreadsheet EW DOCS no. 1117252

Table 5: Large geothermal systems: water analyses

(Huser and Jenkinson, 1996)

Field	Feature	Date	Sample	CT	AT	pH	Li	Na	K	Ca	Mg	Rb	Cs	Cl	SO_4	B	SiO_2	NH_3	Tot HCO_3	Tot H_2S	F	Cond	Fe	As	^{18}O	^{2}H
				°C	°C	pH	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mS/m	mg/L	mg/L	‰	‰
ATIAMURI	Atiamuri	**11/05/1994**	**7323/17**	**70**	**19**	**7.29**	**4.9**	**472**	**24**	**0.73**	**0.02**	**0.19**	**1.12**	**362**	**49**	**13.1**	**272**	**2.4**	**620**	**<1**	**14**	**208**	**<0.3**	**1.4**	**-2.22**	**-30.3**
		8/07/1993	**7169/2**	**66**	**18**	**7.43**	**5**	**443**	**22**	**0.64**	**0.01**	**0.18**	**1.08**	**354**	**49**	**12.9**	**262**	**1.6**	**589**	**<1**	**13.9**	**218**	**<0.25**	**0.95**		
	Atiamuri Large Spring	15/03/1978	3937	69		8.7	3.93	445	20.1	1	0.01	0.18	1.06	328	41	11.2	280		565							
HOROHORO	Horohoro	**11/05/1994**	**7323/18**	**47.2**	**19**	**8.39**	**0.61**	**219**	**4.5**	**0.65**	**0.07**	**<0.05**	**<0.05**	**168**	**41**	**2.4**	**150**	**0.46**	**177**	**<1**	**11**	**100**	**<0.3**	**0.62**	**-4.81**	**-35.4**
		8/07/1993	**7169/1**	**43.7**	**18**	**8.3**	**0.55**	**188**	**4.2**	**0.86**	**0.17**	**<0.05**	**<0.05**	**150**	**37**	**2.1**	**140**	**0.37**	**159**	**<1**	**11.5**	**91**	**<0.25**	**0.48**		
	Horohoro Hot Spring	4/02/1985	5981/2/m	52	22	8.32								172	42		152									
		17/04/1984	5717	49.9	22	8.38	0.6	224	6	2	0.12	0.04	0.06	169	41	2.4			244							
		4/02/1980	4674	55		8.5		209	1.9	0.07	0.26			168	45		149		285							
		6/11/1963	1291	47		8.7	0.5	186	4.3	9				155	40	9	152			0.3	14					
MOKAI	North Mokai (Waipapa)	**3/05/1994**	**7323/13**	**60.8**	**18**	**6.46**	**2.6**	**253**	**13.8**	**10.1**	**1.3**	**0.15**	**0.34**	**371**	**7**	**4.5**	**129**	**<0.10**	**152**	**<1**	**1.3**	**133**	**<0.3**	**0.62**	**-6.72**	**-42.1**
		15/07/1993	**7178/2**	**59.6**	**20**	**6.49**	**2.8**	**248**	**13.5**	**10.1**	**1.3**	**0.16**	**0.4**	**380**	**8**	**4.5**	**130**	**<0.10**	**119**	**<1**	**1.3**	**141**	**<0.25**	**0.53**		
		19/10/1983	5624/6	58		6.55	2.93	258	15	10.8	1.1	0.17	0.42	362	9	5	144		119							
		14/06/1982	5194/1	59.4		6.25	2.76	251	12	9	1.25	0.14	0.38	371	4	4.3			139							
		8/04/1980	4697	57.5		6.35		252	13.4	9.1	1.1			370	8	4	137		155							
		8/04/1980	4696	57.5		6.3		243	12.9	8.9	1.2			353	8	3	127		140							
		8/04/1980	4695	57.5		6.65	2.77	250	13.2	9.2	1.2	0.142	0.33	364	8	4	197		170							
		3/05/1978	3692/a	58		6.95								370	6.8	4.2	130		90	<2						
	South Mokai	**3/05/1994**	**7323/12**	**51.5**	**18**	**6.3**	**0.16**	**176**	**9.9**	**12.3**	**2.5**	**<0.05**	**<0.05**	**34**	**<5**	**<0.1**	**116**	**<0.10**	**1043**	**<1**	**0.5**	**76.5**	**0.92**	**<0.001**	**-7.28**	**-43.8**
		15/07/1993	**7178/1**	**49.2**	**20**	**6.31**	**0.17**	**170**	**9.6**	**11.7**	**2.4**	**<0.05**	**<0.05**	**31.2**	**5**	**0.32**	**117**	**<0.10**	**961**	**<1**	**0.54**	**78.2**	**0.9**	**<0.001**		
		19/10/1983	5624/6	49		9.11	0.16	173	7.6	11.6	1.9	0.03	0.03	29.1	20	5	139									
		14/06/1982	5194/2		14	6.05	0.15	174	8	11	2.38	0.03	0.03	35	5	0.4										
		8/04/1980	4699			6.05		175	9.9	11.7	2.1			39	9		118									
NGATAMARIKI	Ngataramariki New	**11/05/1994**	**7323/22**	**89.5**	**15**	**7.21**	**3.4**	**565**	**30**	**6.8**	**0.35**	**0.31**	**0.59**	**613**	**55**	**9.6**	**251**	**1.2**	**496**	**<1**	**2.5**	**264**	**<0.3**	**0.14**	**-4.88**	**-38**
		21/05/1993	**7137**	**88.5**	**20**	**7.3**	**3.4**	**553**	**28**	**6.4**	**0.3**	**0.27**	**0.54**	**605**	**49**	**9**	**241**	**1.16**	**479**	**<1**	**2.5**	**285**	**<0.25**	**0.15**		
	Ngatamariki Main Pool	1/10/1974	3371/4	88.5		7.95	3.38	518	31.2	6.44	0.2	0.31	0.56	579	36	8.45	235		343							
		1/03/1960	W/215			7.34	2.9	450	24	7.5	0.96	0.05	<0.04	461	99	7	250	0.3								
	Blue Pool	9/01/1987	6424/2/m	71.1	26	7.8	3.6	583	33.2	6	0.23	0.29	0.67	639	65	9.9	270		437							
		16/07/1986	6356/a	71.2	18	7.8	3.5	579	34.2	5.1	0.23	0.31	0.68	638	70	9.5	270		443							
		28/05/1986	6311/a	71	19	7.7	3.6	571	32.5	5.1	0.25	0.31	0.7	634	68	9.6	280		456							
		18/12/1984	5960/1	78	28	7.67	3.6	498	31.5	4.21	0.16	0.33	0.69	628	69	9.5	244		450							
		24/07/1979	4412			7.81	3.53	510	32	5.1	0.19	0.39	0.02	597	40	9.1	245		458							
	Flowing Spring (Blue)	7/06/1983	5444/1	81.5	15	8.63	3.47	563	29.8	3.9	0.16	0.33	0.66	630	48	9.3	261		408							
OHAAKI	Ohaaki	**27/04/1994**	**7323/11**	**32.5**	**19**	**6.64**	**0.78**	**219**	**10.6**	**17.8**	**11**	**<0.05**	**<0.05**	**54**	**<5**	**1.2**	**133**	**1.3**	**847**	**<1**	**1.5**	**105**	**0.97**	**0.12**		

