GEOTHERMAL OVERVIEW REPORT

1991

THE BAY OF PLENTY REGIONAL COUNCIL

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GEOTHERMAL

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INTRODUCTION

1.1 OBJECTIVES

The objective of the Geothermal Overview is to provide the Bay of Plenty Regional Council (BOPRC) with a review of:

i) geothermal legislation;
ii) physical basis of geothermal resources;
iii) geothermal values;
iv) geothermal impact and management;
v) available data pertaining to geothermal fields, areas and prospects in the Bay of Plenty;
vi) geothermal monitoring.

1.2 LEGISLATIVE BASIS

Historically, responsibility for and management of geothermal resources had been divided between a number of Acts and various authorities.

The two major Acts previously controlling geothermal resources were:

i) Geothermal Energy Act 1953;

ii) Water and Soil Conservation Act 1967

Other Acts of minor significance to geothermal management were:

a) Health Act 1956;

b) Reserves Act 1977;

c) Town and Country Planning Act 1977.

1.2.1 Geothermal Energy Act 1953

This concerned the safety of bores, licensing of bores, collection of resource rentals and closure of bores. The statutory authority was the Ministry of Energy. This Act also defined geothermal water as that which had been heated to greater than 70°C.

1.2.2 Water and Soil Conservation Act 1967

This Act placed the management of the nation's water resources under the control of Regional Water Boards. The major management tool was the water right. In respect of geothermal water, the legislation required:

1. All abstractors and users of geothermal resources (excluding domestic) to hold water rights;

2. All geothermal discharges to be controlled by water rights.

The major problem was that water required for reasonable domestic needs was exempted from control by the water right process. This meant that geothermal fluid abstracted for domestic purposes or for use in heat exchangers could not be controlled. The Bay of Plenty Catchment Commission faced this problem in regard to management of the Rotorua Field where the majority of geothermal use was for domestic purposes. An amendment to the Act in 1981 clearly defined geothermal fluids above 70°C as water resources and thus under the control of Regional Water Boards.

1.2.3 Resource Management Act

The Resource Management Act (enacted 4 July 1991 but not operative until 1 October 1991) has clearly redefined and reorganised the management of geothermal resources. The following discussion highlights those sections of the Act which are of relevance to geothermal resources and geothermal management.

1.2.3.1 Definitions

The Act defines the meaning under the Act of various terms. Those relating to geothermal resources are listed below:

Contaminant: any substance (including gases, liquids, solids, and micro-organisms) or energy (excluding noise) or heat, that either by itself or in combination with the same, similar, or other substances, energy, or heat

a) When discharged into water, changes or is likely to change the physical, chemical, or biological condition of the water: or

(b) When discharged onto or into land or into air, changes or is likely to change the physical, chemical,or biological condition of the land or air onto or into which it is discharged:

Fresh water:	all water except coastal water or geothermal water.
Geothermal energy:	energy derived of derivable from and produced within the earth by natural heat phenomena. and includes all geothermal water.
Geothermal water:	water heated within the earth by natural phenomena to a temperature of 30 degrees Celsius or more: and includes all steam, water and water vapour, and every mixture of all or any of them that has been heated by natural phenomena.
Kaitakitanga:	exercise of guardianship; and, in relation to a resource, includes the ethic of stewardship based on the resource itself.
Mineral:	a naturally occurring inorganic substance beneath or at the surface of the earth, whether or not under water; and includes all metallic minerals, non-metallic minerals, fuel minerals, precious stones, industrial rocks and building stones, and a prescribed substance within the meaning of the Atomic Energy Act 1945.
Natural and physical resources:	land, water, air, soil, minerals, and energy, all forms of plants and animals (whether native to New Zealand or introduced), and all structures.
Natural Hazard:	any atmospheric or earth or water related occurrence (including earthquake, tsunami, erosion, volcanic and geothermal activity, land slip, subsidence, sedimentation, wind, drought, fire, flooding) that adversely affects or may adversely affect human life, property, or other aspects of the environment.
Tikanga Maori:	Maori customary values and practices.
Treaty of Waitangi:	As defined in section 2 of the Treaty of Waitangi Act 1975.

