Guideline for mapping and monitoring geothermal features

Bay of Plenty Regional Council
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September 2012

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Bay of Plenty REGIONAL COUNCIL

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Prepared by BJ Scott, GNS Science

Cover Photo: Prince of Wales Feathers and Pohutu geysers in eruption and Te Horu spring (foreground) – Photographer B J Scott

Acknowledgements

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Part 1: Guideline for mapping and monitoring geothermal features

1.1 Introduction

Geothermal systems often have some form of surface expression, which is associated with heat and mass being discharged from the geothermal system. This is typically referred to as a geothermal area. They are variable and may not always reflect the size or nature of the subsurface system. Generally the more heat discharged, the more surface activity will be present.

Geothermal refers to any system that transfers heat from within the earth to its surface. When the transfer of heat involves water, hydrothermal features representing the geothermal system may form on the surface. Examples of hydrothermal features include hot springs and pools, geysers, mud pools, fumaroles, and hot and warm ground. DSIR Report 38D (1974) catalogued New Zealand geothermal systems and later Mongillo and Clelland (1984) updated this. These are shown in Figure 1 and summarised in Appendix 2.

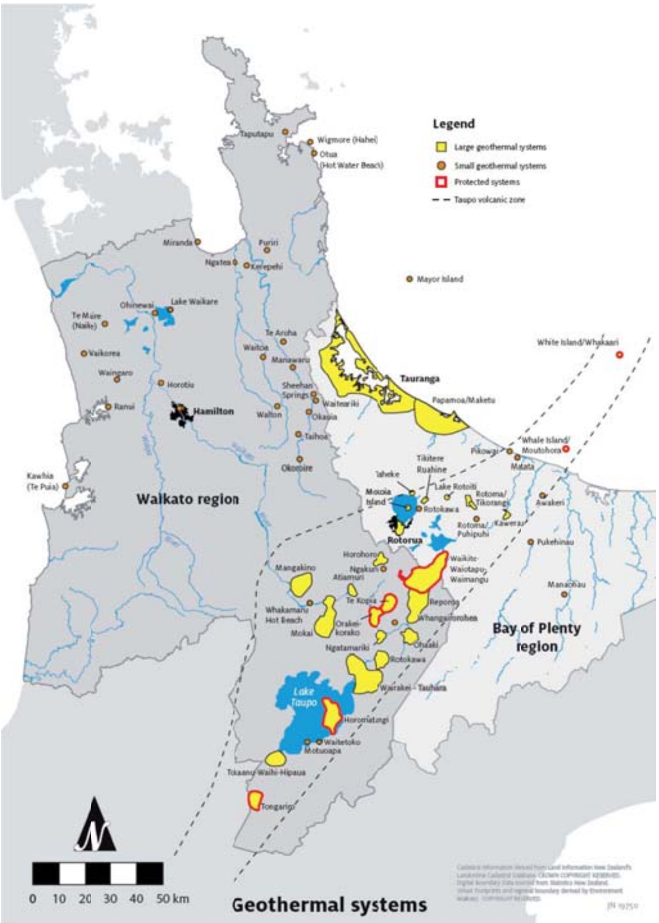

Figure 1 Sketch map showing the geothermal systems in the TVZ courtesy Waikato Regional Council

Geothermal features are an obvious expression of a geothermal system, and can be used to determine parameters of the sub-surface system by mapping and characterising them. They are also an indicator of the system behaviour and response to reservoir utilisation or natural variation, if in an undisturbed (non-exploited) natural state. Identifying the locations of geothermal features and monitoring their heat, water flow, and chemistry can provide aspects of the data needed for fundamental science and to support informed decisions about management options.

Geothermal features may have intrinsic, amenity, economic, social and cultural values. They can be used for heating, bathing, tourism, and scientific study that aid understanding of other resources and processes such as volcanic eruptions. Traditional Māori uses of geothermal features include cooking, bathing, heating, ceremonial uses, preparing and preserving food, mining the pigmented mud korowai, and timber treatment. Geothermal features can produce valuable minerals, provide landscape diversity, and their dependent ecosystems provide ecosystem services such as buffering other ecosystems from heat and toxic minerals.

Historically development of geothermal energy has had an adverse impact on geothermal features, particularly geysers, hot springs, and fumaroles. Care must be taken to prevent damage to them. Because geothermal features are relatively rare, it is important we enjoy them and protect them for the future. To achieve this we need a catalogue of some form, describing and characterising them.

This report provides a guideline to two aspects of acquiring information about surface geothermal features:

1 mapping and describing them, and
2 monitoring changes through time which may be due to natural or human-related causes.

These surveys may also be supported by large-scale surveys of aspects such as vegetation, ground temperatures, Thermal IR and aerial photography.

1.2 Background

Surface geothermal features are fragile and easily damaged. Hot springs and geysers are sensitive to any changes in their underground water supply, and are easily affected by natural events such as earthquakes and landslides. Over the last 100 plus years, however, the impact of humans has been vastly greater than that of natural change, with the exception of the 1886 Tarawera Rift eruption at Rotomahana, which destroyed and submerged much of the Pink and White Terraces and created the Waimangu geothermal field.

Traditional Māori activities caused only minimal disturbance. Greater human impact on geothermal features began early in the 20th century, when outflows were channelled and wells were drilled to help meet the demands for hot water for bathing and heating. This accelerated after the Second World War. The population increased and there were few effective controls on the drilling and discharge of bores for domestic and commercial use.

New Zealand's first geothermal power station was built at Wairākei, near Taupō. By the time the first stage was commissioned in 1958, the geysers at Geyser Valley and Taupō Spa had ceased to flow, being attributed to the well draw off. When the Ōhaaki–Broadlands field was drilled and the wells discharged, the Ōhaaki–Ngāwhā boiling pool ceased to flow, and water levels fell. Much of the Ōrākei Kōrako thermal area was flooded in 1961, when the Waikato River was dammed and Lake Ōhakuri was formed to generate hydroelectricity. In the 1980s the Rotorua Geothermal Field became a concern when the system was obviously stressed by excessive draw-off. Some of the geysers had ceased erupting and the water levels of flowing springs had fallen. Aspects of the tourism industry that relied on them were threatened. Monitoring was needed to quantify the effects, and action required to reduce those activities causing the effects.

