Waikato Regional Council Technical Report 2012/10

The Waikato regional geothermal resource

www.waikatoregion.govt.nz
ISSN 2230-4355 (print)
ISSN 2230-4363 (online)

Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato

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21 March 2012

Document #: 1767056

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Abstract

The Waikato region contains approximately 70 per cent of the nation's geothermal resources. Waikato Regional Council is responsible for sustainable management of the regional geothermal resource. This report provides an overview of the nature, extent and condition of the regional geothermal resource, and its current and potential uses.

1 Management of geothermal resources

The Resource Management Act 1991 (RMA) s30 gives regional councils the control of the taking or use of geothermal energy and water, together with controlling the quantity, level and flow of geothermal water, as well as the control of discharges of contaminants into or onto land, air, or water and discharges of water into water. RMA s30 also confers on regional councils the function of managing indigenous biological diversity.

The legend of Ngatotoirangi describes how geothermal energy arrived in New Zealand and gives a basis for understanding the relationship tangata whenua in geothermal areas have with the resource. Tangata whenua with particular interest in geothermal resources within the Waikato region are people from Waikato-Tainui, Te Arawa, Ngati Tuwharetoa, Ngati Tahu, Ngati Raukawa, Maniapoto and Hauraki.

In recent years, several factors have influenced Waikato Regional Council's understanding of geothermal resources and their management. We have learnt more about the uniqueness and fragility of geothermal features and ecosystems [Parkyn and Boothroyd, 2000; Duggan and Boothroyd, 2001; Duggan and Boothroyd, 2002; Stevens *et al.*, 2003; Wildland Consultants Ltd., 2004, 2006a, 2006b, 2007a, 2007b; Cody 2007; Keam *et al.*, 2005]. At the same time, society is becoming more aware of the value of biodiversity and is placing a greater value on rare ecosystems and their dependent organisms [Department of Conservation, 2000]. In addition, the tourism value of geothermal resources is becoming more important to the people of the region [APR Consultants, 1994; Bay of Plenty Regional Council, 1999; Chrzanowski, 1997; McDermott Fairgray *et al*, 1996; Luketina, 2002]. The adverse effects of some uses of geothermal resources are becoming better understood, and society is requiring that such effects not be placed as a burden on society, but as a cost for those who cause the effects. Sustainability of natural and physical resources is becoming more important and the issues surrounding sustainability are becoming better understood [UNCED, 1992].

2 Description of geothermal resources

2.1 Definitions

Geothermal energy is defined in RMA s2 as: "energy derived or derivable from and produced within the earth by natural heat phenomena; and includes all geothermal water".

Geothermal resources can be divided naturally into management units known as **geothermal systems**. A geothermal system is an individual body of geothermal energy (including geothermal water) not believed to have a fluid connection to any other in the upper few kilometres of the Earth's crust. At greater depths, it is accepted that there is a common heat source, and this is consistent with Māori understanding of the geothermal resource. In some cases there is doubt over the near-surface hydrological separation between particular geothermal systems. A geothermal system may be indicated by geothermal surface features such as an isolated hot spring or set of hot springs, or a much larger set of features. Alternatively, there may be no visible expression at the surface.

All known geothermal systems in New Zealand are hydrothermal systems, i.e. they involve a circulating body of geothermal water that transports heat and minerals from depth to near the surface. Some of this water is discharged to the surface via geothermal features such as springs and fumaroles. There may be other, hidden geothermal systems that do not support hydrothermal circulation. These are known as Hot Dry Rock systems. Overseas, attempts are being made to tap such systems by creating Enhanced Geothermal Systems, in which water is injected into the system via a well, and recovered from another well once it is heated.

The extent of a geothermal system is taken to be the extent of the interconnected bodies of water heated within the earth by natural phenomena to a temperature of 30 degrees Celsius or more. The determination of the land boundaries of geothermal systems is difficult because within the earth the interconnected geothermal water bodies are irregularly located, and horizontal cross-sections at different depths can lie under different areas of land.

The Waikato Regional Plan defines and maps the system boundaries for all known high-temperature geothermal systems in the Waikato region. Council policies and rules relating to use of geothermal resources apply within these boundaries, which are conservatively based on resistivity measurements to 500 and 1000 metres depth, drilling results, location of springs, geology, and all other available geochemical and geophysical data. (Risk 2000a, 2000b, 2003).

Based on the current understanding of the origins of geothermal systems, they can be divided into three types – **magmatic** systems**, volcanic** systems, and **tectonic** systems. In a **volcanic** geothermal system the heat source is active volcanic magma. The heat from a **magmatic** system is believed to derive from a body of magma, or pluton, which has become completely or nearly disconnected from the magmatic core of the Earth and risen close to the surface of the Earth. There may be intrusions of fresh magma from time to time. T**ectonic** systems are associated with areas of above average temperature gradient and active faulting. Hot water may be confined to the fault, with no extensive reservoir of geothermal water associated with the system.

These three types can be divided into **high-** and **low- temperature** systems. Most volcanic and magmatic systems are high-temperature systems but some of the older ones are low-temperature. All the tectonic systems are low-temperature systems.

Most high-temperature systems are **large** in extent. They each cover many square kilometres and extend to depths of several kilomentres. They contain many cubic kilometres of heated rock and geothermal fluid with temperatures of up to 350 °C in the currently accessible upper few kilometres of the system.

Most low-temperature systems are **tectonic** systems that are **small** in extent. In addition to these tectonic systems, some ancient magmatic or volcanic systems have lost most of their heat and now only produce warm water, and are considered to be small systems. Small systems contain small quantities of geothermal water that is generally lower in heat and mineral content. They have few surface features and in general, the surface features are less rare and less vulnerable than those found in the high temperature systems. These systems are nevertheless important culturally, and economically as sources of hot water for bathing. Small geothermal systems are scattered throughout the region, including the Taupo volcanic zone. They generally produce water of less than 100 °C, and are small in area and volume of water discharged.

A large geothermal system may contain more than one geothermal **field**. A geothermal field is an area of separate upflow that may have surface features. For example the Wairakei and Tauhara fields are supported by individual upflows on the Wairakei-Tauhara geothermal system.

Geothermal **features** are defined as surface manifestations of geothermal processes or discharges, including steam-fed features, geothermal water-fed features, and remnant features such as hydrothermal eruption craters and ancient sinters.

They include hot or steaming ground, hot springs and pools, deposits of sinter, sulphur, and other minerals, mud pool, and fumaroles. A feature or **group** of features usually has a thermophilic or thermotolerant ecosystem associated with it. A field may contain many groups of such features, or isolated individual features.

Geothermal features and ecosystems are important for several reasons. Geothermal features and ecosystems are rare, extremely fragile and many are impossible or almost impossible to restore once damaged. They buffer the biosphere from the high temperatures and toxic chemicals in geothermal outflows. As a geothermal discharge flows over sinter terraces, it cools and adds to the sinter, depositing other minerals in the process. Thermally tolerant plants and micro-organisms living in the outflow extract further minerals. The reduced toxicity of the geothermal fluid discharge has enabled other plants, animals and micro-organisms to evolve. Geothermal biota and animals make significant contributions to biological diversity, scientific understanding, scenery, and aesthetic enjoyment. Thermally tolerant plants, animals and micro-organisms also have intrinsic qualities.

Some geothermal systems have many surface features while others have very few or none either because of natural reasons or because their surface features have been irreparably damaged by human intervention. Some geothermal features exhibit a wide range of natural variability in their discharge behaviour and extent of surface expression, while others remain quite stable over years and even decades. Some geothermal features are more highly valued for their natural characteristics, including their biodiversity and intrinsic values, than others. Some are more resilient to human intervention, resource development and land use than others. Some have been severely degraded by human activities, some have been moderately affected, and some are pristine. Although all geothermal features are rare in terms of the area of land they occupy internationally, nationally and regionally, some are more rare than others.

2.2 Characteristics of the regional geothermal resource

Each system, field, and feature has a range of **characteristics**, including energy, mineralised fluids, biodiversity, topography, scenic and recreational values, and cultural values.

The Waikato region's **regional geothermal resource** includes all geothermal water and energy, material containing energy or fluid (derived from within the earth) surrounding any geothermal water, all surface manifestations of geothermal processes, and all plants, animals, micro-organisms and characteristics dependent on geothermal energy, located in the region. This resource occurs throughout the Waikato region, although its surface expression is most concentrated in the Taupo and Rotorua districts (see Map 1, which shows the indicative locations of the regional geothermal resource).

The regional geothermal resource, the individual systems making up the regional resource, and the individual features within those systems each have their own set of geothermal characteristics (see Figure 1).