Field	Feature	Date	Sample	CT	AT	pH	Li	Na	K	Ca	Mg	Rb	Cs	Cl	SO_4	B	SiO_2	NH_3	Tot HCO_3	Tot H_2S	F	Cond	Fe	As	^{18}O	^{2}H
				°C	°C	pH	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mS/m	mg/L	mg/L	$^{o}/_{oo}$	$^{o}/_{oo}$
ORAKEIKORAKO	OK Manganese Pool - 120	**11/05/1994**	**7323/21**	**70.3**	**19**	**7.55**	**3.3**	**263**	**40**	**2.1**	**0.23**	**0.41**	**0.5**	**275**	**104**	**2.9**	**290**	**0.14**	**152**	**<1**	**10.2**	**140**	**<0.3**	**0.51**	**-4.52**	**-33.7**
		8/07/1993	**7169/3**	**64**	**18**	**7.42**	**3.1**	**241**	**37**	**2**	**0.23**	**0.38**	**0.48**	**254**	**108**	**2.8**	**278**	**<0.10**	**146**	**<1**	**8.4**	**137**	**<0.25**	**0.37**		
		9/02/1983	5352/8	94.1	18	8.7	4.11	322	48.6	1.7	0.05	0.53	0.67	339	99	3.6	376		207							
	OK Guest House Pool	**27/04/1994**	**7323/10**	**85.8**	**19**	**7.86**	**3**	**346**	**17**	**0.7**	**0.01**	**0.2**	**0.6**	**312**	**65**	**3.2**	**254**	**0.26**	**317**	**<1**	**9.8**	**163**	**<0.3**	**0.61**	**-4.13**	**-33.8**
	Waihunuhunu - 674	**18/10/1995**	**7582/4/M**	**52.3**	**15**	**7.21**	**0.62**	**113**	**5.2**	**3.8**	**0.53**	**0.01**	**<0.05**	**57**	**19**	**0.59**	**118**		**229**	**<1**						
		27/04/1994	**7323/9**	**58.9**	**19**	**7.07**	**0.61**	**118**	**3.5**	**3.7**	**0.47**	**<0.05**	**<0.05**	**57**	**21**	**0.65**	**105**	**<0.10**	**237?**	**<1**	**1.5**	**53.6**	**<0.3**	**0.24**	**-6.84**	**-42.1**
		8/07/1993	**7169/4**	**58**	**18**	**7.62**	**0.58**	**115**	**3.1**	**3.3**	**0.51**	**<0.05**	**<0.05**	**54.2**	**20**	**0.66**	**105**	**<0.10**	**196**	**<1**	**1.6**	**54.1**	**<0.25**	**0.22**		
		1965		79.5		7.9	1.2	180	8	4	2			106	16	1.09	130		271							
REPOROA	Opaheke #7	**27/04/1994**	**7323/6**	**97.1**	**19**	**7.26**	**5.4**	**654**	**40**	**1.2**	**0.04**	**0.38**	**1.26**	**744**	**29**	**12.3**	**274**	**3**	**571**	**1**	**6.1**	**316**	**<0.3**	**0.93**	**-4.46**	**-36.8**
		8/07/1993	**7169/7**	**95.3**	**18**	**7.22**	**5.3**	**665**	**40**	**1**	**0.03**	**0.38**	**1.27**	**746**	**30**	**12.7**	**268**	**2.41**	**601**	**2.5**	**6.1**	**348**	**<0.25**	**1**		
ROTOKAWA	Rotokawa #4	**14/06/1994**	**7341/3**	**94.2**	**14**	**6.83**	**3.4**	**430**	**34**	**21**	**1.6**	**0.35**	**0.31**	**538**	**99**	**18.2**	**198**	**3.6**	**155**	**<1**	**2.2**	**231**	**0.3**	**0.91**	**-5.33**	**-42.4**
		28/01/1994	**7291/1**	**80.2**	**25**	**7.82**	**3**	**393**	**30**	**18**	**1**	**0.38**	**0.53**	**496**	**112**	**17.7**	**218**	**3.6**	**115**	**<1**	**1.6**	**197**	**<0.3**	**1.5**		
	Rotokawa #4A	**14/06/1994**	**7341/1**	**78.4**	**18**	**2.63**	**2.8**	**379**	**47**	**35**	**8.3**	**0.5**	**0.46**	**447**	**685**	**15.5**	**238**	**10**		**27.1**	**3.2**	**355**	**6.3**	**0.15**	**-3.54**	**-35.9**
		28/01/1994	**7291/2**	**75**	**25**	**2.4**	**2.7**	**362**	**42**	**35**	**8.4**	**0.47**	**0.42**	**418**	**932**	**13.2**	**246**	**9.5**		**20.8**	**3.2**	**401**	**9.6**	**0.15**		
	Rotokawa #22	**14/06/1994**	**7341/4**	**90**	**14**	**2.27**	**3**	**366**	**50**	**43**	**8.5**	**0.64**	**0.66**	**454**	**980**	**16.3**	**313**	**20**		**<1**	**2**	**571**	**14**	**0.86**	**-3.71**	**-35.9**
		28/01/1994	**7291/4**	**80.1**	**25**	**2.1**	**3.1**	**375**	**53**	**44**	**8.5**	**0.68**	**0.67**	**450**	**1038**	**16.5**	**319**	**17**		**<1**	**1.8**	**558**	**15**	**1.1**		
	Rotokawa #10	**14/06/1994**	**7341/5**	**74.5**	**14**	**2.6**	**5.3**	**462**	**206**	**33**	**7.4**	**1.79**	**1.02**	**629**	**803**	**25.7**	**352**	**36**	**290**	**<1**	**2.4**	**485**	**0.46**	**1.2**	**-0.95**	**-28.1**
		1/02/1994	**7291/5**	**72.5**	**24**	**2.42**	**5.3**	**473**	**206**	**33**	**7.6**	**1.84**	**1.05**	**635**	**898**	**25.4**	**355**	**33**	**110**	**<1**	**2.2**	**508**	**0.68**	**1.3**		
TAUHARA	Taharepa	**9/06/1994**	**7323/26**		**17**	**6.57**	**0.71**	**169**	**33**	**24**	**4.4**	**0.08**	**<0.05**	**115**	**131**	**2.1**	**232**	**2.9**	**377**	**<1**	**0.62**	**107**	**<0.3**	**0.13**	**-6.78**	**-44.8**
	Terraces	**9/06/1994**	**7323/27**		**17**	**6.97**	**3.2**	**314**	**33**	**17**	**5.4**	**0.17**	**0.17**	**332**	**70**	**6.6**	**239**	**0.77**	**371**	**<1**	**0.62**	**165**	**<0.3**	**0.22**	**-6.85**	**-46.8**