Detailed investigations of a geothermal resource will include the quantification of the surface expression. Geothermal features are mapped to characterise them and sampled to define their chemistry. Other studies, such as heat flow, may also be undertaken.

Geothermal surface features can change due to natural perturbations, for instance weather patterns, climate changes, or earthquake and volcanic activity. They can also change due to human activities, such as nearby production of geothermal energy or land use practices.

Geothermal surface features can be hazardous. Boiling pools can cause thermal burns (and death). Concentrations of toxic chemicals (mercury, arsenic, etc.) and toxic or asphyxiant gases (hydrogen sulphide, carbon dioxide) are also hazardous. Some systems may also have the potential for hydrothermal eruptions.

Currently there are no formal guidelines or procedures in place for mapping or monitoring of geothermal features. This report outlines procedures for the collection of data from surface geothermal features.

A national standardised methodology will provide capability for consistent description of geothermal features throughout New Zealand. Geothermal systems are complex. Studying and monitoring their surface expression will add to many aspects of the geothermal knowledge base, making it possible to compare them from place to place and over time. These will also contribute to natural hazards knowledge and safety.

1.2.1 The key for assessments and understanding is baseline data

Natural variation in energy, water and chemistry cannot be assessed without suitable baseline data. Nor can potential impacts from human activities, seasonal variation, climate change etc. be determined.

Without baseline data, it is difficult to determine normal variation and significant changes that may represent broader geological events or induced changes from exploitation. Some changes will be short-term (hourly, daily, weekly, seasonal, annual) and these need to be distinguished from long-term trends where the surface expression maybe getting larger or smaller; hotter or cooler.

Good baseline data will also help scientific researchers' test hypotheses about geothermal systems and their surface expression and help clarify phenomena such as the interaction of geothermal water with local cold groundwater.

Changes in the surface expression of geothermal systems can also have environmental impacts on terrestrial and aquatic ecosystems, and water, riverbed and soil chemistry. Monitoring can help document the impact of, or recovery from, development of a geothermal system. This may include monitoring elevation data which can detect subsidence due to fluid production. It is also necessary in identifying likely effects of development or construction activities. Geothermal features may be affected by development or construction, or the presence of features may affect managerial decisions (e.g., road construction or building in thermal areas). Regional and District planning can place restrictions on activities that can have an adverse effect on surface geothermal features.

Quantifying and documenting geothermal features provides valuable data and information that can be used in further research and education activities. This can also be a source of data for monitoring and assessment efforts (although research and education can disturb or have a detrimental impact on geothermal features). Monitoring data can provide information for local interpretation activities, supporting tourism etc. Baseline data can also help quantify vandalism.

Changes in physical appearance of geothermal features may support assessments of geological hazards, such as landslides, hydrothermal eruptions or volcanic (magmatic) activity. Monitoring of hydrothermal systems is often included in volcano monitoring programmes.

1.3 Geothermal features

Surface geothermal features in New Zealand are hydrothermal in nature, being water or steam dominated; with most groupings having gradational boundaries. A classification has been developed for the Bay of Plenty Regional Policy Statement (RPS) and is adopted here for guidance (Figure 2). The surface features range from those that are in high energy states (fluid or steam), through over-flowing to non-over-flowing pools (lower energy).

Surface geothermal feature types and habitats			
Geyser		**Mud Geysers**	**Fumarole**
Primary Flowing Springs	**Mixed Flowing Springs**	**Mud pots**	**Steaming Ground**
Primary Non flowing pools	**Mixed Non flowing pools**	**Mud Pool**	**Heated Ground**
Primary geothermal fluid ←-------→	*Mixed/diluted geothermal fluid*	*Mixed diluted fluid and/or steam heated* ←--------→	*Steam Fed*

Figure 2 A schematic representation of surface geothermal features. These can range from eruptive overflowing to non-flowing states. The fluids range from primary geothermal fluids, to mixes and steam.

Three broad categories of habitats are also supported by surface geothermal features. These are:

1 the atmosphere above and around them,

2 the aquatic environments of pools, lakes, marshes and streams which they flow and seep into, and

3 areas affected by heated or hydrothermally altered ground.

Three major types of fluids are common in surface geothermal features. Some features receive hot 'primary' geothermal fluids directly (or almost directly) from depth (Figures 3, 4 and 5). These are usually classed as alkali chloride waters and are saturated (with respect to temperature) with SiO_2; and their outflows form silica deposits. These fluids may also have dissolved CO_2 and H_2S components. In other features the fluids will mix and become diluted, usually with shallow ground waters and by interaction with CO_2-rich bicarbonate fluids (Figures 6, 7 and 8). Some will also be influenced by steam, condensing to produce more acidic fluids (H_2SO_4), often referred to as acid sulphate fluids and muds (Figures 9 and 10). The third type of geothermal feature is dominated by steam passing through ground to heat the ground and form warm to hot ground (Figure 13). If enough steam passes it will develop into a fumarole (Figures 11 and 12).

The various feature types are discussed in more detail below.

1.3.1 Geysers

A geothermal spring which erupts occasionally or frequently, producing an intermittent or continuous discharge from its vent (Figure 3). This is vigorous enough to forcefully eject liquid water into the air. This includes hot water geysers, perpetual spouters, soda geysers, and crypto-geysers. Crypto-geysers (meaning hidden geysers) are discharging geothermal features that exhibit the characteristic cyclicity of a geyser except that they do not project columns or jets of water. Cyclicity is exhibited by regularly fluctuating water levels and discharge rates.

The area of a geyser comprises that of the spring basin, the splash-zone and the area covered (intermittently) by surface water discharge. This typically produces sinter deposits, which would be included in measurements of the total area of the geyser.

Figure 3 Prince of Wales (S72) and Pohutu (S75) geysers at Te Puia, Whakarewarewa, Rotorua. Photographer BJ Scott.