Water: (a) Water in all its physical forms whether flowing or not and whether over or under the ground;

(b) includes fresh water, coastal water and geothermal water;

(c) does not include water in any form while in any pipe, tank or cistern.

Water body: fresh water or geothermal water in a river, lake, stream, pond, wetland, or aquifer, or any part thereof, that is not located within the coastal marine area.

1.2.3.2 Purposes and Principles

The Act describes the purpose and principles of the Act. Those which are related to geothermal resources and management are:

5. Purpose - The purpose of the Act is to promote the sustainable management of natural and physical resources.

6. Matters of national importance - All persons exercising functions and powers under it [the Act], in relation to managing the use, development, and protection of natural and physical resources, shall recognise and provide for the following matters of national importance:

   (b) The protection of outstanding features and landscapes from inappropriate subdivision, use and development;

   (c) The protection of areas of significant indigenous vegetation and significant habitats of fauna;

   (e) The relationship of Maori and their culture and traditions with their ancestral lands, water, sites, waahi tapu, and other taonga.

7. Other matters - All persons exercising functions and powers under it [the Act], in relation to managing the use, development and protection of natural and physical resources, shall have particular regard to -

   (a) Kaitiakitanga;

   (b) the efficient use and development of natural and physical resources;

(d) Intrinsic values of ecosystems;

(e) Recognition and protection of the heritage values of sites, buildings, places or areas;

(f) Maintenance and enhancement of the quality of the environment;

(g) Any finite characteristics of natural and physical resources.

8. Treaty of Waitangi - In achieving the purpose of this Act, all persons exercising functions and powers under it, in relation to managing the use, development, and protection of natural and physical resources, shall take into account the principles of the Treaty of Waitangi (Te Triti o Waitangi)

1.2.3.3 Functions of the Regional Council in respect of geothermal areas

The Act lists the functions of the Regional Councils under the Act. Those functions which directly involve geothermal resources are:

30 (1) (a) The establishment, implementation, and review of objectives, policies and methods to achieve integrated management of the natural and physical resources of the region:

30 (1)(b) The preparation of objectives and policies in relation to any actual or potential effects of the use, development, or protection of land which are of regional significance.

30 (1)(c)(iv) The avoidance or mitigation of natural hazards.

30 (1) (e) The control of the taking, use, damming, and diversion of water, and the control of the quantity, level, and flow of water in any body including-

(iii) The control of the taking or use of geothermal energy.

1.2.3.4 Discussion

The redefinition of geothermal water as that above 30°C has tidied up a grey area in dealing with natural waters with elevated temperatures. It has, however, meant that warm waters (as result of conductive heat transfer rather than magmatic influence) are now defined as geothermal. This overview therefore includes those warm water resources as part of the geothermal resources of the Bay of Plenty.

The inclusion of heat, water and energy under the control of the Regional Council will now allow proper control and effective (as well as legal) management of the geothermal resource. Every licence under the Geothermal Energy Act 1953 and authorisations under s. 9(1)c and authorisations under s. 11 of that Act shall, to the extent that it licences or authorises the taking, tapping use or application of geothermal energy shall be deemed either a coastal permit or water permit under the Resource Management Act.

The specific references to protection of outstanding landscapes and areas of significant indigenous vegetation will require Council to carefully consider the unique nature of geothermal areas.

The function of the Regional Council in respect of mitigation of natural hazards has geothermal implications for Council. Geothermal areas are notoriously unstable. Development in the past has seen former active areas infilled and subsequently developed for housing and commercial purposes. Consequently events such as hydrothermal eruptions can cause significant damage. As the geothermal pressures and water levels rise in the Rotorua area as a result of the Bore Closure programme, such hydrothermal eruptions are expected to become more common.

The most important feature of the legislation is the requirement to consider the principles of the Treaty of Waitangi and the relationship between Maori and their culture and traditions with ancestral lands, sites, waahi tapu and other taonga. Essentially, as geothermal resources are considered taonga, then the question of ownership and management rights to geothermal resources becomes extremely important. This argument is explored further in Section 3.4.1.