	Lake Front	**9/06/1994**	**7323/28**		**17**	**6.48**	**0.82**	**201**	**39**	**26**	**4.3**	**0.09**	**<0.05**	**156**	**107**	**2.8**	**240**	**2.6**	**509**	**<1**	**0.68**	**117**	**0.98**	**0.14**	**-6.84**	**-45.4**
	Spa Spring	**9/06/1994**	**7338/1**	**92.2**	**22**	**6.26**	**0.41**	**144**	**35**	**25**	**9.7**	**0.15**	**<0.05**	**9.7**	**410**	**0.19**	**331**	**2.9**	**49**	**<1**	**1.3**	**96.3**		**0.062**	**-5.61**	**-35.9**
	Primary Spring	**9/06/1994**	**7338/2**	**78**	**22**	**6.53**	**0.23**	**95**	**15**	**15**	**3.1**	**0.05**	**<0.05**	**7.4**	**211**	**<0.01**	**290**	**1.2**	**95**	**<1**	**1.6**	**59.1**		**0.01**	**-7.05**	**-46.3**
	AC Spring	**9/06/1994**	**7338/3**		**22**	**6.68**	**0.19**	**88**	**14**	**8.2**		**0.06**	**<0.05**	**7.2**	**146**	**0.12**	**258**	**1**	**126**	**<1**	**1.8**	**49.8**		**0.022**	**-6.92**	**-47.2**
TE KOPIA	Murphy's Farm	**18/10/1995**	**7582/2/M**	**61**	**15**	**7.57**	**0.46**	**80**	**3.6**	**3.5**	**0.54**	**0.03**	**0.08**	**82**	**19**	**0.81**	**139**		**52**	**<1**						
		11/05/1994	**7323/20**	**53.3**	**19**	**7.48**	**0.48**	**78**	**2.5**	**4.1**	**0.44**	**<0.05**	**<0.05**	**79**	**21**	**0.85**	**119**	**<0.1**	**48**	**<1**	**4**	**40.3**	**<0.3**	**0.13**	**-6.62**	**-40.8**
		21/05/1993	**7135**	**61**	**22**	**8.02**	**0.47**	**82**	**3.2**	**3.4**	**0.4**	**<0.05**	**0.11**	**83**	**22**	**0.91**	**134**	**<0.10**	**27**	**<1**	**4.6**	**44.2**	**<0.25**	**0.18**		
		5/03/1992	6997/8	61.5		7.5	0.41	86	3.4	3.7			0.096	89	18	0.9	140		56							
TOKAANU	Bathhouse Spg Tokaanu	**4/05/1994**	**7323/16**	**66**	**16**	**6.37**	**26**	**1927**	**162**		**0.18**	**1.68**	**4.8**	**3165**	**76**	**95**	**309**	**4.9**	**132**	**<1**	**1.6**	**961**	**<0.3**	**10.3**	**0.18**	**-33.3**
		18/10/1993	**7242/2**	**66**	**19**	**6.18**	**26**	**1927**	**171**	**43**	**0.22**	**1.72**	**5.1**	**3258**	**82**	**92**	**306**	**4.78**	**134**	**<1**	**1.6**			**10**		
		3/05/1966	1939/45	67		6.85	21.8	1750	165	37				2936	69	89	320	1.7	22		2					
TONGARIRO	Lower Emerald Lake	**30/03/1994**	**7317/6**	**10.1**	**19**	**4.17**	**<0.05**	**3.9**	**0.72**	**12.4**	**5**			**0.7**	**69**	**<0.05**	**21**	**<0.1**	**8**	**<0.05**			**0.73**			
		26/03/1993	**7117/4/m**		**20**	**4.47**	**<0.05**	**3.2**	**0.46**	**9**	**4.4**			**0.6**	**56**	**<0.05**	**22**		**<5**	**<0.01**			**0.5**			
		23/04/1992	7012/1/m		19	5.46	<0.05	3.5	0.58	7.6	4.4	<0.05	<0.05	0.67	45	<0.05	22		<5	<0.05			<0.2			
		16/02/1983	5356/1	13.5		7.8	<0.04	3.4	<0.5	5.9	2.39	<0.03	<0.03	<2	30	<1.0	25						0.07			
	Blue Lake	**8/05/1994**	**7138/4**		**21**	**5.73**	**<0.05**	**0.44**	**0.06**	**0.11**	**0.06**			**0.06**	**0.3**	**<0.05**	**<2**		**<20**	**<0.01**			**<0.2**			
		30/03/1994	**7317/1**	**12**	**16**	**5.82**	**<0.05**	**0.4**	**<0.05**	**0.17**	**0.05**			**0.6**	**0.6**	**<0.05**	**<2**		**<5**	**<0.05**			**<0.05**			
		23/04/1992	7012/3/m		20	5.85	<0.05	0.49	0.1	0.1	0.07	<0.05	<0.05	0.72	0.25	<0.05	<1		<5	<0.05			<0.02			
		4/04/1989	6680/1/m	8	21	5.9	<0.01	0.65	0.04	0.1	0.07	<0.05	<0.05	1	1.7	<0.05	<1		<5	<0.05			<0.2			
		16/02/1983	5359	18.2		5.3	<0.04	0.56	<0.5	<0.5	0.08	<0.03	<0.03	<2	2	<1.0	<5						0.04			
		8/02/1981	4836/4			6.17	<0.04	0.46	0.1	<0.05	0.6			2	1	<1.0	<10						<0.04			
	KETETAHI Iron Spring	**14/09/1994**	**7377/1**	**62.3**	**20**	**6.29**	**0.08**	**34**	**10.5**	**43**	**25**			**1.4**	**564**	**2.1**	**243**	**17.4**	**225**		**0.33**		**4.6**	**0.005**		
		28/08/1990	6853/1		25	7.33	<0.05	28	10.2	60	36	0.05	<0.05	1.17	310	<0.05	201		63	<0.05			4.8	<1		
		23/04/1989	6675/1/m	69			0.02	25	7	36	22	0.04	<0.03	3	141	1	164									
	KETETAHI Balck Cauldron	**14/09/1994**	**7377/2**	**81.2**	**20**	**6.65**	**<0.05**	**12.2**	**8.1**	**26**	**15**			**0.71**	**1135**	**201**	**148**	**290**	**192**	**<1**	**<0.1**		**6**	**0.005**		
		30/08/1990	6853/2		25	3.34	<0.05	64	17.2	150	135	0.11	>0.05	5.85	1980	181	230		82	<0.05			12	<1		
		4/04/1989	6680/5	79.1	22	2.7	0.04	54	17	130	96	0.12	<0.05	29	1600	276	245		102	0.35			11	<1		