1.3.2 Primary flowing springs (primary geothermal waters)

A geothermal spring which maintains a continuous (or regular intermittent) overflow of chloride-enriched water (Figure 4).

These are very likely to deposit sinter in the overflow channel.

This type may also include springs submerged underwater that would be likely to deposit sinter if they were no longer submerged.

Figure 4 Ngararatuatua Spring (S529) at Te Puia, note the light grey sinter surround and algae assisted discharge apron (lower left). Photographer BJ Scott

The area of a spring would include that of the spring basin, together with the area covered by any surface outflow from the pool and any sinter deposits created by that outflow.

1.3.3 Primary Non-flowing pools (primary geothermal waters)

A depression, usually sinter-lined, that naturally receives primary geothermal waters from depth (Figure 5). To maintain their temperature and chemistry these pools will have some form of sub-surface inflow/discharge. The area of a pool comprises that of the basin, together with the area covered by any variation of the water level.

Figure 5 Rachel Pool, Government Gardens, Rotorua. Photographer D Graham

1.3.4 Mixed Flowing Springs (mixed chemistry)

Figure 6 Spring S428, Whakarewarewa Photographer D Graham

Any geothermal spring which maintains a continuous (or regular intermittent) overflow, but is not discharging primary geothermal waters (Figure 6). This type may also include submerged springs that would be flowing if it were no longer submerged.

The area of a spring includes that of the spring basin, together with the area covered by any surface outflow from the pool.

1.3.5 Mixed non-flowing pools (mixed chemistry)

A depression that naturally receives mixed geothermal fluids from depth and whose discharge is also below-ground (Figure 7).

The area of a pool comprises that of the basin, together with the area covered by any variation of the water level.

Figure 7 Spring S326 Rereawaho, Whakarewarewa. Photograph B J Scott

1.3.6 Mud geysers and volcanoes

A steam heated mud pool that occasionally or frequently erupts. The eruption produces an intermittent or continuous discharge by surging, boiling, throwing, splashing, or jetting it into the air above a static water/mud level. This type of activity can build up mud volcanoes (Figure 8).

Figure 8 Ngamokaiakoko (Frog Pond) S262, Te Puia, Whakarewarewa. D Graham

The area covered by a mud geyser/volcano includes the mud pool, its banks, and any mud formations built up by the ejection of mud from the pool.

A basin of turbid steam heated mud that occasional disrupts the surface. There will generally be little or no water ponding in this feature type. These can grade into mud pools described below.

1.3.7 Mud pots

The area of a mud pot comprises that of the pool itself, its banks, and any mud formations built up by the ejection of mud within the pool (Figure 9).

Figure 9 Mud pots at Whakarewarewa Village (S336). M Lowe

1.3.8 Mud pools

A basin of turbid-muddy steam-heated water and mud (Figure 10).

The appearance of these features can be affected by rainfall, i.e. they may dry out in summer and flood in winter. These can grade into mud pots described above. The area of a mud pool comprises that of the pool itself and its banks.

Figure 10 Mud pool at Te Kopia. J Newson.

1.3.9 Fumaroles

Superheated fumarole

A naturally occurring steam or gas vent (including those found underwater). The main discharge consists of steam and other gases, with a temperature greater than the local boiling temperature of water (Figure 11).

Figure 11 Fumarole #0 at White Island (118 °C) Photographer K Britten

The area of a fumarole consists of the vent, any surface accumulating mineral deposits derived from its gases, and any ecosystems dependent on the heat and condensate about the vent.

Fumaroles

A naturally occurring steam or gas vent (including those found underwater). The main discharge consists of steam and other gases, with a temperature equal or less than the local boiling temperature of water (Figure 12).

The area of a fumarole consists of the vent, any surface accumulating mineral deposits derived from its gases, and any ecosystems dependent on the heat and condensate from the vent.

Figure 12 Fumaroles on the shore of Lake Rotomahana. Photographer B J Scott

1.3.10 Steaming ground

A ground area discharging steam, diffusively passing through surface soils, with boiling in the ground within 0.2m of the surface, and night-time ground surface temperatures greater than 15 °C above ambient (Figure 13).

Figure 13 Steaming ground in the Craters of the Moon thermal area, Wairakei. Photographer B J Scott

1.3.11 Heated ground

A ground area with surface soils radiating heat from underground geothermal sources where there isn't boiling in the ground within 0.2 m of the surface and the night-time surface temperature is greater than 5 °C above ambient.

1.3.12 Other

As geothermal systems are complex and a variety of interactions can occur there is significant potential for 'other' feature types to occur, hence other is reserved for these. Examples may include features like;

Molten sulphur producing spring(s) or fumarole(s)

In some geothermal and volcanic environments there can be sufficient heat to melt the elemental sulphur (119 °C), which is then brought to the surface.

Kaipohan

Cold gas discharge, consisting mostly of CO_2 of deep geothermal origin, with no associated steam discharge, but of sufficiently large flow-rate to influence vegetation.

The surface expression of a geothermal system may also include land form features like eruption craters and abandoned sinter terraces. Typically the craters will contain surface features (pools, springs or warm ground); hence the larger feature containing these should be recorded as an aspect of the location of the surface features.

1.4 Habitats

1.4.1 Geothermally altered atmosphere

An area of terrestrial habitat of indigenous thermo-tolerant species that is tolerant of or dependent on geothermally influenced atmospheric conditions, primarily a heated moist atmosphere (Figure 2).

1.4.2 Geothermally influenced aquatic habitats

An area of naturally occurring aquatic habitat of thermo-tolerant, thermophilic or otherwise extremophilic indigenous species, which may form part of an ecosystem(s), in a water body influenced by natural geothermal input (Figure 2).

1.4.3 **Heated ground or cooled acid ground**

An area of terrestrial habitat containing thermo- or acid-tolerant indigenous ecosystems or species or those adapted to other particular chemical compositions on current or formerly geothermally heated ground, which may form part of an ecosystem(s). Typically these will be found in association with a variety of surface geothermal features as described above (Figures 2 and 13).

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Part 2: Designing a mapping project

As with any scientific project, the single most critical issue is the objective of the project.