Characteristics of the regional geothermal resource include:

i) Thermal energy contained in rocks and magma deep in the earth and carried by water
ii) Mineralised fluids (containing e.g. silica, lithium, and boron)
iii) The characteristics of all geothermal systems and features within it including the geophysical and biological features and processes associated with the surface expression of geothermal energy and fluids.

Characteristics of a geothermal system may include:

1) A body of thermal energy contained in rocks deep in the earth and carried by water

2) A convective inflow of cool, fresh water and a consequent outflow of heated mineralised fluids (containing e.g. silica, lithium, and boron)
3) Surface discharges of geothermal heat and mineralised fluids, such as springs and steam features
4) Land formations created by geothermal processes, such as hydrothermal eruption craters and sinter terraces
5) Biodiversity (a variety and uniqueness in genes, species and populations of plants, animals and micro-organisms).

Characteristics of a geothermal feature may include:

a) A surface discharge of steam, water, gases, and minerals
b) A flowing or standing body of water whose origin is either entirely or partly geothermal
c) Time-dependant behaviours such as intermittency of geysers
d) Infrequent or single eruptions such as hydrothermal eruptions and mud eruptions
e) Mineral depositions such as sinters and sulphur crystals
f) Mud volcanoes, mud flows, concentric mud ring patterns
g) Remnant geomorphological features such as hydrothermal eruption craters, geothermal collapse pits and associated caves
h) Heated or chemically altered ground
i) Terrestrial and aquatic geothermal ecosystems influenced by heat, humidity, and water and gas chemistry and flow.

The regional geothermal resource also has intrinsic, amenity, economic, social and cultural values. The extent and variety of natural characteristics of the regional geothermal resource provide a wide range of benefits. At times, geothermal characteristics highly valued by some people are developed at the expense of characteristics that may be highly valued by others. This has led to conflicts and a reduction in the extent and variety restricting the range of benefits available in future.

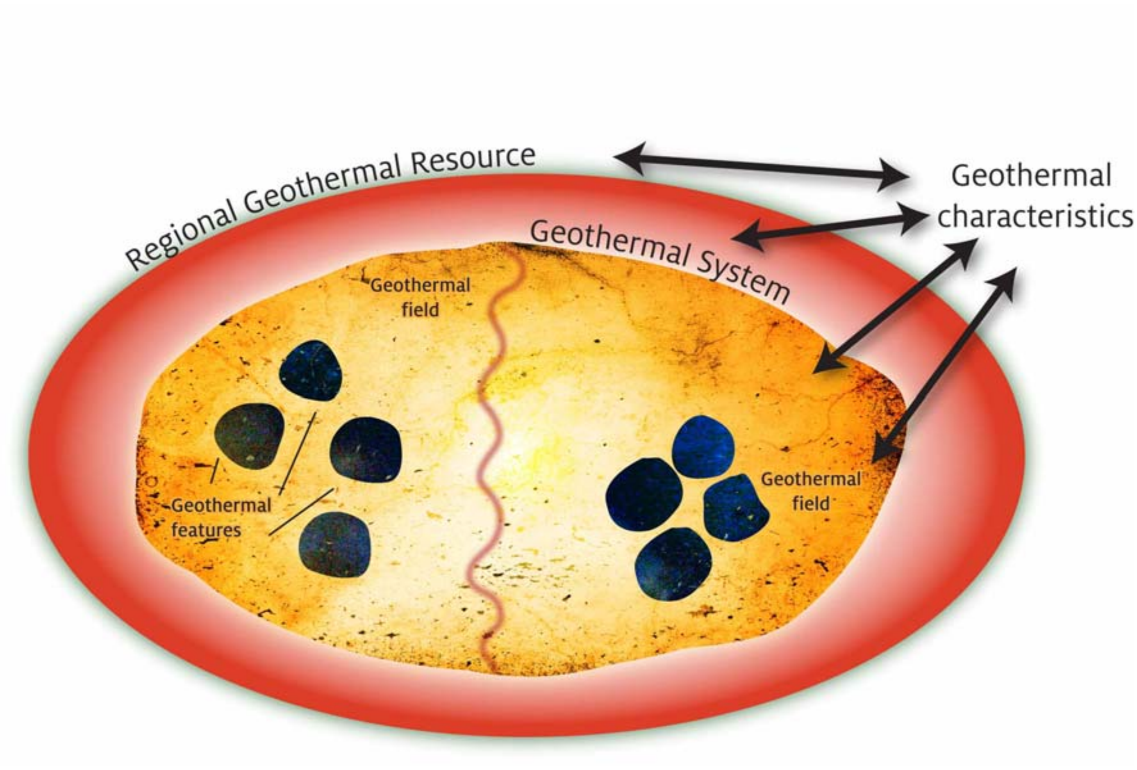


Figure 1: Geothermal geographic terminology

3 Geothermal resources of New Zealand

All but one of New Zealand's high-temperature systems are found in the Taupo Volcanic Zone, a zone of active volcanism that stretches from Mount Ruapehu in the central North Island to White Island in the Bay of Plenty and beyond (See Table 3-1). The Waikato region has 15 known high-temperature systems and the Bay of Plenty region, 5 including Waimangu-Waikite-Waiotapu, which overlaps the boundary between the two regions. The Tongariro Geothermal System extends into Manawatu-Wanganui region. The only other high-temperature system is Ngawha, in Northland.

There are approximately 105 low temperature geothermal systems in New Zealand, with nearly a third of them being in the Waikato region (See Table 3-2).

Table 3-1: High temperature geothermal systems of New Zealand

<table>
<tr><th>Northland</th><th>Manawatu-Wanganui</th><th>Waikato</th><th>Bay of Plenty</th></tr>
<tr><td>Ngawha</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>Kawerau</td></tr>
<tr><td></td><td></td><td></td><td>Rotoma</td></tr>
<tr><td></td><td></td><td></td><td>Rotorua</td></tr>
<tr><td></td><td></td><td></td><td>Tikitere-Taheke</td></tr>
<tr><td></td><td></td><td></td><td>White Island (Whakaari)</td></tr>
<tr><td></td><td></td><td colspan="2">Waikite-Waiotapu-Waimangu</td></tr>
<tr><td></td><td></td><td>Atiamuri</td><td></td></tr>
<tr><td></td><td></td><td>Horohoro</td><td></td></tr>
<tr><td></td><td></td><td>Horomatangi</td><td></td></tr>
<tr><td></td><td></td><td>Mangakino</td><td></td></tr>
<tr><td></td><td></td><td>Mokai</td><td></td></tr>
<tr><td></td><td></td><td>Ngatamariki</td><td></td></tr>
<tr><td></td><td></td><td>Ohaaki</td><td></td></tr>
<tr><td></td><td></td><td>Orakei Korako</td><td></td></tr>
<tr><td></td><td></td><td>Reporoa</td><td></td></tr>
<tr><td></td><td></td><td>Rotokawa</td><td></td></tr>
<tr><td></td><td></td><td>Te Kopia</td><td></td></tr>
<tr><td></td><td></td><td>Tokaanu-Waihi-Hipaua</td><td></td></tr>
<tr><td></td><td></td><td>Wairakei-Tauhara</td><td></td></tr>
<tr><td></td><td colspan="2">Tongariro</td><td></td></tr>
</table>

Table 3-2: Low temperature geothermal systems

(approximate numbers) (from Mongillo and Clelland 1984, Waikato numbers updated)

Region	No. of systems
Northland	5
Auckland	5
Waikato	31
Bay of Plenty	20
Gisborne	1
Taranaki	3
Hawkes Bay	6
Manawatu-Wanganui	1
Wellington	0
Nelson	0
Tasman	0
Marlborough	0
West Coast	21
Canterbury	9
Southland	4
Otago	0
Chatham Islands Territory	0
Total	**105**

4 Geothermal resources of the Waikato region

4.1 Geothermal systems of the Waikato region

The Waikato region contains approximately 70 per cent of New Zealand's geothermal resources, in terms of the number of known high-temperature systems, and in terms of stored heat calculations (Lawless and Lovelock, 2001). There is a clear distinction between the region's large geothermal systems and its small geothermal systems. The large systems are all found in the Taupo Volcanic Zone. The small geothermal systems are scattered throughout the region, including the Taupo Volcanic Zone.

The region contains four active volcanoes (Ruapehu, Ngauruhoe, Tongariro and Horomatangi), but there is only one known large high-temperature volcanic geothermal system, at Tongariro. The nature of the Horomatangi system, within the volcanic crater known as Lake Taupo, is not known. The Ruapehu system, including the crater lake (which sits just outside the regional boundary in the Manawatu-Wanganui region) comprises mainly surface water heated by volcanic gases rising into the lake and is only a few kilometres in extent, but has high temperatures (Ingham *et al.*, 2009). There is no known significant body of geothermal water associated with the only other active volcano in the region, Ngauruhoe. Some of the low-temperature geothermal systems in the Hauraki basin are remnant volcanic systems with a large body of cooling geothermal water (Hochstein, 1979).