Field	Feature	Date	Sample	CT	AT	pH	Li	Na	K	Ca	Mg	Rb	Cs	Cl	SO_4	B	SiO_2	NH_3	Tot HCO_3	Tot H_2S	F	Cond	Fe	As	^{18}O	^{2}H
				°C	°C	pH	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mS/m	mg/L	mg/L	°/oo	°/oo
WAIHI	Waihi #47 Whakatara	**9/06/1994**	**7323/29**		**17**									**469**					**551**						**-6.16**	**-42.2**
		4/05/1994	**7323/15**	**76**	**16**	**6.86**	**3.3**	**284**	**45**		**24**	**0.33**	**0.58**	**470**	**28**	**14.2**	**224**	**3**	**455**	**<1**	**0.21**	**203**	**<0.01**	**1.2**	**5.94**	**-42.1**
		18/10/1993	**7242/1**	**76**	**19**	**6.55**	**3.3**	**280**	**46**	**52**	**24**	**0.32**	**0.58**	**477**	**30**	**14.8**	**214**	**3.1**	**539**	**<1**	**0.21**		**<0.01**	**1.1**		
		19/04/1966	1939/14	75		6.55	2.7	242	42	66	29	0.1	0.3	440	27	13.3	212	2	468		0.2		0.01	0.01		
WAIKITE	Waikite WE1031	**11/05/1994**	**7323/19**	**101.2**	**19**	**7.38**	**2.4**	**220**	**8.8**	**8.5**	**0.18**	**0.11**	**0.28**	**143**	**36**	**1.5**	**162**	**0.3**	**366**	**<1**	**2.5**	**104**	**<0.3**	**0.38**	**-6.31**	**-40.7**
		21/05/1993	**7136**	**99.6**	**20**	**7.76**	**2.4**	**219**	**8.6**	**8.8**	**0.2**	**0.08**	**0.33**	**143**	**37**	**1.5**	**161**	**0.19**	**342**	**<1**	**2.8**	**106**	**<0.25**	**0.36**		
		21/01/1992	6914/32	99.5		7.8	2.2	215	8.8	7.8	0.22	0.11	0.31	145	39	1.46	167		338							
WAIOTAPU	Waiotapu #24	**27/04/1994**	**7323/8**	**92.2**	**19**	**1.97**	**1.9**	**318**	**28**	**18**	**2.2**	**0.36**	**0.11**	**475**	**1370**	**5.6**	**319**	**27**		**1.3**	**0.34**	**70**	**11**	**2.1**	**-2.78**	**-33.4**
		8/07/1993	**7169/5**	**90.5**	**18**	**2.03**	**1.9**	**279**	**29**	**17.7**	**1.9**	**0.34**	**0.16**	**428**	**1659**	**5.1**	**319**	**24.9**	*****	**1.8**	**0.27**	**7.8**	**12.7**	**2**		
		1978		81		2.5	2.9	384	65	2.5	4.1		0.59	614	530	2.35	412	47			0.88					
	Champagne Pool WT	**27/04/1994**	**7323/7**	**76.1**	**19**	**5.54**	**8.3**	**1115**	**153**	**34**	**0.05**	**1.53**	**1.26**	**1905**	**90**	**26**	**426**	**34**	**237**	**11**	**4.9**	**616**	**<0.3**	**5**	**3.17**	**-23.3**
		21/01/1994	**7289/1**	**75.5**	**25**	**5.72**	**8.4**							**1929**												
		8/07/1993	**7169/6**	**74.9**	**18**	**5.6**	**8.4**	**1090**	**148**	**33**	**0.05**	**1.51**	**1.23**	**1858**	**91**	**26**	**427**	**31.8**	**220**	**8.8**	**5**	**680**	**<0.25**	**5.1**		
		7/06/1986	6317/m	74	20	5.5	8.3	1065	144	33	0.55	1.42	1.27	1814	68	25.2	438		393							
		14/04/1984	5716/2	75.5	22	6.07	8.2	990	144	36	0.04	1.41	1.25	1807	64	25.1	380		424	18.1						
		3/04/1984	5720	75	19	5.98	8.2	990	142	36	0.05	1.45	1.28	1813	57	25	410		290	11.1						
		31/01/1984	5679/2	74	25	6.17	8.33	1109	150	34.2	0.06	1.41	1.28	1839	39	25	433		188.9	5.51						
		10/01/1984	5672/1	76	27	5.87	8.23	1113	138	34.7		1.4	1.3	1835	43	25.3	410		344	18						
		15/12/1983	5670/1	74.2	26	5.95	8.19	1103	141	33.7	0.05	1.4	1.27	1817	64	25.2	418		416							
		8/12/1983	5653/1	74.5		5.45	8.37	1091	149	32.3	0.04	1.44	1.31	1845	37	27.6	440		250							
		23/11/1983	5638/1	76		7.05	8.07	1088	143	32.4	0.03	1.41	1.25	1825	62	25.3	420			28.7						
		27/10/1983	5626			5.58	8.04	1079	143	32.6	0.04	1.41	1.27	1820	65	12.5	435		170	23						
		3/08/1983	5538/1	73	19	5.24	8	1072	143	33.6	0.05	1.57	1.33	1816	63	24.6	429		331					4.5		
		19/05/1983	5428/11	75				1078	141	33.8	0.06			1820	54		420		220	27						
		17/03/1983	5383/7	75	20	5.63	8.25	1102	151	35.1	0.048			1898	52.5	25.4	443		345	28						
		18/05/1982	5126	73	15	7.82	8.04	1109	150	33.8	0.06	1.54	1.33	1912	108	25.6	468			21						
		24/07/1958					8.2	1137	160	30.7	2.8			1961	143	27.2		10.7			5.2					
		27/06/1955				6.5	8	1146	160	29	2.4			1879	99	27	170	4.5	366	22	4.05					
		1926				4.9		1215	164	38.6	0.3			1990	119	23.9	448	37	43	18						
WAIRAKEI	WK Totara Gut	**4/05/1994**	**7323/14**	**33.5**	**18**	**6.62**	**<0.05**	**25**	**4.8**	**9.4**	**3.7**	**<0.05**	**<0.05**	**8.5**	**26**	**0.1**	**117**	**<0.1**	**94**	**<1**	**0.18**	**19.9**	**<0.3**	**0.012**	**-6.87**	**-43.4**
		15/07/1993	**7178/3**	32	20	6.72	<0.05	24	4.4	9	3.7	<0.05	<0.05	9.2	27	0.1	116	<0.10	64	<1	0.17	19.7	<0.25	0.008		