Without a clear objective, selecting appropriate techniques to apply and collecting all the data that may be useful in the future becomes problematic. Without a clear sense of purpose a geothermal mapping or monitoring program may not meet current or future needs, especially in terms of resource characterisation and classification, which then affects management decision for development or protection. For data to be useful, all studies must be well planned and implemented with care.

When describing a geothermal feature there will be a mix of hard (quantitative) data like temperatures, water level and flow which will be directly measured, with soft data (qualitative) like colour, ebullition height and gas bubbles that will be estimated and have less precision.

Mapping of geothermal features in New Zealand has been systematic in only some areas. Mapping projects include:

- Those formally published such as Lloyd (1959, 1975, 1972) covering Waiotapu, Whakarewarewa and Orakei Korako respectively. Glover *et al* (1992) mapped Waikite area, while Espanola (1974) covered Tikitere and Taheke.
- Those found in University thesis, like Keywood (1991) who mapped features at Waimangu and Rotomahana.
- Part of unpublished maps or reports held in GNS Science and other collections (e.g. universities).

GNS Science, Bay of Plenty Regional Council and Waikato Regional Council hold collections of these data and for some areas have collated portions of these collections.

The mapping and characterisation of geothermal features can be approached at three levels.

Level 1: **Coarse –** major or apparently significant features are located, mapped and described.

Level 2: **Detailed –** an attempt is made to map and describe <u>all</u> surface features. Additional data such as chemistry, fluid flows and heat flows is added to the location and descriptions.

Level 3: **Comprehensive** – an extension of level 2. Additional data (geophysical, biological and ecological) is obtained to define the surface and sub-surface extent of the surface expression of the geothermal system and attributes such as habitats.

Although Level 3 studies provide the most detailed interpretations of the surface expression of a geothermal system, appropriately designed level 1 and level 2 studies can provide significant information useful for research, resource estimation, management and protection.

To construct a database of feature parameters (temperature, water level, colour etc.), chemistry, and photography requires documenting and monitoring the location of geothermal features, as well as other attributes. The key data required includes:

- Locating precise geographic coordinates of individual geothermal features assigning the feature a unique identifying number and adding information such as existing names (these have changed with time).
- The physical attributes of the feature. These will include size, shape, temperature, water level or flow, colour, turbidity, chemistry, and activity being measured, and Photographs taken from a designated photo point.

Digital archives of geothermal features assist information sharing, change detection, and integration with other spatial data and details of these data are discussed below.

Surface geothermal features are the most obvious expression of a geothermal system. Extinct and inactive surface features are an indication of past activity from a geothermal system, hence should be included in a survey of a geothermal area as landform features. Many will contain surface features (pools, springs or warm ground) and the larger feature containing these should be recorded as an aspect of the location of the surface features.

2.1 Mapping procedures and protocol

The following sections discuss the collection of data related to mapping geothermal features (GF's). This is the data needed to fill in the Geothermal Feature Survey form or the Geothermal Feature Re-Survey form (Appendix 1).

The form can be printed and completed in the field with a pencil or it could be adopted for use on an electronic notebook. When locating and describing a feature the goal is to collect as much information as possible. Use the form to collect these data, which can be filed as hard copy or entered to a database. These data will be of use for later interpretation.

Equipment required for these measurements and safety is discussed below.

2.1.1 Feature identification

This block on the form includes a unique ID for the feature, historic ID's, names (including current, local and historic), the geothermal field and codes for these. The feature's name can change with time, but there should only be one **Feature ID** number ever allocated. Unfortunately people have used various numbering or identification systems for their own studies, creating considerable confusion when another researcher attempts to resample or monitor a feature (have I got the same one?).

Historically the first systematic spring numbers were sequential and prefixed by the NZMS 86 sheet number, i.e. N94/4/xx (Gregg and Laing 1951)[1]. The Waiotapu springs were numbered N85/3/xx and N85/6/xx (Lloyd, 1959, 1963). Later Ōrākei Kōrako springs were number N85/8/xx (Lloyd, 1972). Other geothermal fields have also been mapped for example Lloyd (1975), Espanola (1974), Glover et al. (1992) and Keywood (1991).

Unfortunately this system has not being adopted by all later users. A flaw of this system was the 'same number' being allocated within a single geothermal field, especially if on a map the feature ID is shortened to just the number (e.g. Lloyd 1959). Another is that mapping systems change. The New Zealand topographic map series has already been replaced twice. Better practice would have sequential

[1] When detailed mapping of geothermal systems started, the largest scale maps available were the NZMS 86 map series (1:15840). These were part sheets of the NZMS 1 series (9 per sheet) published at 1:63,000 scale (1 inch to mile).

numbering of features within each recognised geothermal field, prefixed by a two-letter code for the **Geothermal Field**; with a third letter F to designate it as a feature number (e.g. KAFXXX for Kawerau features WAFXX for Waiotapu etc. where xxx is the unique feature number.). This is then relatively consistent with the practice for identifying production and monitor bores and the newly introduced vegetation data. The **Geothermal Field** name and **Field Code** are recorded on the field form.

DSIR Report 38D (1974) and later Mongillo and Clelland (1984) catalogued New Zealand geothermal systems (Figure 1). A summary of these system names in the greater Taupo-Rotorua area is presented in Appendix 2 along with 2 letter codes. The **Geothermal Field** name and **Field Code** is selected from this listing.

Feature ID

A geothermal feature is identified by:

- (Feature ID) 3 letter code and sequential number
- (Geothermal Field) field name and
- (Field Code) 2 letter code for the field (e.g. RO, WA, WA).

Feature name

A single feature may have several names; English, Māori, historic and local. The commonly used name of a feature thus changes with time. As all are valid names, data records must have capacity to record several names. Sometimes existing names are assigned to the wrong feature creating confusion.

1 — Feature ID thus covers*:*
Feature ID:............................*3 letter code and sequential number (Appendix 2)*
Geothermal Field*: ....Full name of geothermal field (Appendix 2*)
Field Code: ....*A 2 letter code - from Appendix 2*
Feature name: ....*Common name*
Historic/local names:.............*Other known names for this feature*
Survey*:..................................A place to record the survey being undertaken*

2.1.2 Feature location

Identifying the feature is critical, as is an accurate location of the feature.