The significance of this argument can be gauged by the fact that since the passing of the Resource Management Act, some 30 claims against geothermal resources have been lodged with the Waitangi Tribunal.

Examples of the type of claims made are given below:

WAI 205

Claimants: Anaru Rangiheua for Rotomahana-Parekarangi Trust and Ngati Tuhoerangi

Concerning: Ownership of the geothermal resource in the rohe of Tuhoerangi.

Date received: 10 June 1991

WAI 206

Claimants: Hirini Moko Mead of Ngati Pahipoto Te Rangihouhiri hapu of Ngati Awa, and Cletus Maanu Paul of Ngati Pikiao, Ngati Hokopu hapu of Ngati Awa for Ngati Awa.

Concerning: Ownership of the geothermal resources on White Island and Whale Island.

1.3 REGIONALLY PREPARED PLANS AND POLICIES

Prior to the formation of the Bay of Plenty Regional Council, planning schemes and management plans were prepared relating in part or in whole to the geothermal resources of the Bay of Plenty. The organisations involved in this process were the Bay of Plenty United Council and the Bay of Plenty Catchment Board.

1.3.1 Bay of Plenty Regional Planning Scheme

Section one of the Bay of Plenty United Council Regional Planning Scheme came into force on 1 August 1989. The following objectives and policies were listed in reference to geothermal resources of the Bay of Plenty. The objectives and policies are reproduced in full and as the then Bay of Plenty United Council was responsible for a greater area than the Regional Council, geothermal areas are mentioned for which the Regional Council does not have responsibility (eg Orakeikorako, Ohaaki).

Objectives

1. To conserve surface manifestations of the geothermal resource which are significant for their scenic, tourist, cultural, biological and scientific value.

2. Subject to Objective 1 above, to encourage the use of the geothermal resource in an efficient way for the best long term use.

3. To provide for appropriate management of the geothermal resource.

Policies and Implementation

1. To promote the preparation of management plans for all geothermal fields in the region.

   a. The United Council will seek changes to the Water and Soil Conservation Act to provide for the preparation of management plans by the regional water boards.

   b. That priority be given to the preparation of management plans for the Rotorua field and for fields listed in Category 2 of Policy 4.

2. To control the extraction and discharge of geothermal fluids.

   a. Control is exercised through the water right procedure of regional water boards and the licensing responsibility of the Ministry of Energy.

3. To protect and enhance the natural activity of the Rotorua field and in particular Whakarewarewa by requiring and encouraging efficient and controlled use of the resource.

   a. That all users of geothermal energy be required to conform to efficiency standards and pay a rental related to the amount of use.

   b. That extractive use be restricted in parts of the field most sensitive in terms of natural activity.

   c. The United Council will seek the co-operation of the Ministry of Energy in conjunction with the Bay of Plenty Catchment Board and Rotorua District Council to implement this policy.

4. To encourage the management and use of the region's geothermal fields in accord with the following classification:

   a. Category 1, complete preservation

      i) Waimangu - Rotoma - Tarawera
      ii) Waiotapu - Waikite
      iii) White Island - Whale Island
      iv) Orakeikorako

b. Category 2, extractive use permitted only where the impact on the natural features of the field is considered acceptable and there is no impact on Category 1 fields.

   i) Lake Rotoiti - Rotoma
   ii) Tikitere - Taheke - Lake Rotokawa - Mokoia Island
   iii) Reporoa - Golden Springs
   iv) Te Kopia

c. Category 3, extractive use permitted.

   i) Tauranga - Mt Maunganui - Matata - Whakatane
   ii) Kawerau - Awakeri
   iii) Horohoro - Atiamuri - Ngakuru
   iv) Broadlands - Ohaaki - Whangairorohea
   v) Ngatamariki

d. The United Council will seek the co-operation of the Ministry of Energy and catchment boards to implement this policy.

5. To support the inclusion of Waimangu and Orakeikorako geothermal fields in a Schedule of Protected Waters in new water and soil legislation.