NB: samples taken as part of the 1996 Regional Geothermal Monitoring Programme have shaded sample dates and references

Abbreviations:

CT - Collection Temperature
AT - Analysis Temperature
pH - per Hydrogen
Li - Lithium
Na - Sodium
K - Potassium
Ca - Calcium
Mg - Magnesium
Rb - Rubidium
Cs - Caesium
Cl - Chloride
SO_4 - Sulphate
B - Boron
SiO_2 - Silica
Tot HCO_3 - Total bicarbonate
Tot H_2S - Total hydrogen sulphide
NH_3 - Ammonia
F - Fluoride
Cond - Conductivity
Fe - Iron
As - Arsenic
^{18}O - Oxygen 18 isotope
^{2}H - Deuterium
epm - Equivalents per million
mg/L - Milligrams per litre
mS/m - Millisiemens per metre
°/oo - permil
°C - degrees Celsius

Taken from EXCEL spreadsheet EW DOCS no. 1117252

Table 6: Large geothermal systems: gas analyses

(Huser and Jenkinson, 1996)

Field	Feature	Code	Date	Sample	CO_2	H_2S	NH_3	He	H_2	O_2	N_2	CH_4	Ar	SO_2	N_2 (air free)	Ar (air free)	N_2/Ar	del ^{18}O	del ^{2}H
ROTOKAWA	Rotokawa	RK1006	14/06/1994	7341/6/N1A	1718	45		0.0055	3.93		24.2	65.6	0.062		24.20	0.062	390		
		"	"	7341/6/N1	1720	45.5	0.12	0.0082	3.84	0.013	25.7	63.8	0.066		25.65	0.065	392	-5.67	-38.1
		"	19/08/1993	7201/N1	1600	41.6	0.035	0.006	3.24	0.024	22.6	59.6	0.065		22.51	0.064	352	-7.1	-46.2
TAUHARA	Hell's Gate		27/01/1993	7065/5	2930	49.20	11.7	0.021	42.60	0.05	78.7	74.2	0.9					-12.39	-67.3
			15/02/1989	6656/6	1326	31.80	15.7	0.015	20.80		26.1	27.5	0.242						
			5/78		840	16.50			16.00		18.6	18.6							
	Pony Club		27/01/1993	7065/3	534	17.00	0.58	0.0021	2.31	<0.005	7.6	10.2	0.063					-9.06	-54.2
			15/02/1989	6656/5	575	19.70	0.04	0.0037	2.98		8.88	12.4	0.073						
TE KOPIA	Te Kopia	TK1001	18/10/1995	7582/1/N	197	6.70		0.0035	0.48	0.002	9.75	1.53	0.208		9.74	0.207	47		
		"	14/07/1994	7355/N1	212	7.88	0.28	0.0036	0.53	0.066	9.97	1.66	0.212		9.72	0.209	47	-8.24	-45.9
		"	30/09/1993	7230/N1A	194	16.3			0.53	118	519	1.39	6.02		79.10	0.757	104	-9.01	-47.9
TONGARIRO	Emerald Lake Fumarole		30/03/1994	133-tnp-lel	3705	120.00	0.11	0.009	0.43		26.8	75.2	0.026	19	26.80	0.026	1030		
	Red Crater		30/03/1994	132-tnp-rc	4164	98.00	0.95	0.0098	3.38		28.2	77.8	0.0328	21.9	28.20	0.033	854		
	TNP Central Crater		30/03/1994	134-tnp-cc	4730	35.00	0.19	0.0125	12.20		34.8	92.4	0.054	3	34.80	0.054	644		
	* Ketetahi #2		14/09/1994	156-kt-2	1862	51.40	14.6	0.0092	30.00		19.8	34.3	0.0086	7.3	19.80	0.009	2300		
WAIKITE	Waikite Scarp	WE1010	11/07/1994	7351/N1	233	1.57	0.16	0.0016	0.030	0.0033	9.09	0.41	0.201		9.08	0.201	45	-12.23	-69.6
		"	11/08/1993	7194/N1	225	2.12	0.23	0.0014	0.032	0.001	7.46	0.38	0.185		7.46	0.185	40		
		"	7/09/1991	6914/11	174	1.60		0.0004	0.013	0.109	2.46	0.126	0.062		2.05	0.057	36		
WAIOTAPU	Maungaongaonga	WT1066	21/07/1994	7357/N1A	356	8.77		0.0014	1.28	0.82	25	1.93	0.314		21.94	0.277	79		
		"	"	7357/N1	349	10.00	<.0.02	0.0014	1.30	0.52	9.43	1.99	0.136		7.49	0.113	66	-13.25	-70.9
		"	11/08/1993	7195/N1A	468	25.30			0.44	196	872	0.94	10.2		141.31	1.458	97		
		"	"	7195/N1	597	29.70	0.031		0.71	351	1530	1.33	17.8		221.47	2.145	103		
WAIRAKEI	Wairakei Thermal Valley	WK1054	30/06/1994	7346/3/N1A	96	4.00													
		"	"	7346/3/N1	102	3.56	0.35	0.00044	0.73	0.165	1.83	0.51	0.029		1.21	0.022	56	-6.29	-38.3
		"	19/08/1993	7202/N1	104	3.72	0.27	0.0005	0.96	0.01	1.51	0.67	0.028		1.47	0.028	53	-9.51	-57.2
	Karapiti #18	WK1045	30/06/1994	7346/2/N1A	177	3.58		0.026	0.77	0.042	4.59	1.46	0.061		4.43	0.059	75		
		"	"	7346/2/N1	167	3.96	0.06	0.0025	0.69	0.0025	3.7	1.36	0.049		3.69	0.049	75	-3.72	-27.2
		"	11/08/1993	7193/N1	207	3.80	0.28	0.0025	0.73	0.001	4.2	1.72	0.073		4.20	0.073	58		
		"	3/90 - 6/91		186	5.82	0.48	0.002	0.76			1.62			3.88	0.068	57		
	Karapiti #22	WK1047	29/06/1994	7346/1/N1A	207	3.14		0.0033	0.70	0.013	5.05	1.38	0.136		5.00	0.135	37		
		"	"	7346/1/N1	207	4.54	0.48	0.0025	0.62	0.102	5.06	1.38	0.100		4.68	0.095	49	-4.35	-28.8
		"	10/08/1993	7192/N2	187	3.44		0.0023	0.58	0.001	4.41	1.28	0.086		4.41	0.086	51		
		"	"	7192/N1	187	3.53	0.48	0.0023	0.58	0.001	4.44	1.3	0.087		4.44	0.087	51		
		"	3/90-6/91		218	5.66	0.48	0.0026	0.74			1.65			5.34	0.100	53		

NB: samples taken as part of the 1996 Regional Geothermal Monitoring Programme have shaded sample dates and references

* This also contains 1.16 millimoles HCl per 100 moles of H2O.

Concentrations are expressed in millimoles of gas per 100 moles of H2O.

To remove air contamination: N2(air free) = N2 analysed - 3.728 x O2 analysed. Ar(air free) = Ar analysed - 0.0446 x O2 analysed. O2(air free) = zero. N2/Ar air = 83. N2/Ar air saturated water = 43

Abbreviations:

CO_2 - Carbon Dioxide
H_2S - Hydrogen Sulphide
NH_3 - Ammonia
He - Helium
H_2 - Hydrogen
O_2 - Oxygen
N_2 - Nitrogen
CH_4 - Methane
Ar - Argon
SO_2 - Sulphur Dioxide
N_2 (air free) - Air corrected Nitrogen
Ar (air free) - Air corrected Argon
N_2/Ar - Nitrogen to Argon ratio
del ^{18}O - Fractionated Oxygen 18 isotope
del ^{2}H - Fractionated Deuterium

Taken from EXCEL spreadsheet EW DOCS no. 1117252

4.3 Small geothermal systems – water samples

The comments and recommendations in this section have been adapted from Huser and Jenkinson (1996).