Locating geothermal features is a key component of mapping and the first step in describing and then monitoring geothermal features. Relationships to other geothermal features, streams, rivers, lakes, infrastructure and landmarks are apparent when they located and mapped. While names of individual features change, their geographic location is unique.

The key data are the geographic **coordinates**, the errors associated with them, and the coordinate and map system the coordinates are in. Historically features have been given coordinates from the NZMS 86, NZMS 1, NZMS 2 and NZMS 260 map series and in terms of Geodetic datum 1949 and WGS 84.

The currently preferred coordinate recording system is the New Zealand Transverse Mercator 2000 (NZTM2000) - the projection used for New Zealand's Topo50 1:50,000 maps[2]. It is based on the NZGD2000 **datum** using the GRS80 reference ellipsoid. This internationally recognised type of projection exhibits a low level of distortion at its east-west extents.

The second preference to locate features on a map is the **coordinates** collected by GPS in the familiar latitude and longitude units. These may be based on the WGS 84 datum, and this can be transformed to NZTM2000. It would be better if they are collected directly in NZTM2000.

A GPS receiver is the best method to collect these data. A quality handheld GPS will obtain a location within 3-8 m, while post-processed data can result in centimetre accuracy (at a cost). Any new or revised mapping project should look at using techniques like Real Time Kinematic (RTK) based on the use of carrier phase measurements from the GPS receivers. RTK based data will not only provide very accurate locations but relative height data is also obtained. Traditionally this has not been available. The preferred technique is thus RTK GPS data. There will be some **error** associated with the coordinates and an estimate of this should be recorded on the field form.

Coordinate data are point data; often a geothermal feature will cover a significant area, especially larger features such as pools. Thus a record of where the coordinates are in **relation** to the feature is required (e.g. outlet). **Elevation** data is important along with its source, accuracy and reference datum i.e. a height off a map (in metres above sea level) will be an orthometric height, while a GPS height will be a Geoid height. These are very different datums. Relative heights obtained via RTK GPS surveys will be very accurate and can be related to orthometric heights by the inclusion of bench marks in the survey. Hence the preferred elevation measure is thus RTK GPS data.

2 — Location thus covers*:*
Coordinates:*..........................NZTM 2000 (east/north), or GPS (lat/long)*
Error estimate (accuracy): *....expressed as ± m*
GPS WP no.:*.........................recorded as cross check*
Relationship to feature: *.........relationship (for larger features), ie outlet*
Elevation:..............................*the derived height (m)*
Map Sheet:*............................NZ Topo50 sheet*
Map Datum:*...........................name the datum used for coordinates above*
Elevation Datum:*...................name the datum used for elevation above*

2.1.3 Feature description

Many attributes can be recorded about a geothermal feature. Some may be transitory. Some may require significant laboratory work (chemistry). The time of the day or season of the year may influence factors like visibility, due to steam.

Firstly the **feature type** needs to be defined. This is discussed above in section 1 and shown in Figure 2. Record **who** made the observations and **when** (time, date), as this can help clarify any ambiguity later.

[2] LINZ recommends where a projection is required within mainland NZ spatial data users use NZTM2000 . The projection is only applicable for the main NZ island group (North, South, Stewart).

There are many attributes to a geothermal feature, discussed below in detail and these should be summarised in the **feature description**. The primary visual attributes to record are the physical size, colour of the pool, clarity/turbidity, ebullition, odours, temperature, water level or over-flow rate, wind speed an air temperature and activity in the feature. The locations of measurements, sampling or photographs also need to be recorded.

A **sketch map** will help considerably. On this show one should record dimensions, locations of ebullitions, depth and temperature measurements and overflows. Also of importance are nearby features, and direction to north. Identify any *sampling sites* (relevant for larger features, so samples are taken from the same location) and *photo points*.

P**hotographs should be used** to capture the spatial and visual attributes of the features. Photographs should show the entire feature and its relationship to adjacent items. This will help identify sampling sites. The sketch will show the photo point to be used for repeat visits.

Details of the **size** need to be recorded. Visual keys such as **colour and water clarity or turbidity** can be indicators of the gross pool chemistry (Figures 5, 6, 7 and 14). Alkali chloride pools will be very clear, mixed water will tend to have less clarity and grow algae, while acid features may have muddy discoloured fluids. **Colour and turbidity** descriptions tend to be subjective, but grouping these observations introduces some form of consistency. For example descriptors like mid blue-green, mid-brown, yellow-green for colour and turbidity qualifiers such as murky, milky and turbid.

Figure 14 Photographs showing a milky/blue pool and turbid grey pool. D Graham

Ebullience reflects the amount of gas or steam in the discharge (Figure. 15). Sometimes a lot of gas can give the misleading appearance of boiling. Is the ebullience steady-state behaviour or is it time dependent? It is sometimes possible to visually quantify this by recording the amount, e.g.; minor small bubble streams (1-10 bubbles) through to vigorous or continuous discharge breaking the pool surface and splashing water about. Usually it is too dangerous to measure the height of this, so it can only be estimated.

Note the location of the gas or steam upwelling on the sketch, as it may reflect multiple vent(s) in a pool. There may also be a gas **odour**. Note predominant odour like H_2S. The presence of some gases can be detected by hand held monitors but the true quantity is more difficult to ascertain without sophisticated equipment.

Figure 15 Photographs showing weak (left) and moderate (right levels of ebullition in spring S55 at Te Puia. Photographer D Graham

The location of a **temperature** measurement is important. In selecting a measuring site consider "is the temperature uniform over the entire feature?" Is it the hottest location, or an overflow temperature? The safest method is to use thermocouples attached to long probes (Figure. 16). IR guns and cameras tend to be affected by steam.

Figure 16 Temperature measurements being made at S529, Te Puia. Note the long probe increasing safety. Photographer D Graham.

Water level needs to be referenced to some stable or permanent feature; subject to choosing an easily identified and physically long-lived benchmark. Although the overflow level is usually used, the reference location may not necessarily be at that level (an offset will be measured with respect to this).