There are fifteen known magmatic system systems in the Waikato region if Horomatangi is included. Such systems contain big volumes of highly mineralised water and steam and extend over many square kilometres. They contain large amounts of energy and most have surface features that are significant because of their rarity, vulnerability, and cultural and scientific value.

There are approximately 104 low-temperature systems in New Zealand, with approximately thirty of them found within the Waikato region (Mongillo and Clelland, 1984). Most of the low-temperature systems are found outside the Taupo Volcanic Zone. These systems are discussed below as a group.

Each of the 15 known large geothermal systems within the region is substantially different from the others in terms of its extent and volume, local geology, reservoir dynamics, and surface outflows.

Atiamuri has two large sinter pools in a Department of Conservation reserve. There are several other sinter-depositing springs in nearby farmland, and some that were submerged by the creation of Lake Ohakuri.

Horohoro is a waning system, with few existing surface outflows but large areas of ancient sinter, indicating that it has been substantially more active than it is today. There is a geothermally heated glasshouse growing flowers commercially.

Horomatangi lies under Lake Taupo, which is the caldera of an active volcano. Investigation with a submarine has revealed sinter spires and fumaroles on the bed of the lake (de Ronde *et al.*, 2002).

Mangakino is the western-most large system in the Taupo Volcanic Zone. It also has few surface features, most of which now lie in the bed of the hydroelectric Lake Maraetai. However, it does not appear to be waning in the same way as Horohoro.

Mokai has its main upflow near the Mokai settlement, with a subsurface outflow flowing eleven kilometres north to the Waikato River. It has steam-fed surface features and few natural and physical resources that would be substantially adversely affected by subsidence, should it occur as a result of system development. Mokai system supports a power station and a glass-house complex providing employment for many local people. A milk processing plant using geothermal energy is planned.

Ngatamariki may have a hydrological connection to Orakei Korako. It has unusual travertine sinters, but none of the springs vigorously deposit sinter. Resource consents have been issued for the operation of a geothermal power station.

Ohaaki was developed in the 1970s, but cold water drawdown near production wells has cooled the production aquifer and electricity output is decreasing. Before production commenced there were several geysers and sinter-depositing springs, including the spectacular Ohaaki Ngawha, which is considered a taonga by Ngati Tahu. The flow to these springs was destroyed by development, and now the Ngawha is kept full by a concrete plug and the input of bore water. Production has also increased the surface expression of steam, and an urupa has become the site of new fumaroles. The site of the main Ngati Tahu marae, situated by the Waikato River, is expected to be inundated as a result of subsidence. As well as a geothermal power station, there is a geothermally-heated timber-drying plant at Ohaaki.

Orakei Korako has New Zealand's largest concentration of geysers and sinter-depositing springs, and supports a tourism operation. There are now approximately 35 geysers within the tourist area, but before the creation of hydroelectric Lake Ohakuri drowned a large part of the geyser field, there were approximately 120 geysers.

Reporoa is contiguous with the Waikite-Waiotapu-Waimangu system, and may be hydrologically linked to it. Many of the sinter-depositing springs at Reporoa are adversely affected by drainage of the surrounding land for farming purposes.

Rotokawa supports two power stations. An extensive area of altered ground has been the site of a sulphur-mining operation, and substantial sulphur deposits remain. Rotokawa has a few sinter-depositing springs, and a large area of geothermal vegetation. Lake Rotokawa is the largest geothermal lake in New Zealand, and has been shown to contain what is believed to be a unique species of leech, which is adapted to live in the highly acidic water with a pH of 2.

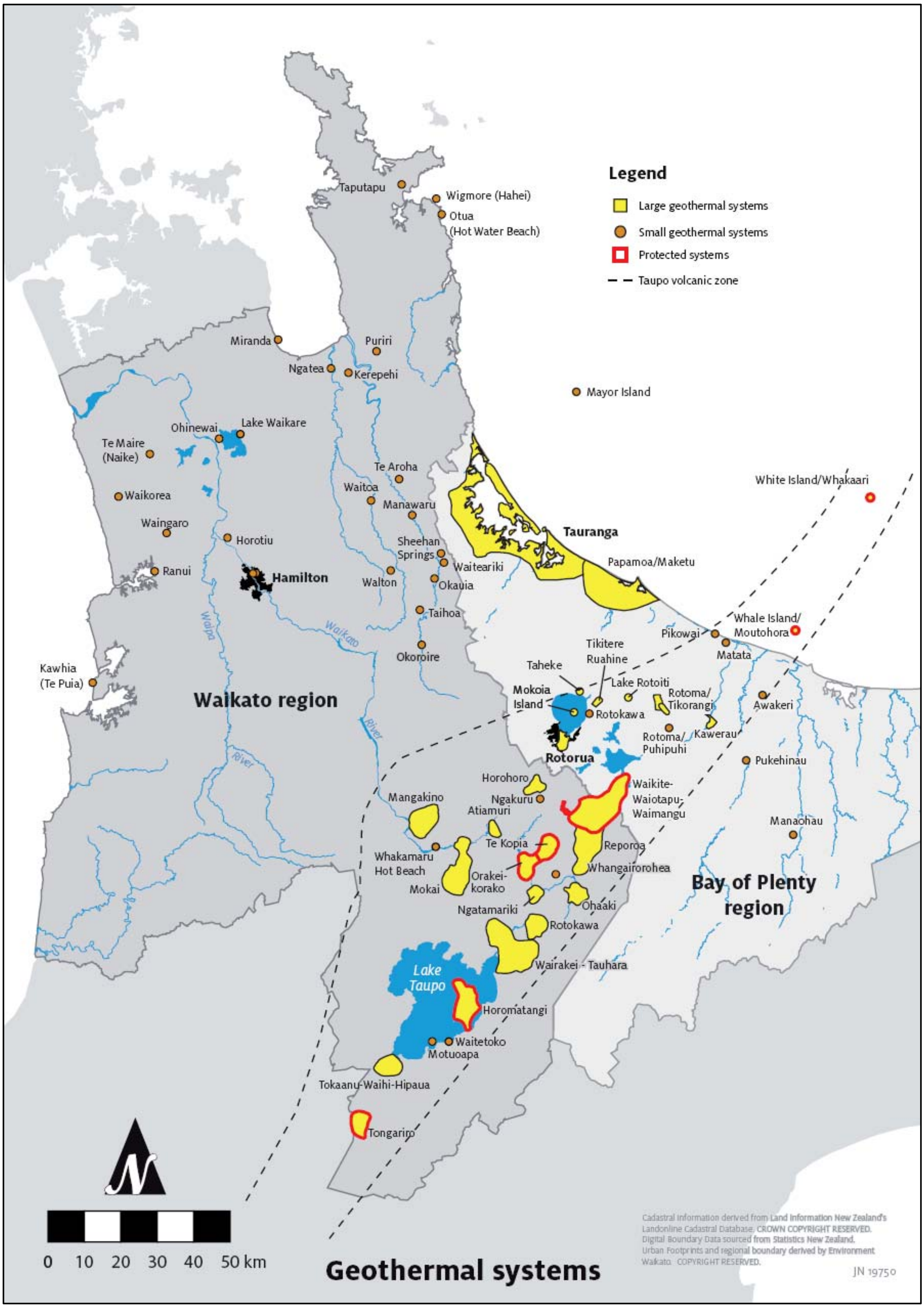
Te Kopia is contiguous with the Orakei Korako system, and may be hydrologically linked. It has a relatively pristine area of geothermal vegetation extending from the base of the Paeroa Scarp to its top, all within a Department of Conservation Reserve and surrounded by mature forest. It has a rare mud geyser and many other pools at the base of the scarp, and several super-heated fumaroles pumping out large volumes of steam at the top of the scarp.

Tokaanu-Waihi-Hipaua has several geysers and sinter-depositing springs at Tokaanu, most of which are in a Department of Conservation reserve. Waihi village also has hot springs at the edge of Lake Taupo, and directly above Waihi there is a large expanse of steaming ground on a steep hillside at Hipaua. This has been the site of several fatal landslides, as chemicals in the geothermal steam destroy the structure of the soil, causing it to slip away and fall onto the village. There are many small uses of geothermal fluid at Tokaanu, including homes, public baths, and accommodation establishments.