Hot Water Beach, Opal Springs and Kawhia have only been sampled once during the previous monitoring programme.

Hot Water Beach Spring, Coromandel

Huser and Jenkinson (1996) list several analyses that demonstrate inconsistent results. Changes in the fluid compositions are most likely due to different amounts of sea water (high chloride, and especially high sulphate, calcium and magnesium) rather than any changes in the thermal source water. The latter would be most difficult to observe due to the sea water contamination. The least contaminated samples were collected in 1973. The best sample was from a 16.5 m well located at N44/314561 (in a camping ground property). The well had an artesian flow and the sample was collected 2 hours after low tide.

Recommendation:

Sample yearly to establish a better baseline than currently available and make sure that samples are collected at or just after low tide. The isotope values in sea water are quite distinctive and will help define contamination. A sample of sea water should also be collected and an isotope analysis undertaken for comparison.

Kawhia

The same comments on sampling apply here as to Hot Water Beach (see above).

Recommendation:

Sample yearly to establish a better baseline than currently available and make sure that samples are collected at or just after low tide. The isotope values in sea water are quite distinctive and will help define contamination. A sample of sea water should also be collected and an isotope analysis undertaken for comparison.

Miranda

Little change has occurred since 1984 (suspect sodium analysis at that time).

Recommendation:

Sample yearly to establish a better baseline than currently available and make sure that samples are collected at or just after low tide. The isotope values in sea water are quite distinctive and will help define contamination. A sample of sea water should also be collected and an isotope analysis undertaken for comparison.

Naike (Te Maire)

Several different sites were sampled in the past. There is little significant change in the chemistry. Between the 1983 and the 1993 and 1994 samplings there was an apparent decrease of 20 °C in the temperature. This should be checked. Is the 65 °C feature different, that is, closer to the source than the present sampling location? This should be determined and recorded. The chemistry is similar to Miranda's.

Recommendation:

Sample yearly. Compare oxygen and hydrogen isotopes to confirm the initial (1994) values.

Okauia – Opal Springs

1994 data correlate well with 1981 data except for sodium and calcium concentrations. Only one sample has been collected in the 1990s compared with two samples (1993 and 1994) for most other sites.

Recommendation:

Sample yearly.

Te Aroha – Mokena Geyser

This is a sodium bicarbonate water and the bicarbonate is the most variable of the constituents due to the process of losing carbon dioxide. However, the chloride concentrations lie between 567 and 582 mg/kg from 1983 to 1996, apart from two outliers (549 and 596 mg/kg).

Recommendation:

Sample yearly.

Waingaro

The chemistry of this feature has been stable since 1981 (suspect sodium and calcium analyses at that time).

Recommendation:

Sample yearly.

Waitoa

This water chemistry is stable apart from bicarbonate and low reported sodium in 1981.

Recommendation:

Sample yearly.

4.4 High temperature geothermal systems – water samples

The comments and recommendations in this section have been adapted from Huser and Jenkinson (1996).

Atiamuri

As with Horohoro, the later (1994) sample is less diluted than the 1993 sample. Both the 1996 samples are more concentrated than that collected in 1978.

Recommendation:

Sample yearly. Should development investigations or changes in the physical characteristics of the springs occur then more frequent monitoring should be considered.

Horohoro

The last two sets of analyses lie mainly within the values obtained from 1963 to 1985. The lower temperature, chloride and silica found in 1993 together with a higher magnesium concentration indicate more dilution of the deep fluid at that time.

Recommendation:

Sample yearly. Should development investigations or changes in the physical characteristics of the springs occur then more frequent monitoring should be considered.

Mokai – North Mokai

The chemistry of this feature at the Waipapa Stream (Mulberry Road) springs is very stable since 1978, apart from the odd suspect analysis (for example, silica for sample 4695).

Recommendation:

Sample yearly.

Mokai – Parekiri at Tirohanga Rd

The chemistry of this feature is stable since 1980. It discharges a low mineralised water. A 55 MW power station was established in 1999 and is now producing 100 MW.

Recommendation:

Sample yearly.

Ngatamariki – Blue Pool, Main Pool and New Pool

The Blue Pool and the Main Pool are identical. However, the Blue Pool ceased to discharge due to earth slippage and in May 1993 the "New Pool" was sampled and in future will be the standard feature. Since 1974 the chloride concentration has increased from 579 to 639 mg/L by 1987 dropping to 605 and 613 mg/L in 1993 and 1994. Low temperatures were reported in 1984 to 1987 but could be due to different measurement points. The 1993 and 1994 chemistry is very stable but showing a slight increase in temperature and concentration of all chemical components, i.e. less dilution.

The apparent variation in chloride could be interpreted as fluctuation (given analytical and measurement error) around a single figure of 609 mg/L. The average of the first two measurements is 609 mg/L, as is the average of the second two.

Recommendation:

Sample yearly. Should development investigations or changes in the physical characteristics of the springs occur then more frequent monitoring should be considered.

Ohaaki

Only one sample has been collected from this feature. Previous data is available from the Ohaaki Pool. This latter feature is at present supplied by a bore and therefore not comparable with historical data. The water has low mineralisation (chloride concentration is 54 mg/kg compared with 1078 mg/kg for the Ohaaki Pool water in its natural state). Thus the feature taps water that gains its heat from steam and/or gas addition to the local ground water plus a small contribution of deep geothermal water. As production from the power station continues the chloride is likely to decrease.

Recommendation:

Sample yearly.

Orakeikorako – Guest House Pool (Map of Australia, S25)

This is a feature that has not been sampled previously. The chemistry is similar to that of Spring #120. It discharges a dilute chloride similar to, but more concentrated and hotter than #120 and is typical of Orakeikorako chloride discharges.

Recommendation:

Sample yearly. The feature has no historical data.

Orakeikorako – Manganese Pool #120

The 1993 and 1994 samples are much cooler (64 and 70.3 °C) than reported in 1983 (94 °C). Chloride concentrations have apparently decreased from 339 to 254 and 275 mg/kg, whilst the silica concentration has dropped by 100 mg/kg. At the same time magnesium concentrations have risen. The large differences suggest that either significant changes have occurred in this area or different features have been sampled. The location of the presently sampled feature should be checked carefully against details in Lloyd's Bulletin. However, Lloyd reports that large changes have occurred in the Golden Fleece springs from "boiling violently and discharging in 1926 to discharging at 87 °C in February 1952 and periods of recession e.g. 1.6m below overflow in March 1961." Thus this pool appears subject to fluctuation. Some of that noted could be associated with the filling of Lake Ohakuri.

Recommendation:

Sample yearly.

Orakeikorako – Waihunuhunu #674A(?)