Measure or estimate **overflow** rates – It can be very difficult to capture all the flow from an individual feature. Sometimes you may only be able to measure the collective flow from a group of features. Flow is the sum of average flow speed and channel cross section. This is usually done by timing a small float along a measured section of the outflow and calculating the flow from;

$$\frac{\text{Width x Depth x Length}}{\frac{\text{Time}}{1000}} \text{ x } 0.7$$

Where the width, depth and length are measured in cm, and time in seconds. The constant 0.7 is a bed roughness factor.

If a heat flow study is being conducted then data like **wind speed** and **air temperature** will also be needed. For cross checking data about the camera and image are also needed. The same applies to samples collected.

Other characteristics of the feature worth recording may include the nature of the ground around it. For steam-dominated features it may be the nature of the discharge (diffuse or strong), fumaroles will be a point source. The vegetation on warm ground can also be a guide to ecosystems. Also record mineral deposits and associated geomorphologic features, like altered ground.

Sinter deposits record the status and style of activity of a discharging or splashing feature. Sinter is a precipitate formed as the fluid cools. It maybe SiO_2 (silica sinter) but it can also be $CaCO_3$ (travertine) depending on the feature chemistry. The nature of the sinter can also indicate past activity of a feature, i.e. there has been alkali chloride or bicarbonate overflows. Various forms of micro structures can be formed, ranging from sheets or ripples, to nodules and spikes that incorporate local material (leaves, trigs) or have being assisted by algae.

Geysers are special cases, and enormous variability is common. To quantify aspects of the frequency and duration of an eruption may require long periods of observation. Data logging the outflow is often the best approach, recording several days of data to obtain a representation of the range. Height is not always a good measure as it can often be influenced by wind, but still should be estimated or measured if possible.

3 — Feature description thus covers:

Feature Type:........................	*pool, spring etc.*
Date and Time:	*when the observations are made*
Observers:	*who was there*
Description:	*physical description of the feature, activity and surround*
Sketch map:..........................	*sketch showing dimensions, north, sampling etc.*
Size:......................................	*dimensions and depth*
Colour:	*water colour*
Clarity and turbidity:	*colour and state of the water*
Ebullition:	*height and strength*
Odour/gas:	*can gas be detected, what type*
Temperature:	
Water level:	*distance below overflow*
Flow rate:	*calculated flow (litres/sec)*
Wind Speed:	*usually m/sec for heat flow calc's*
Air temperature:	*for heat flow calc's*
Camera:	*helps in cross checking photos*
Image number:	*cross check when downloaded*
Water sample:.......................	*information about samples*
Isotope sample:.....................	*information about sample*
Gas sample:..........................	*information about sample*
Biological sample:	*information about sample*
Additional comments:............	*anything else*

The "additional comments" is an opportunity to record anything else relevant to the surface feature (e.g.: known to have erupted; now flowing but is known to change over time).

2.1.4 Feature use and threats

Some features will also be **used** for activities like cooking or scalding etc. If there is evidence of this it should be recorded.

Threats to the feature from changes in land use, inadequate protection from stock or people, landslide etc. should also be recorded.

Related to location data is **access data**, such as how to get to it. This is useful for gaining access to the feature.

4 — Feature use and threats thus covers: Feature use:*......................... note any uses* Feature threats:*.................... note any threats*

2.1.5 Administration

This is mainly related to the transfer of the field data to databases and safe storage of the data. Also recorded are any references related to the information.

5 — Administration data may include: *References:* *Date entered:* *Photographs downloaded:*

Part 3: Designing a monitoring project

Mapping and characterising geothermal features to provide detailed interpretations of a geothermal system to support research, resource estimation, management and protection is outlined above. In this section monitoring projects are outlined. This is collecting data to assess changes with time. These must be carefully planned and implemented to ensure quality data is obtained.

Documenting and monitoring the attributes allows for construction of a database. Key data required are the physical attributes of the feature and includes descriptions, and measurement of the feature to record data such as temperature, water level or flow, colour, turbidity and activity. It should include sketches and/or photography.

The features selected for monitoring have to be representative of the geothermal system. They need to capture likely changes and response to reservoir changes by management policy or land disturbances like building, road works or other infrastructural construction. Sampling interval and sampling locations are important.

When designing a monitoring project it is important to consider the proposed or expected analysis and quality control on the data. Hence some form of specification may be needed for reporting the raw data.

Data collection may be done via regular site visits or logging feature parameters on data loggers. Sampling interval may range from seconds to daily, monthly or yearly.

Monitoring may also be undertaken for event response to assess hazards. This particularly applies in geothermal areas used as tour attractions or could be related to volcanic unrest.

3.1 Monitoring procedures

Many of the attributes required for monitoring are the same as those required for mapping and describing geothermal features like pools and springs.

Careful attention to completion of section 3, the Geothermal Feature Survey field sheet will achieve this goal. A simplified Geothermal Feature re-survey sheet is also presented in Appendix 1. The primary features to observe and record are temperature, water level, overflow rate, colour, turbidity, ebullition- upwelling and nearby conditions.

A monitoring project may also include steam dominated features, quantifying parameters to define the mass discharge and heat loss. However, details of these additional studies and sampling techniques are beyond the scope of this guideline. For discussion of these, refer to these reports or papers Hochstein and Bromley (2001), Bromley and Hochstein (2000), Bromley (2000), Dawson (1964), Dawson and Dickinson (1970), Dawson and Fisher (1964) and Miotti *et al.* (2010).

Chemical sampling of water is frequently included in geothermal monitoring projects. Rosen et al. (1999) outline in detail a guideline for the collection of groundwater samples for chemical and isotope analysis, while Klyen (1996) outlines sampling fluids and gases from bores and surface features. Presented in Appendix 3 are the field guidelines used by GNS Science for sampling water from surface geothermal features.

For detail on the feature descriptions, refer to section 2.1.3 above.