Tongariro on Mt Tongariro is New Zealand's only high-altitude geothermal system. There are outflows at Ketetahi, Te Maari, and the Tongariro summit. Ketetahi Springs is a taonga of Tuwharetoa and is on private property surrounded by the Tongariro National Park. Within Ketetahi Springs there are unusual acid geysers, and the geothermal area supports a high-altitude thermophilic midge that is not known to live anywhere else. Tongariro geothermal system extends into the Manawatu-Wanganui region.

Waikite-Waiotapu-Waimangu system has many geysers, sinter-depositing springs, mud pools and other features, including the spectacular Champagne Pool at Waiotapu. There is a large tourist operation on the Waiotapu field, and one of the world's largest bee-keeping operations uses geothermal heat for warming hives and processing honey. Most of the Waimangu field is in the Bay of Plenty region. Waimangu is the youngest geothermal field in the world, having been created in the 1886 eruption of Mt Tarawera. It also has a large tourism operation.

Wairakei-Tauhara once supported two large geyser fields, but the flow to these was destroyed by the geothermal development for the Wairakei Power Station and may also have been affected by works in the bed of the Waikato River associated with the installation of the Taupo Control Gates for hydroelectric developments. In the 1990s the Waiora Lakes, an extensive area of geothermal lakes and pools of different colours in the north-west of the system dried up as a result of hydrological changes induced by development. The Wairakei Power Station has been operating since 1959, and was the second geothermal power station ever built in the world, and the first to tap wet steam. Part of the Wairakei field has experienced subsidence of up to 15 metres as a result of the geothermal development. Some of the Taupo urban area is built over part of the Tauhara geothermal field, and has also experienced subsidence believed to be caused by extraction from Wairakei. There are two power stations operating at Wairakei and resource consents have been issued for another. One power station has been built at Tauhara, and consents granted for a second. Timber processing, a native plant nursery, an orchid growing operation, a prawn farm, and a tourist attraction of artificial sinter terraces all use geothermal fluid and energy. Craters of the Moon and the Wairakei Thermal Valley are tourist attractions on areas of geothermal activity whose discharge has been modified from water discharge to steam as a result of large-scale extraction. There are many geothermally-heated homes, motels, and swimming pool complexes.



Map 1: Geothermal resources of the Waikato region

4.2 Geothermal features of the Waikato region

The Waikato Regional Policy Statement (Waikato Regional Council, 2000) and Waikato Regional Plan (Waikato Regional Council, 2011) define some geothermal features as **significant geothermal features**, based on an analysis of their rarity, vulnerability to changes induced by large-scale geothermal development or caused by other uses of land and water, and to natural influences such as weathering (Keam, Luketina and Pipe, 2005). The definition of significant geothermal feature types is reproduced below in Table 4-1:

Table 4-1: Significant geothermal feature types

Feature type	Definition
Geyser	Any naturally occurring geothermal spring that occasionally or frequently erupts producing an intermittent or continuous discharge by the evolution of a phase dominated by steam or other gases, vigorous enough to eject forcefully liquid water by surging, boiling, throwing, splashing, or jetting it into the air above a static water level or vent opening. This includes hot water geysers, perpetual spouters, soda geysers, and crypto-geysers[1]. The area of a geyser comprises that of the spring basin and the area covered (perhaps intermittently) by surface water composed of the undiluted discharge from the geyser, and by any sinter deposits created by that discharge.
Spring vigorously depositing sinter	Any naturally occurring geothermal spring that vigorously deposits sinter on surfaces covered by its outflow, or any submerged geothermal spring that would be likely to vigorously deposit sinter if it were no longer submerged. The area of a spring vigorously depositing sinter comprises that of the spring basin, together with the area covered by any surface water composed of the undiluted outflow from the pool and any sinter deposits created by that outflow.
Recent sinter	Any sinter body that has received natural sinter deposition since 1900 but which is no longer receiving natural sinter deposition. This includes carbonate sinters (travertine). The area of a recent sinter body consists of that of all interconnected sinter in a single occurrence and the land formations underlying it.
Geothermal habitat on heated ground or cooled acid ground	Any area of terrestrial habitat of thermotolerant indigenous species on current or formerly geothermally heated ground.
Habitat dependent on geothermally-altered atmosphere	Any area of terrestrial habitat of indigenous thermotolerant species that is tolerant of, or dependent on geothermal alteration of, atmospheric conditions.
Mud geyser	Any naturally occurring geothermally heated mud pool that occasionally or frequently erupts. The eruption produces an intermittent or continuous discharge caused by the evolution of a phase dominated by steam or other gases. This must be vigorous enough to forcefully raise liquid mud by surging, boiling, throwing, splashing, or jetting it into the air above a static water level. This includes mud volcanoes exhibiting this behaviour. The area covered by a mud geyser includes the mud pool, its banks, and any mud formations built up by the ejection of mud from the pool.

[1] Crypto-geysers (meaning hidden geysers) are discharging geothermal features that exhibit the characteristic intermittency of a geyser except that they do not project columns or jets of water into the sky. Generally the intermittency is exhibited by regularly fluctuating water levels and discharge rates. Inferno crater at Waimangu is the largest crypto-geyser that we know of, although when we monitor flows on a daily basis on other pools we find there are others, such as the northern Whangapoa Spring.

Feature type	Definition
Molten sulphur-producing spring	A hot spring whose water supply passes through elemental sulphur bearing rock at a temperature sufficiently high to melt the sulphur (119°C) and bring it to the surface.
Superheated fumarole	Any naturally occurring vent, including those found underwater, whose main discharge consists of steam and other gases of geothermal origin with a temperature greater than the local boiling temperature of water. 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 fluid flowing from the vent.
Mud pool	Any naturally occurring basin of turbid water or mud heated (or recently heated) by geothermal processes. The area of a mud pool comprises that of the pool itself, its banks, and any mud formations built up by the ejection of mud from the pool.
Geothermally-influenced aquatic habitat	Any area of naturally occurring seasonal or permanent aquatic habitat of thermotolerant, thermophilic, or extremophilic indigenous species in a water body or part thereof influenced by natural geothermal input, or in a geothermally-influenced water body.
Geothermally-influenced water body	Any naturally occurring wetland, lake, pool, or stream, or portion thereof (including the bed and banks), whose chemical or temperature profile is significantly influenced by natural geothermal input and which is either: • a standing water body of greater than 30m² surface area, or • a flowing water body longer than 100 metres and with a flow greater than 0.1m³/sec in which natural geothermal input has caused the water to have: • a temperature of greater than 30°C, or • a chloride concentration of greater than 120g/m³, or • a sulphate concentration of greater than 60g/m³, or • geothermal mineral deposition, measured at least 7 days after a significant rainfall event. In large or poorly mixed water bodies, only those portions which meet the above conditions are included in this definition.
Hydrothermal eruption crater	Any naturally occurring crater produced by the explosive boiling of geothermal water without the direct involvement of near-surface magma, and by the consequent ejection of material derived from the rock matrix. The area of a hydrothermal eruption crater comprises that of the crater, its sides, and the ejecta deposited around the crater.
Culturally significant feature	Any geothermal surface feature, whether artificial, natural, or modified that is deemed significant following consideration of the criteria for determining significance of cultural heritage resources in appendix 4 of the Waikato Regional Policy Statement.

In addition to the feature types included in the table above because of their relative rarity and vulnerability, a special feature type, “Culturally significant features” is included. This allows for the protection of specific artificial or otherwise non-significant geothermal features that have attained outstanding cultural or scientific importance, according the criteria for determining significance of cultural heritage resources, as set out in RPS appendix 4. An example of a culturally significant feature could be Mokena Geyser at Te Aroha, which is in fact a geysering bore, but which has high scientific, tourist and historical significance.

There are other geothermal features in the region that have not been included as significant. These include but are not limited to:

- fumaroles producing steam of less than 100°C

- heated or steaming ground
- geothermally altered ground
- collapse pits
- geothermal springs or seeps, and
- ancient sinter.

5 Uses of the regional geothermal resource

Uses of the regional geothermal resource include:

a) an important thermal energy source for electricity generation at Wairakei-Tauhara, Ohaaki, Rotokawa and Mokai
b) domestic and commercial space heating by hot water and steam in the Taupo and Tokaanu urban areas
c) domestic and commercially operated thermal bathing pools (e.g. Taupo, Miranda, Te Aroha, Tokaanu, Waingaro, Whitianga and Okauia)
d) commercial hot water operations such as prawn farming at Wairakei, tourism at Wairakei Terraces, commercial glasshouses at Tauhara, Wairakei, Horohoro and Mokai, and timber drying at Ohaaki
e) the scientific study of geothermal features, processes, and ecosystems
f) Māori traditional and contemporary use throughout the region
g) tourist, recreational and scenic attractions
h) a source of micro-organisms for industrial processes.