The Bay of Plenty Regional Council formally adopted the Bay of Plenty United Council Planning Scheme and therefore the geothermal policy contained within became the geothermal policy of the Regional Council.

Under the Resource Management Act, the Bay of Plenty United Council Planning Scheme is known as a Transitional instrument and will be incorporated into a Transitional Regional Plan. This Transitional Plan will be deemed operative from 1 October 1991.

1.3.2 Rotorua Geothermal Management Plan

In 1986, the Rotorua geothermal field was considered to be under severe stress and this resulted in Government action and forced closure of bores. Recognising the need for management of the field, the Bay of Plenty Catchment Board prepared a Management Plan for the Rotorua Geothermal Field.

The Bay of Plenty Catchment Board set the following goals for the management of the Rotorua Geothermal Field:

1. To restore and preserve the natural surface features of the Rotorua Geothermal Field;

2. Within such constraints as set by Goal 1, allow controlled utilisation of the field as a source of geothermal fluid and energy;

3. To monitor recovery of the pressure and temperature in the geothermal aquifer and natural features of the field.

These goals were to be achieved through the implementation of the following policies:

1. Division of the field into zones based on rhyolite and ignimbrite geology;

2. Allocation by priority of use;

3. Use reduction by saving wastage.

Under the Water and Soil Conservation Act, water management plans are not explicitly recognised. Therefore the plan has no legal status and can not be used as evidence in water right hearings. The Rotorua Geothermal Management Plan was not formally adopted by the Bay of Plenty Catchment Board.

The Resource Management Act provides for the preparation of management plans and gives them legal status. For the future adoption of the Rotorua Geothermal Management Plan, the provisions under the Resource Management Act must be followed. This includes a renewal of the public participation process.

1.3.3 Kawerau Geothermal Field

Evidence given at water right hearings for Right No 2635 (geothermal discharge to Tarawera river) and 2443 (establishment of geothermal power station) repeatedly called for the preparation of a comprehensive management plan for the Kawerau field. All parties involved with the geothermal development of the field recognised the need for the management plan. It is believed that sufficient technical evidence (ie a model of the field) is available on which to base the plan, however this is currently under the control of the Crown and is not readily available as it is considered commercially sensitive information.

CHAPTER TWO

PHYSICAL BASIS AND MANIFESTATIONS

2.1 INTRODUCTION

The physical manifestations of geothermal activity range from impressive geysers (eg Pohutu), through steaming ground (eg Waimangu) to small springs supplying hot water (eg Awakeri Springs). The interaction of many factors controls the nature of these surface expressions.

2.2 VOLCANIC

The majority of geothermal features of the Bay of Plenty lie within the Taupo Volcanic Zone (TVZ). The location of the TVZ is shown in Figure 2.1. The structure of the earth's surface is comprised of a series of continental plates. Where these plates adjoin, subduction can occur. This is where one plate is forced under another. These movements create giant fault zones called Benioff Zones that dip from the oceans floor at angles of 30 to 60 degrees. Where the Benioff Zones intersect the Gutenberg Low Velocity channel at depths of 100 or 200 kilometres is the site of the melting of the crustal materials to form volcanic magmas. The magmas force their way to the earth's surface to form volcanic chains. The North Island of New Zealand straddles a Benioff Zone and the volcanic activity of the TVZ results from such a deep crustal structure (Stevens 1980).

The TVZ probably developed about 2 million years ago (Selby 1985).
This then is the source of heat powering the geothermal systems.

Rainfall infiltrates to great depths (ie several kilometres) where it is heated by the shallow magma and then rises to the surface, passing through the overlying strata, driven by temperature gradients. Therefore the water gains heat from the reservoir rocks and the magma beneath. The overlying strata is also heated by the rising fluid. The chemistry of deep source geothermal fluid will reflect some magmatic content such as sodium-chloride, boron and fluoride.

Most New Zealand geothermal reservoirs are liquid (rather than steam/gas) containing high temperature water under hydrostatic pressure. This water which reaches the surface through faults and other fissures discharges as :

i) geysers and hot springs

ii) fumaroles, mud pools and acid springs.