3.2 Equipment

Observing geothermal features is not equipment-intensive. Geothermal features are in damp and humid conditions, sometimes with corrosive atmosphere so equipment needs to be selected with this in mind. In addition the remote location of some features effectively precludes the use of heavy or cumbersome equipment.

The primary tools are a field note book, digital camera, temperature measuring equipment and a tape measure (5m metal). Field observations can be directly or electronically recorded. The field sheets presented in Appendix 1 should be used as a guide to ensure all data is collected.

Direct temperature measurements are usually best made with a type K thermocouple fitted in a 2 m fibreglass tube with a 5m long cable to the recording instrument. The thermocouples are robust and having them fitted in a tube allows safe access to most features. A variety of digital thermometers can interface with thermocouples. Use of IR thermometers has limitations, particularly if steam is present but has the advantage of being able to be rapidly deployed and from a safe distance, but maximum temperatures may not be obtained..

Other equipment includes waterproof notebook (or electronic version), maps and past reports including photographs. A GPS receiver is required to obtain position data for mapping the features. RTK techniques are preferred, for best accuracy.

3.3 Personal protective gear

Geothermal areas are intrinsically hazardous. Follow company health and safety policy. Such policy should cover:

1. Gaining permission to access the site,
2. A communication plan with the company base,
3. The appropriate and serviceable communication devices and
4. The use of field intention forms.

The field party must have experienced staff with first aid training. Their personal equipment must also be suitable for the environment.

Clothing – sturdy shoes, long sleeves, long pants, high viz

1. Walking stick (ground probe), leg protection (gaiters or high top gumboots), radio, first aid kit, 2 litres water, (gas meter).
2. Sampling – gloves, pitcher, (hearing protection), (safety glasses).

Approach all hot springs and seepages with extreme care, as even minor features can be located in unstable terrain (Figure 17).

Figure 17 An example of the dangers near a geothermal feature.

Before describing or sampling, closely scrutinize the features surroundings, noting hazardous overhangs and direction of any airborne hot discharge. Work as far from the feature edge as practicable when sampling or measuring, to leave a safety margin for ground collapse or personal instability.

Geothermal gases CO_2, H_2S, CO, SO_2 originating from fumaroles (steam and gas vents) may be present in dangerous concentrations. Gases may pond in low areas because they are heavier than air, displacing air/oxygen. Portable gas monitors should be used to ascertain gas levels.

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Appendices

Appendix 1 – Geothermal Feature Survey

Feature ID		Historic ID		Feature Name	
Geothermal Field		Historic / Local Name			
Field Code		Survey			

Coordinates (Northing / latitude)		Error Estimate	
Coordinates (Easting / longitude		Elevation	
GPS WP No.		Relationship to Feature (outlet, centre, etc)	
Map Sheet		Map Datum		Elevation Datum	

Feature Type		Date / Time		Observer(s)	
Description					

Sketch Map: Show dimensions, North, photo point (P), sample (S), temperature (T), coordinate location (C) and relationship to nearby features	Size	
	Colour	
	Clarity, Turbidity	
	Ebullition	
	Odour Gas	
	Temperature	
	Water Level	
	Flow Rate	
	Wind Speed	
	Air Temperature	
	Camera	
	Image Number	
	Water Sample	YES ☐ NO ☐
	Details	
	Isotope Sample	YES ☐ NO ☐
	Details	
	Gas Sample	YES ☐ NO ☐
	Details	
	Biological Sample	YES ☐ NO ☐
	Details	

Additional Comments			
Feature Use		Feature Threats	
Access Information			

OFFICE USE ONLY

Reference		Date Entered		Entered By	
Photographs Downloaded	YES ☐ NO ☐	Where			

GEOTHERMAL FEATURE RE-SURVEY

Survey		Date/Time		Observer(s)	
Feature ID		Feature Name			
Description					

Sketch Map: Show dimensions, North, photo point (P), sample (S), temperature (T), coordinate location (C) and relationship to nearby features		
	Size	
	Colour	
	Clarity, Turbidity	
	Ebullition	
	Odour Gas	
	Temperature	
	Water Level	
	Flow Rate	
	Wind Speed	
	Air Temperature	
	Camera	
	Image Number	
	Water Sample	YES ☐ NO ☐
	Details	
	Isotope Sample	YES ☐ NO ☐
	Details	
	Gas Sample	YES ☐ NO ☐
	Details	
	Biological Sample	YES ☐ NO ☐
	Details	

Additional Comments	

GEOTHERMAL FEATURE RE-SURVEY

Survey		Date/Time		Observer(s)	
Feature ID		Feature Name			
Description					

Sketch Map: Show dimensions, North, photo point (P), sample (S), temperature (T), coordinate location (C) and relationship to nearby features		
	Size	
	Colour	
	Clarity, Turbidity	
	Ebullition	
	Odour Gas	
	Temperature	
	Water Level	
	Flow Rate	
	Wind Speed	
	Air Temperature	
	Camera	
	Image Number	
	Water Sample	YES ☐ NO ☐
	Details	
	Isotope Sample	YES ☐ NO ☐
	Details	
	Gas Sample	YES ☐ NO ☐
	Details	
	Biological Sample	YES ☐ NO ☐
	Details	

Additional Comments	

Appendix 2 – Listing of primary geothermal fields in the greater Taupo-Rotorua area

Geothermal field	Field code	Surface features	Geothermal vegetation
White Island	WI	WIF	WIV
Whale Island	WH	WHF	WHV
Mayor Island	MY	MYF	MYV
Awakeri	AK	AKF	AKV
Kawerau	KA	KAF	KAV
Rotoma-Tikirangi-PuhiPuhi	RM	RMF	RMV
Lake Rotoiti (Centre Basin)	CB	CBF	CBV
Taheke	TA	TAF	TAV
Tikitere	TI	TIF	TIV
Lake Rotokawa	LR	LRF	LRV
Rotorua	RR	RRF	RRV
Lake Okataina	LO	LOF	LOV
Lake Tarawera	LT	LTF	LTV
Waimangu-Rotomahana-Tarawera	WM	WMF	WMV
Waiotapu	WT	WTF	WTV
Waikite-Puakohurea	WA	WAF	WAV
Atiamuri	AT	ATF	ATV
Mangakino	MA	MAF	MAV
Horohoro	HH	HHF	HHV
Te Kopia	TK	TKF	TKV
Mokai	MK	MKF	MKV
Orakei-Korako	OK	OKF	OKV
Reporoa	RP	RPF	RPV
Whangairorohea	WG	WGF	WGV
Ngatamariki	NM	NMF	NMV
Ohaaki-Broadlands	OH	OHF	OHV
Rotokawa	RK	RKF	RKV
Wairakei	WK	WKF	WKV
Taupo-Tauhara	TH	THF	THV
Horomatangi	HT	HTF	HTV
Waihi-Hipaaa	WH	WHF	WHV
Tokaanu	TO	TOF	TOV
Tongariro	OG	TGF	TGV