All of these uses have the potential to increase in scale and to expand into new areas. In addition there is the potential for extraction of useful minerals such as silica, lithium, boron, gold, silver, and zeolites. Sulphur has been extracted at Rotokawa in the past, and may be extracted somewhere in the region in the future.

Geothermal activity has high economic worth, as a source of low-carbon energy and as an important tourist attraction. The regional geothermal resource makes an important economic contribution locally, regionally and nationally.

In 2001 there were more than two million visits to geothermal attractions in the Waikato region (Luketina, 2002) (see Figure 2). A conservative estimate is that this has increased 10 per cent since then. Fifty per cent of visitors to Taupo visit geothermal attractions (McDermott Fairgray Ltd *et al.*, 1996), and 30 per cent of overseas visitors to the country visit geothermal attractions (Ministry of Energy, 1982). In 2007 tourism was worth between $700 million and $800 million to the Waikato region (Phillips, 2009).

Assuming that on average, every visit to a geothermal attraction leads to spending of $50 (including entry fee (when charged), other spending at the site (e.g. food, souvenirs), and a component of overall trip expenses including travel and accommodation, geothermal tourism can be estimated to be worth approximately $110 million to the Waikato region's economy.

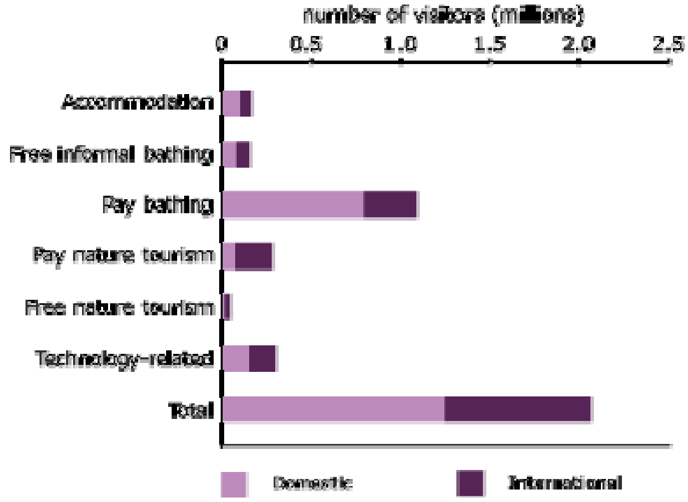


Figure 2: Visitor numbers to geothermal attractions in 2001

Visitor attractions can be managed in accordance with sustainable management principles, protecting and enhancing the geothermal resource and increasing awareness and understanding through education and interpretation. Surface outflows and muds have long been used for health treatments and promoting wellness.

5.1 Large-scale extractive uses

In 2011, New Zealand's total primary energy supply was 817 petajoules (PJ) (Ministry of Economic Development, 2011). Nineteen per cent (153 PJ) of this came from geothermal sources. The Waikato region provides 90 per cent of the primary geothermal energy extracted in New Zealand. While most of this is taken for electricity generation, within the region approximately 50 separate industries, including accommodation and tourist facilities, also take small amounts of heat for direct uses.

In 2011, New Zealand's total electrical energy supply was 162 PJ per year. Geothermal energy from the country's nine geothermal power stations provided 13 per cent (21 PJ) of our national electricity supply (Ministry of Economic Development, 2011). Eighty per cent of this (17 PJ) comes from the seven geothermal power stations in the Waikato region, and based on existing plans for additional power stations, the Waikato region's production of electricity from geothermal sources is expected to double over the next ten years. Geothermal electricity is the lowest cost source of new electricity generation for New Zealand (Denne, 2007).

The electricity generating capacities (median values) from all large geothermal systems in the Waikato region, using a 100 year sustainability period has been calculated by Sinclair Knight Merz (2002) and is listed below in Table 5-1, grouped according to current system status in the operative Waikato Regional Policy Statement and Waikato Regional Plan.

Table 5-1: Generating capacities (median values) for geothermal systems in the Waikato region (adapted from Sinclair Knight Merz, 2002).

Development systems	MWe	Protected systems	MWe	Ltd dev systems	MWe
Horohoro	1	Horomatangi	114	Atiamuri	2
Mangakino	14	Orakei-Korako	33	Tokaanu-Waihi-Hipaua	60
Mokai	42	Te Kopia	29	**Total**	**62**
Ngatamariki	36	Tongariro	30		
Ohaaki	39	Waiotapu-Waikite	102	Research Systems	MWe
Rotokawa	90			Reporoa	13
Wairakei -Tauhara	249				
Total	**471**	**Total**	**308**	**Total**	**13**

The use of geothermal energy for large-scale direct heat use and electricity production displaces the use of the next expensive and readily available source electricity generation, combined cycle gas turbine (CCGT), until the economically available geothermal energy is used up.

The environmental cost from air emissions of CCGT has been estimated at $11.15 per megawatt hour (MWh) (Denne, 2007, Figure 4) compared to zero cost for geothermal electricity generation. While geothermal electricity production does release a small quantity of gases, the report assumes that these gases would be released anyway over time due to natural discharge. This has not been proven, and there is some evidence that increased boiling in the reservoir due to pressure drawdown causes an overall increase in CO_2 discharges (Sheppard and Mroczek, 2002).

In any case, the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009 assign default emissions factors to geothermal electricity producers as net emitters, and Denne's analysis does not take this into account. Notwithstanding these considerations, use of Denne's figures indicate that the environmental air emissions cost to replace the 2008 geothermal energy production of 11.5 PJ or 3.2 million MWh would be $35.68 million a year (Denne, 2007). Replacing the projected doubling of geothermal generation over the next ten years would incur a total of $71.36 million a year.

The production cost of electricity for a CCGT plant has been estimated at $77/MWh compared to $52/MWh for geothermal (Denne, 2007, Table 3). Therefore the production cost to replace the 2008 production of 11.5 PJ or 3.2 million MWh would be $80 million a year. The cost to replace the projected doubling of geothermal generation over the next ten years would be a total of $160 million a year. This assumes a 25 year plant life. Since geothermal plants typically run for longer than 30 years as long as the geothermal field is not exhausted by then, the actual cost of replacing geothermal will be greater, assuming all the other assumptions made in the analysis are valid.

However, since available geothermal energy in a particular reservoir is a finite resource if the rate of energy take is greater than energy input through conductive or advective recharge, it can only displace the use of fossil fuels until all economically available geothermal energy in that reservoir is used up. Innovations in geothermal exploration, drilling, reservoir management and energy conversion techniques can enable access to more geothermal energy.

Besides large uses, there are many other potential and existing smaller uses of geothermal energy and fluid that can be undertaken in these systems. However, some of the existing uses are productively inefficient because for technical reasons it is often easier to keep wells producing continuously, and they take and discharge more fluid than is needed for the purpose. In many cases, a single well can provide sufficient energy and fluid for the needs of several households. In cases where only heat, rather than heat and fluid, is required, the use of down-hole heat exchangers is a far more efficient use than taking and discharging fluid. While not having an effect on the deep aquifers, this can adversely affect the sustainability of the shallow aquifers that they take from, and associated geothermal features.

5.2 Adverse effects on geothermal features

In some cases large-scale extraction of energy and fluid has led to the demise of geysers, and to large scale increases in heat flow. Many significant geothermal ecosystems have been extensively modified or destroyed as a consequence although reinjection can reduce the damage and sometimes partially reverse it. There is no documented evidence to suggest all damage is reversible; instead new flow regimes occur, and introduced species invade the modified habitats. Extraction can also increase the rate of steam discharge, enhancing steam-fed features such as hot ground and fumaroles. Where new surface outflows have occurred, existing land use has prevented or retarded the establishment of geothermal ecosystems. As a result, natural geothermal ecosystems are extremely rare.

Already most of the region's geothermal features have been lost or degraded as a result of major electricity developments, either hydroelectric or geothermal. Most of the geysers at Orakei Korako are now underwater as a result of the creation of the hydroelectric Lake Ohakuri. Figure 3 shows the decrease in numbers of sinter-forming springs and geysers since the 1940s.