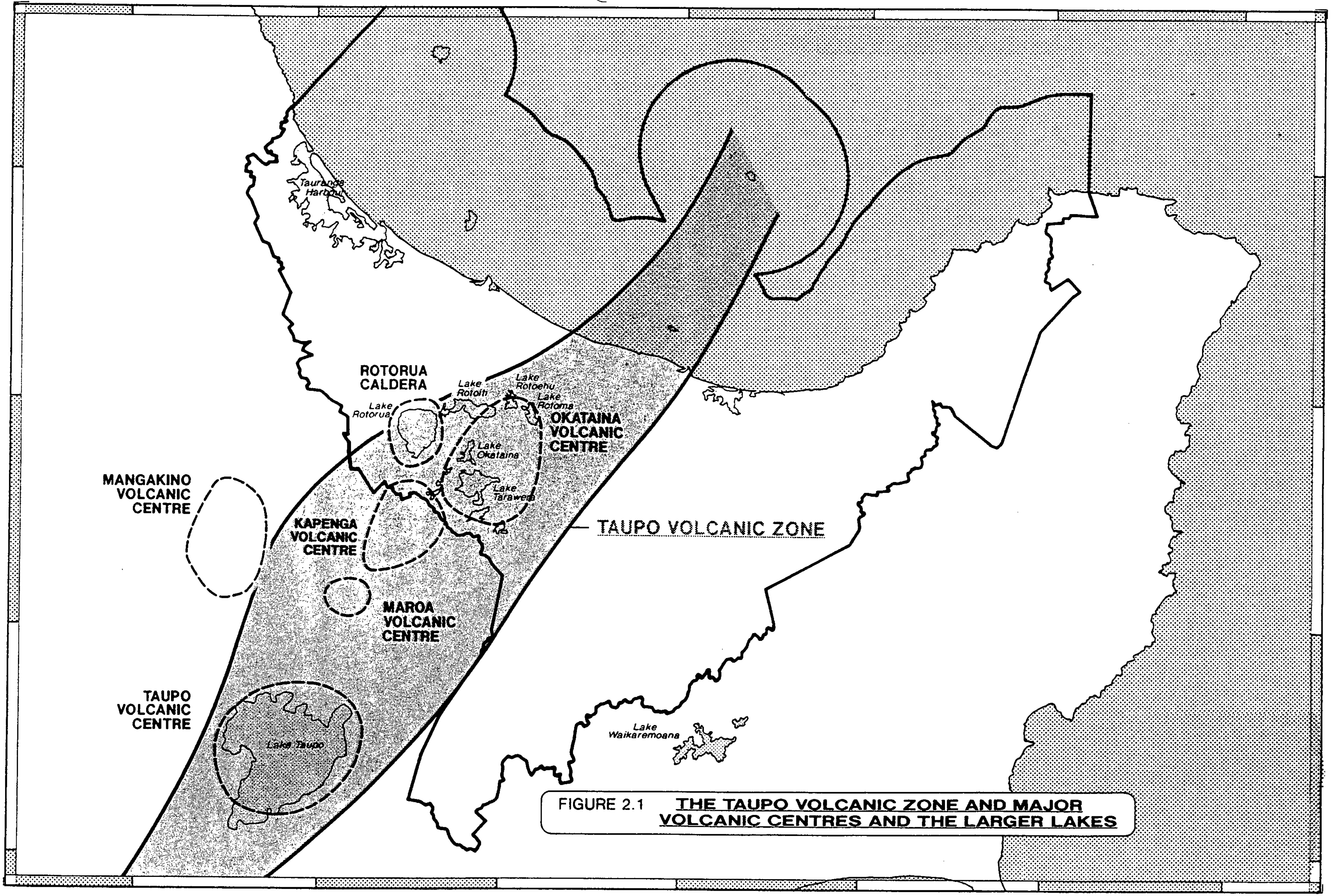

FIGURE 2.1 **THE TAUPO VOLCANIC ZONE AND MAJOR VOLCANIC CENTRES AND THE LARGER LAKES**

Geysers and hot springs

These represent the discharge of deep reservoir geothermal fluids. The chemistry of the water is generally classed as alkaline-chloride as a result of the alkaline pH and high chloride content. The water is very clear and near to boiling (eg temperatures measured during monitoring in Whakarewarewa fluctuate around the 98 degree Celsius mark). Such water tends to deposit silica as it cools.