The site presently sampled is not #674 (L E Klyen compared the description given by Environment Waikato workers with that from earlier work) and should be renumbered, say as 674A, to avoid confusion in future. The water is cooler and more dilute than the other two Orakeikorako features selected for monitoring.

Recommendation:

Sample yearly.

Reporoa – Opaheke #7

Only 1993 and 1994 data are available and are in good agreement.

Recommendation:

Sample yearly. Should development investigations or changes in the physical characteristics of the pool occur then more frequent monitoring should be considered.

Rotokawa Springs #4, #4A, #22 and #10

It impossible to compare past and present data due to the transient nature of these springs, especially 4 and 4A in the lagoon area. A 24 MW power station has been operating of the field since 1998.

Recommendation:

Sample yearly.

Tauhara

Other reports are available to Environment Waikato with the historical data and also more recent data for these features and as they are part of an ongoing monitoring program, no further comment will be made here.

Te Kopia – Murphy's Farm

The reported temperature decrease of 8 Celsius degrees in 1994 is a little suspicious but the decreasing chloride and silica together with an increase in magnesium concentrations suggests an increase in the ground water component of the discharge. In 1995 a more ‘normal’ temperature was recorded and the chemistry was again as that in 1992/1993.

Recommendation:

Sample yearly. Make sure that the same feature is sampled so that any change in temperature and chemistry, as seen in 1994, can be verified.

Tokaanu Bathhouse Spring, Tokaanu #5

No significant changes are observed between the two 1993 and 1994 samples. The waters have a high chloride concentration indicating a large deep water component with little dilution.

Recommendation:

Sample yearly.

Tokaanu: Waihi – #47 – Whakatara

Two samples were collected in 1994 because the first had lost CO_2 due to the collection technique used. The 1993 and 1994 samples are very consistent and the 1966 sample a little diluted in comparison. These medium chloride springs indicate a smaller deep water component than in the Bathhouse spring (see below).

Recommendation:

Yearly sampling. Two samples have already been analysed for isotopes therefore it is not necessary to repeat this for the next sample.

Tongariro: Ketetahi – Black Cauldron

The acidic features at Ketetahi are subject to more variation in chemistry than those in other areas which are supplied by deep seated chloride waters. There is an added uncertainty with this feature in whether the 1994 sample was collected from the same location as those in 1989 and 1990.

Recommendation:

IGNS will sample this feature yearly and will make results available to Environment Waikato.

Tongariro: Ketetahi – Iron (Fe) Spring

Although this feature is readily identified, the chemistry is very variable, for example, sulphate = 141, 310, and 564 mg/kg.

Recommendation:

IGNS will sample this feature yearly and will make results available to Environment Waikato.

Tongariro – Blue Lake

This is virtually a freshwater lake with no discernable thermal input (it freezes in winter).

Recommendation:

Annual monitoring should continue, as the low mineralisation present will enable any future thermal input to be readily identified. IGNS will sample this feature yearly and will make results available to Environment Waikato.

Tongariro – Lower Emerald Lake

This low temperature lake shows a possible chemical trend from 1983 to 1994 with decreasing pH and increasing sulphate and magnesium.

Recommendation:

IGNS will sample this feature yearly and will make results available to Environment Waikato.

Waikite WE1031 ("Manuroa")

This feature has exhibited very stable chemistry in 1992, 1993, and 1994.

Recommendation:

Sample yearly.

Waiotapu – Champagne Pool

This feature has a long history of observation and 19 sets of analytical data are shown in Huser and Jenkinson (1996), mainly for 1983 to 1986. As a pool that is subject to evaporation (hence the temperature below boiling) the variations shown are expected. The latter two sets are in good agreement.

Recommendation:

Sample yearly.

Waiotapu – Spring #24

A different sampling site is being sampled now than the site previously named #24. However, sampling should be continued at the present site. As this is an acid sulphate spring the chemistry will vary depending on the amount of H_2S and the oxidation that occurs.

Recommendation:

Sample yearly.

Wairakei – Totara Gut

Only two samples have been collected and show no significant changes. The water has a very low chloride (similar to non-geothermal ground water). This is expected as the deep chloride water disappeared from surface features in the early 1960s.

Recommendation:

Sample yearly.

4.5 Fumaroles – gas samples

The comments and recommendations in this section have been adapted from Huser and Jenkinson (1996).

The results of all previous monitoring data are shown in Huser and Jenkinson (1996). They also include some historical data where it is available. Unlike the case for springs, it is difficult to find old results as many of the fumaroles sampled in the past are not discharging now (for example, Karapiti Blowhole) or it is impossible to correlate the old and new with any certainty. Sampling of all features should continue.

Ketetahi – Ketetahi #2 and Tongariro – Emerald Lake, Red Crater and Central Crater fumaroles

Huser and Jenkinson (1996) show the first reported analysis of these fumaroles. They all have a high gas content. It is notewothy that the N_2/Ar ratios are high to very high, indicative of a volcanic/magmatic gas source.

Recommendation:

The features will be sampled yearly as part of an IGNS research project and the results reported to Environment Waikato.

Rotokawa – RK1006

Little change has occurred in this feature between 1993 and 1994. The increase in gas content shown by most of the gases is possibly due to condensation.

Recommendation:

The feature should be sampled yearly and duplicates collected and analysed.

Tauhara – Hell's Gate and Pony Club

Since 1978 Hell's Gate fumarole has increased in gas content. This indicates condensation of steam as it passes through the ground towards the fumarole. In 1995 a further increase was noted and by 1996 the fumarole was too weak to sample. Hell's Gate #2 has been substituted in the Taupo/Tauhara monitoring programme (Glover and Klyen, 1996). The 1995 and 1996 samples from the Pony Club fumarole show a similar increase (Glover and Klyen, 1996) likely due to the same cause.

Recommendation:

The features should be sampled yearly.

Te Kopia

It is not possible to say whether the "Te Kopia Fumarole" sampled in 1965 is the same as that sampled in 1993 and 1994. Thus the difference in chemistry cannot be stated to be a change with time as opposed to a difference due to a change in location. The 1993 sample has high air contamination and an unusually high H_2S compared with the 1994 samples. The 1994 duplicates show good agreement.

Recommendation:

The feature should be sampled yearly and duplicates collected and analysed.

Waikite – Waikite Scarp

This feature has low gas content similar to Wairakei fumaroles. The duplicate samples show differences which are not simply a change in the gas/steam ratio.

Recommendation:

The feature should be sampled yearly and duplicates collected and analysed.

Waiotapu – Maungaongaonga

This area was difficult to sample and the feature sampled in 1993 had large air contamination. In 1994 access was gained to the most vigorous feature and this will be monitored in future. Any comparison of data between the two features as change with time would be invalid. The duplicate samples collected in 1994 have different amounts of air contamination. 7357/N1 is the least contaminated as seen by the lower nitrogen and higher hydrogen sulphide.

Recommendation:

The feature should be sampled yearly and duplicates collected and analysed.