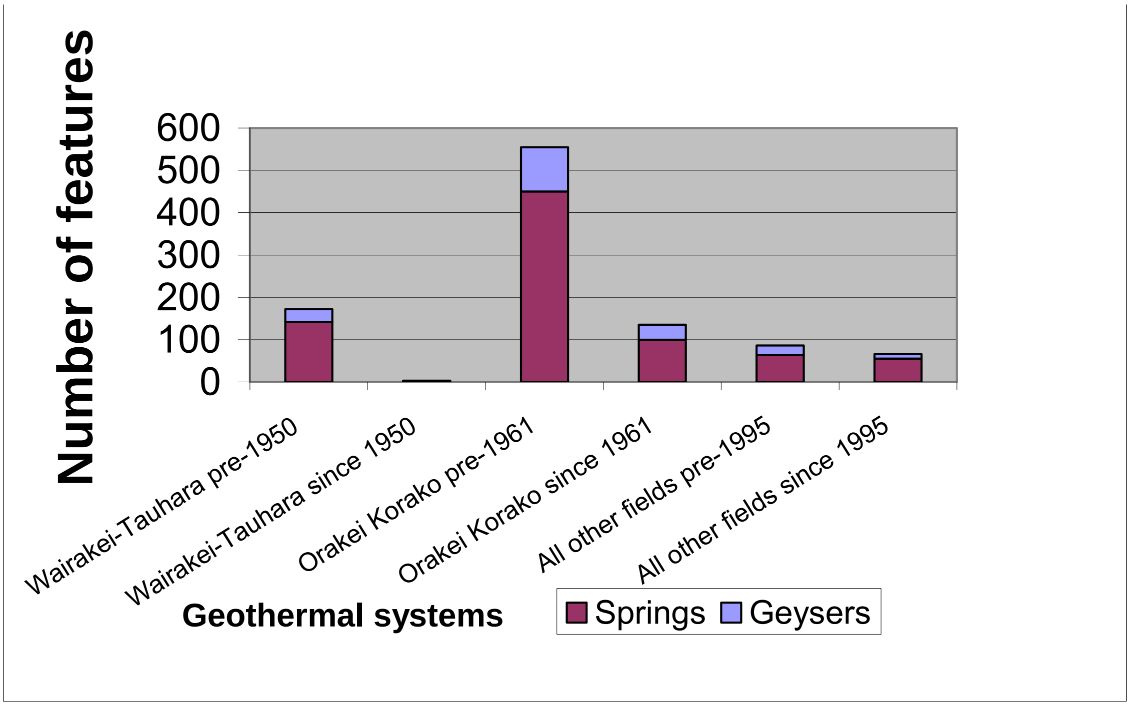


Figure 3: Decrease in sinter-forming springs and geysers since 1950

Many highly valued characteristics of geothermal systems and their surface features and dependent ecosystems are either under threat or already adversely affected from inappropriate use of the surrounding land. For example, at Reporoa, land drainage for farming has caused some sinter-depositing springs to cease discharging. Forestry in geothermal areas can lead to geothermal features being damaged by trees falling into them and harvesting machinery destroying delicate sinter terraces. Allowing livestock or vehicles access to geothermal features, or using geothermal features as rubbish dumps can lead to a range of adverse effects including the crushing of fragile sinters and rare native plants, animals and micro-organisms. Spray drift and surface run-off can damage vegetation buffer zones and contaminate geothermal surface water, harming or destroying the native thermophilic ecosystems.

Land uses associated with the operation of a geothermal power station, such as roading and tracking, and the placement of bores, pylons, buildings, dumps, and other infrastructure, can destroy or adversely affect geothermal features if they are placed on or near them.

Geothermal tourism can lead to littering and vandalism. Building access roads, or paths for the tourists to walk on, can lead to contamination of pools and sinter by paving materials such as gravel. Native vegetation, including thermophilic species can be destroyed or contaminated with adventive exotic species. In some cases features are drained or flows altered in order to preserve the paths that lead to or near them.

Subdivision and land development can restrict or prevent access to, and efficient use of, the geothermal resource.

5.3 Adverse effects on the environment from extractive uses

The life-supporting capacity of air, water, soils, and ecosystems can be degraded by artificial inputs of geothermal water, heat, and contaminants. Rivers and aquifers used for drinking water can have their water quality adversely affected, and river ecosystems can be degraded.

Although there is some natural discharge of geothermal energy and fluids into the Waikato River, artificial discharge, mainly from the Wairakei Power Station, has increased the concentrations of mercury, arsenic and boron in the water, and increased its temperature. This has long-term and short-term adverse effects on water quality and the riverine ecosystem. As a result of the combined effects of the natural and artificial geothermal discharges, and impoundment of water in the dams in the Waikato hydro-electric system, the beds of most of the Waikato River hydro-electric dams have high concentrations of arsenic in their sediments and have been officially classed as contaminated sites (Huser 2005). Some aquatic weeds and sediments harvested from the lakes for maintenance purposes have to be disposed of in dedicated landfill sites due to their high arsenic concentrations.

At times, and in various locations, particular uses of geothermal resources have adverse effects on land uses. Large-scale extraction of geothermal fluid from geothermal systems has caused land subsidence, leading to loss of productive and culturally important land through flooding and change in contour, and damage to buildings and infrastructure. For example, large-scale geothermal fluid extraction at Wairakei-Tauhara and Ohaaki has led to land subsidence.

Extraction can also increase the rate of steam discharge through geothermal ground, increasing land instability and leading to hydrothermal eruptions, landslides, and the creation of tomos. In some cases increased steam discharge, through the ground and infrastructure such as steam separators, pressure valves and cooling towers can cause steam hazards across roads and alter the microclimate in low-lying areas.

Shallow reinjection at various geothermal fields has led to increased discharge from springs, and ground inflation, both of which can cause property damage and adverse effects on existing land uses.

6 Sustainability, renewability & efficiency

Section 2 of the RMA (1991) defines energy produced from geothermal sources as renewable energy and section 7(j) requires particular regard to be had to the benefits to be derived from the use and development of renewable energy. These benefits include a reduction in the use of fossil fuels for electricity generation and hence a reduction in greenhouse gas and some other emissions (Denne, 2008) and its reliability independent of climatic conditions.

Renewability and sustainability are two different concepts. For an energy source, renewability describes a property of the resource, whereas sustainability relates to how the source is used [Stefansson, 2000; Thain, 2003]. For an energy source to be considered renewable, the rate of input of energy must be the same or greater than the rate of extraction over the period of renewability (see figure 2). When discussing the renewability of any energy source, the timeframe for renewability needs to be specified. For example, coal deposits are renewable over geological ages, but not over a human timeframe.

In the case of electricity generation from a hydrothermal system, the rates of extraction of energy and fluid from the accessible reservoirs are generally far greater than the natural recharge rate. Recovery of the reservoir to the pre-extraction baseline is expected to take hundreds or thousands of years [Pritchett, 1998]. Therefore, the timeframe for renewability of geothermal resources is far greater than for other energy sources also considered renewable in section 2 RMA (1991) such as wind, wave, solar, hydro and biomass.

Studies show that the durations of typical hydrothermal systems range from 5,000 to 1,000,000 years [Thain, 2003]. During this time repeated pulses of heat may pass through the system for a time, and the area may retain some heat continuously for longer periods. These conditions may lead to temperature fluctuations and hydrodynamic variations during the history of the system. During a period of 1,000,000 years, erosion, deposition, and tectonic processes may also affect the hydrology of a geothermal system. On a geological timescale high temperature individual geothermal systems are essentially ephemeral.

Most energy sources generally classed as renewable are either essentially unaffected by use (solar, wind, wave, tidal) or take no more than a few years to recover their energy-producing capacity (hydro, biomass). However, extraction of the fluid and energy in a geothermal system beyond the natural rate of discharge depletes the usable resource found within the upper aquifers. Recovery of a severely depleted aquifer by the replenishment of fluid and energy from lower depths to a point where it is economic to resume some production is expected to take a similar duration to that of the initial production [Pritchett, 1998; Ledingham, 1998; Rybach *et al.*, 2000].

Any large-scale extraction of geothermal fluid and energy at a rate equal to or greater than the rate of renewal will inevitably affect any dependent ecosystems. It also can destroy geothermal surface features. However, if the extraction of energy from a geothermal system, is less than this, then only extremely small developments could proceed. Much of the resource would therefore not be available for extractive use by current, and the next few, generations. Such a restrictive management regime would not promote sustainable management of the regional geothermal resource.