Appendix 3 – Geothermal surface feature water sampling

The methodology for collecting water sample from geothermal features described below is based on the collective experience of staff from DSIR and GNS science, results from the GNS Sciences geothermal laboratory (data quality) and techniques outlined by Klyen (1996).

Different techniques and sampling procedures are required for different analyses.

For pH and analysis of dissolved gases (total bicarbonate and total sulphide) or the non-metals (anions) use rubber sealed glass bottles, filtered or raw samples. If the sample cannot be processed by a laboratory in under 36 hours they should be pre-treated in the field as described below.

For analysing the metals, boron and silica use a filtered sample which have been acidified. Samples for Arsenic and Antimony will be pre-spiked with 1 N NaOH.

For isotope analysis use a glass bottle with rubber insert-metal lid.

Methodology

Wherever possible sample hot springs at the point of up-flow. Failing this, collect a sample at the outflow. Shallow or small discharges are best sampled with a handheld scoop or a syringe, to avoid disturbance of any sediment in the feature. If access is difficult, e.g. a pool in deep pit, use an extending sampling pole to gain safe access.

Always wear gloves with insulating properties when sampling hot springs.

The standard geothermal water analysis includes pH, total Bicarbonate, Sodium, Potassium, Calcium, Magnesium, Lithium, Rubidium, Caesium, Chloride, Sulphate, Boron, Silica and total Sulphide. Other analytes commonly measured are Aluminium, Arsenic, Bromide, Fluoride, Iron, Nitrate, Phosphate, Antimony, Ammonia, Oxygen 18 and Deuterium.

Sampling vessels and some of the equipment necessary to collect samples for the geothermal water analyses are illustrated (Figure 18) and discussed below:

1. A rubber sealed glass bottle: Used for collecting water samples without a co-existing headspace (air at the top of the bottle). The rubber extends over the neck of the bottle to allow for contraction during cooling and is closed by a double wing nut and bolt clamp. Samples are used for measuring pH and analysis of dissolved gases (total bicarbonate and total sulphide). If rubber seal bottles are not available, use a 500ml plastic bottle. When sampling using the plastic bottle, minimise the amount of headspace (best done by filling and capping bottle while submersed).

   If the sample cannot be processed by laboratory in under 36 hours they can be pre-treated by collected a raw 100ml sample. If the pH is greater than 9 then 4 drops of 6 molar Zinc Acetate are added. If the pH is less than 9 then caustic soda (240 mg/l NaOH) is added until the pH is greater than 9. Then it is treated with Zinc Acetate as described above.

2. 500 mL plastic bottle: Raw sample.

3. A 100 mL plastic bottle with filtered sample: The filtered sample and the raw sample are used to analyse the non-metals (anions)

4 A 100 mL plastic bottle with filtered sample which has been acidified with 1 ml 1:1 HNO_3 (nitric acid). Used for analysing the metals and boron and silica.

5 A 7 or 11 ml glass bijou bottle. Has metal lid with rubber insert. Sample used for isotope analyses.

6 A pre-spiked with 1 N NaOH, 100 ml plastic bottle. Sample required for As and Antimony analyses.

Figure 18 Back row from left to right: Rubber seal glass bottle and 500 ml plastic bottle for raw samples. Middle row: 100 ml plastic bottles for filtered and acidified, filtered, and raw, pre-spiked with 1 ml of 8 N NaOH (As and Sb). Front row: 60 ml syringe, 11 ml glass bijou bottle for isotopes, 47 mm plastic filter holder, 1:1 nitric acid, 47 mm filters (0.45 microns), and small disposable filter unit (with 45 microns filter).

Raw sample collection procedures

The rubber seal and the 500 mL plastic bottle are used to collect raw samples (numbers 1 and 2). Rinse these bottles three times with the sample water prior to being filled and sealed. Make sure that the clamp on the rubber seal is about 2/3 of the way up the rubber in order to allow sufficient room for volume contraction of the hot water.

Filtering

Rinse the interior of the syringe, place the filter holder on the end of the syringe, and then filter 10-20 ml of water to waste before any of the filtered sample goes into the bottle. This applies to every new filter you use. A new filter must be used at each sample site.

Rinse the filtered bottle and cap with a small amount of filtered sample water three times, before being filled with filtered sample water.

Rinse the filtered acidified bottle and cap with filtered sample water three times prior to filling with filtered sample water. Once the bottle is filled to the bottom of the neck with the filtered sample, add 1mL of 1:1 Nitric Acid (HNO_3), to acidify.

Collection of Samples for As and Sb

Fill a 100 ml plastic bottle with a raw sample. Bottle to be pre-spiked with 1 ml of 8 N NaOH. Obviously the bottle is not to be rinsed with the sample in this case.

Isotope Collection

Rinse 3 times and fill a 7 ml or 16 ml glass bijou bottle with raw sample. The bottles need to be overfilled and the metal lid screwed down quickly to try and avoid any air entrapment. Note: The metal lids have a rubber insert.

Labels

Clearly label the bottles with the date of collection, temperature of the sample at collection and the sample location e.g. name of spring.

The filtered and filtered+acidified samples need to be clearly identified with the correct label on the correct bottle, as does the pre-spiked bottle for As & Sb. Use water-insoluble (spirit) marker pen to label the bottles. Printed labels should be covered with cellotape to prevent wear or water damage.