Wairakei – Karapiti #18 and #22

Based on maps Finlayson was able to "identify" eight fumaroles sampled in 1961 that were still active in 1991. KP22 is within five metres of Fj and KP18 is 40 metres SW of Ff. However, the most that can be said is that the pairs are in the same general location. Changes have been observed with time. In particular, in 1961 there was a pattern of decreasing CO_2/H_2S ratios from NE to SW across the Karapiti area. In 1991 this had disappeared and the steam from all the fumaroles was much more homogeneous. This is interpreted as due to changes underground. Initially hot water was flowing and separating steam as it moved along. The first steam produced had high gas concentrations and high CO_2/H_2S ratios (due to the different solubilities of the two gases. By 1991 the fumaroles were supplied by a steam reservoir which was much more homogeneous. During 1990-1991 samples were collected at approximately monthly intervals. The average value for KP18 and KP22 are shown in Huser and Jenkinson (1996). This does not show the changes over the year. For KP22 the standard deviation for the CO_2 is 20.3 (9.3 per cent). There are 3 months when the CO_2 is low at 185 mM/100M, compared with the average 218. There is also one month (October 1990) when the H_2S is low and the CO_2/H_2S ratio is very high. This latter phenomenon is seen in all of the thirteen fumaroles monitored. Thus there are changes that occur during a year but that may not be part of a trend.

Recommendation:

In order to pick up a trend, monitoring will have to be done more frequently than annually (perhaps biannually). This area is one that has been affected by development and a lot of data is available for Karapiti Blowhole itself although that feature has long since become extinct. With the drilling of wells to the west for the Poihipi Power Station it is important to monitor the Karapiti fumaroles.

Wairakei Thermal Valley (Geyser Valley)

Whilst, again, the three features reported (GVcpL, GV169 and WK1054) cannot be regarded as exactly the same vent they are within 10 to 20 metres of each other and the first two are likely to be the same. A trend over the 26 years is observed as the gas concentrations decrease. Little change is observed between August 1993 and June 1994.

Recommendation:

Due to the good correlation between duplicates and the historical data yearly sampling is sufficient with no duplicates (unless unexpected changes are observed).

References

Cody, Ashley Douglas (2000): *Monitoring and exception reporting on geothermal features in Atiamuri Ecological District: report for year 1 July 1999 to 30 June 2000*. Contract Report No. PO 16618 for Environment Waikato, Hamilton. 22 p.

Cody, Ashley Douglas (2001): *Monitoring and exception reporting on geothermal features in Waikato Region: report for year 1 July 2000 to 30 June 2001*. Contract Report for Environment Waikato, Hamilton. 31 p.

Cody, Ashley Douglas (2002): *Monitoring and exception reporting on geothermal features in Waikato Region: report for year 1 July 2001 to 30 June 2002*. Contract Report for Environment Waikato, Hamilton. 48 p.

Cody, Ashley Douglas (2003): *Monitoring and exception reporting on geothermal features in Waikato Region: report for year 1 July 2002 to 30 June 2003*. Contract Report for Environment Waikato, Hamilton. 48 p.

Cody, Ashley Douglas (2004): *Monitoring and exception reporting on geothermal features in Waikato Region: report for year 1 July 2003 to 30 June 2004*. Contract Report for Environment Waikato, Hamilton. 48 p.

Cody, Ashley Douglas (2005): *Monitoring and exception reporting on geothermal features in Waikato Region: report for year 1 July 2004 to 30 June 2005*. Contract Report for Environment Waikato, Hamilton. 32 p.

Cody, A.D., R.F. Keam, K.M. Luketina, and D. Speirs (2007, in press): *Sinter-depositing Springs and Geysers in the Waikato Region*., Waikato Regional Council, Hamilton

Duggan, I. and I. Boothroyd (2001). *The distribution of biota from some geothermally influenced waters in the Taupo Volcanic Zone*. A report for Waikato Regional Council, Hamilton, NIWA**:** 31.

Duggan, I. and I. Boothroyd (2002). *The distribution of biota from some geothermally influenced standing waters in the Taupo Volcanic Zone*. A report for Waikato Regional Council, Hamilton, NIWA**:** 38.

Environment Waikato (2006a). *Waikato Regional Policy Statement: Proposed Change 1: Geothermal Section – (15 August 2006)*. Waikato Regional Council, Hamilton. 44 p. http://www.ew.govt.nz/policyandplans/rpsintro/index.htm.

Environment Waikato (2006b). *Proposed Waikato Regional Plan: Proposed Variation 2: Geothermal Module – (19 November 2006)* Waikato Regional Council, Hamilton. 110 p. (As at August 2007 this is available only in hard copy from Environment Waikato)

Hampton, W.A., K.A. Rogers, and P.R.L. Browne (2001)**:** *Geothermal Activity (Past and Present) in the Environment Waikato Region: an Annotated Bibliography*, 2001. A report for Waikato Regional Council, Hamilton, by University of Auckland.

Holwerda, N. and Blair, I (2007): *Mapping of Geothermal Streams and Springs*, Environment Waikato Technical Report No. 2007/10, Document No. 115987, April 2007.

Huser & Jenkinson, (1996): *Regional Geothermal Features Monitoring Programme*, Waikato Regional Council Technical Report 96/18, Waikato Regional Council, Hamilton. 42p.

Keam, R.F., K.M. Luketina and L.Z. Pipe (2007, in press): *Definition and Listing of Significant Geothermal Features in the Waikato Region*. Waikato Regional Council, Hamilton.

Lynne, Bridget Y. (2007): *Hydrothermal Eruption Craters within the Horohoro Thermal Area and Tauhara.* A report for Waikato Regional Council, Hamilton, March 2007. Environment Waikato Document No. 1161585, 48 p.

Parkyn, S. and I. Boothroyd (2000). *Aquatic biota of geothermal ecosystems: annotated bibliography of biodiversity, distribution and environmental significance*. A report for Waikato Regional Council, Hamilton, NIWA**:** 23.

Stevens, M.I., A.D. Cody, and I.D. Hogg (2003): *Habitat Characteristics of Geothermally Influenced Waters in the Waikato Region*. A report for Waikato Regional Council, Hamilton, by Waikato University, Hamilton.

Wildland Consultants Ltd (2004): *Geothermal Vegetation of the Waikato Region: Revised 2004*. A report for Waikato Regional Council, Hamilton.

Wildland Consultants Ltd (2006a): *Priorities for Pest Plant and Animal Control, and Fencing at Geothermal Sites in the Waikato Region.* A report for Waikato Regional Council, Hamilton.

Wildland Consultants Ltd (2006b): *Field Evaluations of Five Geothermal Sites, Waikato Region, June 2006.* Report No. 1403 for Waikato Regional Council, Hamilton. 26 p.

Wildland Consultants Ltd (2007): *Evaluation and Mapping of Selected Geothermal Site for Minor Variation to Waikato Regional Plan – Geothermal Vegetation and Geophysical Properties: February 2007.* A report for Waikato Regional Council, Hamilton. Environment Waikato Document No. 1161554, 55 p.