Total reinstatement of the heat and mass flux regime within a depleted geothermal system is theoretically possible only after an infinite time, but recovery to about 98 per cent of pre-production rates will take hundreds of years (Luketina, 2005). Figure 4 shows the projected response of the springs at Geyser Valley, Wairakei from continued large-scale take from the field until 2050 followed by cessation of take (from O'Sullivan and Mannington (2005))

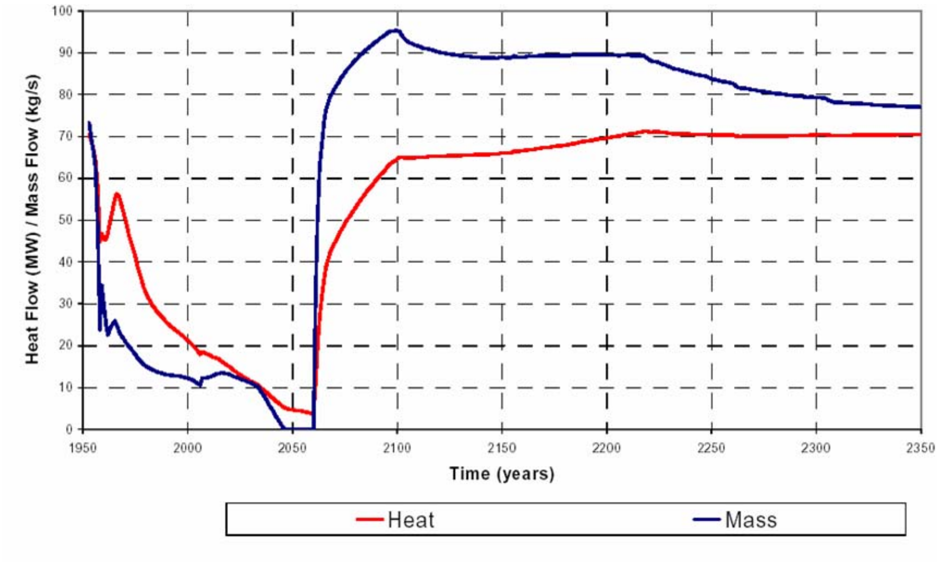


Figure 4: Heat and mass flows at Geyser Valley

Sustainability can refer to either weak or strong sustainability. Strong sustainability requires no loss of natural resources, and thereby provides future generations with at least the opportunities of today's generation. However, weak sustainability allows the depletion of some natural resource stocks, as long as future generations will still be at least as well off as today's generation, through technological change and the like.

Geothermal resources can be used sustainably (using a definition of weak sustainability) over any given period through controlled depletion. As with renewability, the timeframe for sustainability must be specified (see Figure 5). To sustain the energy-producing potential of a geothermal system to meet the reasonably foreseeable needs of future generations, extraction must be at a rate that can be maintained by those future generations. The depletion of the available energy and fluid in a geothermal reservoir within one or two generations, leaving the reservoir in a state where recovery of natural outflows will take hundreds or thousands of years, falls short of sustainable management of the resource.

In addition, it is desirable that the use of the resource is efficient, otherwise more resources will be demanded than is necessary for a given purpose, and additional environmental costs may occur. Another issue with sustainability is need versus luxury, and the continued demand for a higher standard of living, with a concomitant demand on energy sources and other resources.

The rate of conversion of heat and kinetic energy from geothermal fluid to electricity ranges from about 8 per cent for older power plants to 21 per cent for more efficientmodern plants. As a general rule, no more than approximately 10 per cent of the heat and kinetic energy in geothermal fluid is converted to electricity [Sinclair Knight Merz, 2002].

For various reasons it is impractical or uneconomic to extract the remaining energy for electricity production, although in some cases it is used for direct heat applications. The used geothermal fluid is then either reinjected into the geothermal system or injected into the ground just outside the geothermal system, where it can be entrained into the convective cycle again. This helps to maintain reservoir pressures at an optimal level that balances recharge and limits adverse effects such as subsidence and changes in surface features. If discharged elsewhere, generally to surface water or onto the ground, the energy, fluid and minerals are lost from the geothermal system and may contaminate natural and physical resources. Therefore, reinjection into the system, or into an area where the fluid will find its way back into the system, is usually more energy-efficient than other discharge methods. It also has the added benefit of maintaining reservoir pressure, thus limiting other adverse effects such as subsidence.

In addition to the energy equation aspect of sustainability, environmental sustainability is concerned with the maintenance of processes on which all life depends. The OECD [2001] has identified four specific criteria that need to be met to ensure environmental sustainability.

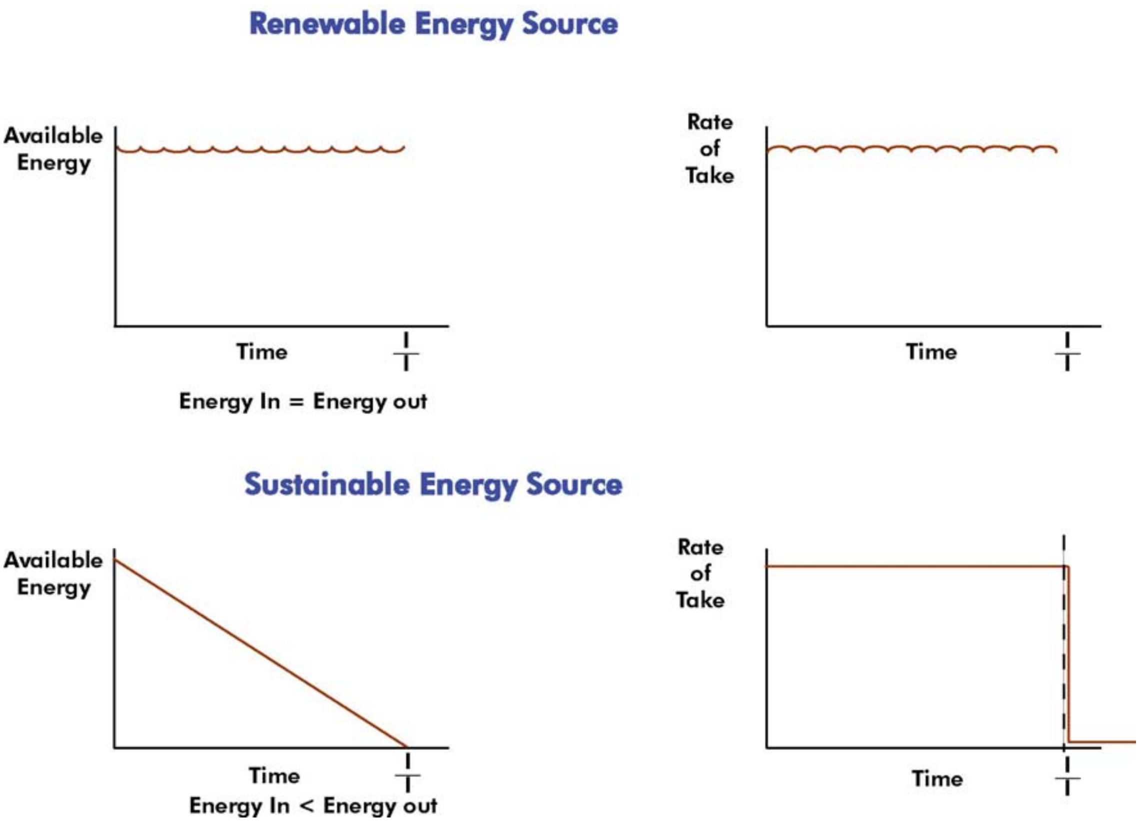


Figure 5: Renewable and Sustainable Energy Sources

These are:

1) regeneration: using renewable resources efficiently and not permitting their use to exceed their long-term rates of natural regeneration
2) substitutability: using-non-renewable resources efficiently and limiting their use to levels that can be offset by substitution of renewable resources or other forms of capital
3) assimilation: not allowing releases of hazardous or polluting substances to the environment to exceed the environment's assimilative capacity
4) avoiding irreversibility: avoiding irreversible impacts of human activities on ecosystems

However, the principles of sustainable management applied to the geothermal resources of the region take into account a great deal more than the ability to extract energy and water over a particular period, from a single system. From a regional perspective, sustainable management can be promoted by balancing resource demands across the region to provide for social, economic and cultural well-being whilst avoiding, remedying, or mitigating adverse effects. Some systems are allocated for efficient energy use and development whereas other systems will be protected from large-scale use and development. This is the approach of this section of the Regional Policy Statement, which sets out a range of classifications for geothermal systems.

Efficient use of energy, as required by section 7 of the RMA (1991), includes several dimensions: productive efficiency (output at a low overall cost); allocative efficiency (allocating resources to production that society values the most); and dynamic or innovative efficiency (where technological change is encouraged and used to produce productivity gains). Conflicting and unclear objectives can lead to wasteful take and discharge resulting in greater loss of heat and fluid than would otherwise be required for the purpose. This is inconsistent with sustainable management and the principle of productive efficiency. Wasteful use can also occur, with geothermal resources being used in the place of more appropriate sources of heat, water, or minerals. This can deprive current and future generations of the ability to use the resource appropriately, and is inconsistent with the principle of allocative efficiency.

6.1 Reinjection and injection

The major portion of geothermal energy is stored as heat within rocks and is primarily accessed through the extraction of geothermal water. The portion of extracted geothermal resource that is not used is discharged to the environment, typically by reinjection of the used fluid back into the geothermal system so that the remaining energy and fluid can be recirculated and used to maintain reservoir pressures.

Targeted reinjection to the system can also sustain reservoir pressures and minimise subsidence, the risk of hydrothermal eruptions, and adverse effects on geothermal surface features.

Once used in a primary process such as electricity generation, a geothermal resource may be of value to secondary, downstream industrial and/or domestic processes. Such a cascaded use of the resource contributes to the efficient use and development of that resource. However, where reinjection or injection is practised, the fluid may need to remain above a certain temperature or pH to prevent deposition of minerals leading to clogging of pipes.

In some cases, particularly where the natural fluid of a geothermal system has been depleted by extraction without reinjection, injection of additional fluid to the system can assist use of the resource by providing a greater volume of extracted fluid from which to extract the energy resident in the system. This additional fluid can be water from any source including fresh water, wastewater, and sea water.

Some geothermal systems consist of hot dry rock with little or no convective cycle bringing hot fluid to the surface. The heat from these systems can be accessed by injecting water or gas and creating an artificial convection cycle by means of wells. While none of the systems have been identified in the Waikato region, it is appropriate to allow for the possibility that they may be in the future.

When energy and fluid are extracted from a geothermal reservoir, the geothermal fluid transports energy during the extraction and replenishment processes. The fluid is replenished by natural upflows, reinjection, and sometimes by an artificial increase in fluid flow as a result of extraction. Provided appropriate management approaches are used to avoid significant land disruption, reservoir cooling and other adverse effects, reinjection can be beneficial by avoiding or mitigating land subsidence reducing the discharge to other natural and physical resources, and helping to sustain the natural flow to geothermal features.

The use of a geothermal system involves control of the interactive dynamic flows of energy and fluid through subterranean material with highly variable properties over areas of tens of square kilometres, to depths greater than five kilometres. This control requires input from many specialised technical disciplines, precise location of fluid takes and discharges, and long-term planning and investment.

6.2 Information management

Sustainable management of a resource requires understanding of the characteristics of that resource. Management of the resource is improved by greater availability of relevant information.

The nature of the geothermal resource is such that there is a relative lack of knowledge. Surface features, where they exist, provide only a very small indication of the extent of the resource and its hydrodynamic characteristics. Geophysical and geochemical techniques, as well as an understanding of the local geology, must be applied to enable understanding of the resource. However, the level of knowledge varies from system to system.

Previously, much of this data and information has not been readily accessible to the public either because of the limitations of the information systems or because of the format in which the information has been presented. In addition much data and information about the regional geothermal resource that was collected by the government using public funds is now retained in confidence by the government as a commercial asset, as is most new data collected. The unavailability of this data and information to regional and local authorities, to the public (including independent researchers) and to resource users creates uncertainty in decision-making, limiting the opportunities for use of the regional geothermal resource. It also can lead to higher costs for ratepayers and resource users through duplication.

Efficient use of the regional geothermal resource involves the efficient extraction (take) from the resource and the efficient application (use) of what is taken. Efficient take of geothermal fluid and energy in a development system is generally encouraged by:

a) integrated and co-operative development of the geothermal system
b) the absence of competitive extraction of fluid or energy from the system
c) consent conditions that reduce environmental risk and provide certainty
d) effective and efficient monitoring and evaluation of the resource state
e) a publicly agreed staged-development plan for each geothermal system spanning short, medium and long term time frames, and
f) public access to peer reviewed resource models, predictions, development scenarios and data.

Efficient use of the taken resource is encouraged by:

a) competition for the extracted resource (e.g. fluid and energy), and
b) security of supply.

The geothermal resource is different from other resources because:

a) knowledge of the resource is usually very limited – especially at the early stages of development
b) geothermal systems are extremely complex, dynamic and interconnected
c) geothermal systems are unobservable and relatively inaccessible
d) geothermal cause and effect relationships are not usually well understood (but becoming better understood over time), and there is often a considerable time delay between cause and effect
e) the costs and risks of developing geothermal systems are very high.

Consequently "ideal" solutions are uncertain because of the lack of understanding of the functioning of a system. Early stages of development will have a strong element of trial and error, and require iterative approaches. As more information is collected, system operations can be better designed to optimise efficiency. This relies on, and assumes, good physical access to all of the land above the resource. Limitations to land will potentially affect the operator's ability to optimise efficient system development.

The inaccessibility of geothermal systems means that knowledge comes from surface features, surveys (especially geophysical) and from data at certain points within the system. Data is then modelled, and only allows tentative conclusions. As the system is developed, knowledge increases, as more data is available for modelling. This lack of certainty is exacerbated by technical disagreements between experts. This has implications for identifying the effects of using the resource, but also for the developer to optimise production.

Adverse effects of take, use and discharge of the geothermal resource are difficult to assign to one of multiple operators because of uncertainty around cause and effect relationships. Remedying adverse effects relies on a co-ordinated and integrated approach and understanding. Again, land access will affect the effectiveness of response.

Good quality data and information is essential for robust policy development and good decision-making.

Under RMA s35, regional councils have a duty to gather information regarding the state of the environment, and to keep records of that information. For that reason, Waikato Regional Council undertakes monitoring and investigation into the extent, variety and condition of the regional geothermal resource and its characteristics, and into the effects of geothermal resource use on the resource and other natural and physical resources. This material has been collected under a wide range of conditions, for various purposes, and over time by developing technologies.

Much geothermal resource data and information has already been collected, and will be collected by resource consent holders. It is important that information derived from this data is peer reviewed to ensure that interpretations (including models and scenarios) reflect expert consensus rather than a high risk or extreme position. It is also important that different interpretations of the data are encouraged, to avoid assumptions becoming entrenched without question.

Collection, maintenance and dissemination of geothermal information are critical for effective resource management, both regionally and nationally. Transparent public access to geothermal resource data and information can promote public confidence in management and foster public appreciation of the resource.

7 Waikato Regional Council reports

In addition to reports generated by such entities as Crown Research Institutes and universities, below is a list of topics showing reports that have either been completed in recent years by or for Waikato Regional Council in respect of geothermal resources. Full bibliographical reference to these documents is in the bibliography.

- **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.
- **Condition and activity of Springs:** From 1995 to the present and ongoing Waikato Regional Council has monitored the behaviour and condition of geothermal springs in the Waikato region and produced annual reports. (Cody 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005; Lynne 2007b, 2008, 2009; Newson 2010, 2012).
- **Earth Science Bibliography:** W.A. Hampton, K.A. Rogers, and P.R.L. Browne (2001): *Geothermal Activity (Past and Present) in the Waikato Regional Council 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.

- **Economic Value to the Regional Economy of Different Uses of Geothermal Resources:** Barns and Luketina, 2011: *Valuing uses of the Waikato regional geothermal resource* provides survey results of the number of visitors to geothermal attractions, at usage rates of geothermal energy for tourism, direct heat applications, and electricity production, and compares the economic contribution of each usage type.
- **Geochemistry:** A geothermal geochemical monitoring programme (REGEMP) for the Waikato region was developed and commenced in 1996 (Huser and Jenkinson, 1996). In 2007 it was revived (Luketina, 2007), with a two-yearly sampling period (Webster-Brown JG, Brown KL, 2008, 2010 (in prep.).
- **Hydrothermal Eruption Craters:** Bridget Y. Lynne, (2007a): *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.
- **Locations of Springs:** In January 2007 Waikato Regional Council monitoring staff visited a selection of geothermal springs and streams in 9 locations to describe and map the features for Regional Plan purposes (Holwerda and Blair, 2007).
- **Resource Capacity:** Sinclair Knight Merz 2002. *Resource Capacity Estimates for High Temperature Geothermal Systems in the Waikato Region* uses stored heat calculations to estimate the amount of available energy in each of the 15 large geothermal systems in the Waikato region.
- **Significant Geothermal Features:** R.F. Keam, K.M. Luketina and L.Z. Pipe (2005): *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.
- **Vegetation:** Wildland Consultants Ltd 2011. Geothermal Vegetation of the Waikato Region - an update based on 2007 Aerial Photographs. 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.
- **Vegetation Restoration and Protection:** Wildland Consultants Ltd 2011. Priorities for Pest Plant Control, Pest Animal Control, and Fencing at Geothermal Sites in the Waikato Region - 2011 Update 2011/28. 27 p. This prioritises all geothermal vegetation sites for protective intervention.

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