Geysers are a particular form of an alkaline chloride spring. The intermittent nature results from:

a) an underground reservoir of water distributed through irregularly shaped and interconnected passageways;

b) increase of the boiling point of water with increasing pressure.

Water throughout the geyser's reservoir reachs boiling point and some steam builds up in the uppermost chamber of the geyser. This steam pressure forces a little of the water out of the geyser. Removal of this water decreases the hydrostatic pressure at all points below. As a result, all the boiling water then flashes into steam and blasts the water and steam up and out of the geyser vent (Longwell et al 1969).

Changes in alkaline-chloride features reflect changes in the pressure of the deep reservoir.

Fumaroles, mud pools and acid springs

These features are termed acid-sulphate features and result from steam heating of shallow groundwater. Rising deep reservoir water, as it boils , creates a mixture of steam, hydrogen sulphide (H_2S), carbon dioxide (CO_2), ammonia (NH_3) and mercury (Hg). This mixture heats and acidifies the shallow groundwater creating steam heated soils and springs with acidic waters high in sulphate and low in chloride. Where the initial steam/gas mixture reachs the surface, steaming ground and fumaroles can result. These features tend to be affected by rainfall and groundwater conditions.

While these two thermal water types represent the majority of geothermal chemistries, the interaction and mixing/dilution with each other and other source waters can create many differing chemistries.

The general chemistry of geothermal water can be described as: major cations are sodium and potassium with smaller amounts of calcium and magnesium; major anion is chloride with smaller quantities of sulphate and carbonate. The water may also contain a large proportion of silica and lesser amounts of trace metals such as fluoride, boron, lithium and arsenic.

2.2.1 Geothermal Systems in Balance

Like all systems, geothermal systems are in balance between upflow from the geothermal fluid reservoir, discharge at the surface and inflows/outflows from the groundwater. Excessive interference with any of the factors can have serious results for the geothermal system.

2.3 NON VOLCANISM GEOTHERMAL

Not all geothermal water and features are associated directly with volcanism (ie magma at shallow depth).

Deep slow moving groundwater may have elevated temperatures as a result of the water being warmed by heat conducted from the earth's centre through the host rock. The rate of warming is known as the geothermal gradient. This gradient suggests that groundwater will increase in temperature by 3 degrees Celsius for every 100 metres of depth. Gradients of 3 degrees/100 metres are considered to be normal for New Zealand (BOPRC 1991). Water heated at depth moves up to the surface via fractures often associated with faults. An example of this is the Awakeri Hot Springs and the other thermal springs located in the Ureweras.

The largest non-volcanism geothermal area is the Tauranga field. This field is associated with a backarc basin. The heat flow for the area results from a combination of conductive and convective heat transfer. The majority (67 percent) of heat flows for this field are between 60 mW m^{-2} and 120 mW m^{-2}. Some bores (Mt Maunganui, Maketu and around the harbour edge at Tauranga) have heat flows greater than 120 mW m^{-2} as a result of high permeability rocks and the vertical transport of warm water (Simpson 1987).

The majority of this type of geothermal feature tends to have low temperature water (ie less than 70°C). They are therefore useful for low temperature direct heat use (see Table 3.1) such as glasshouse heating and the heating of swimming pools but not for application of power production technology.

2.4 SUBMARINE GEOTHERMAL ACTIVITY

The TVZ extends out from the coastline of the Bay of Plenty with thermal activity occurring on Whale and White Islands. Submarine geothermal activity also occurs out on the continental shelf. This is indicated by a number of gas bubbling zones lying along an axis, parallel to the Whakatane Graben, between Whale Island and White Island (Duncan and Pantin 1969).

CHAPTER THREE

GEOTHERMAL VALUES

3.1 INTRODUCTION

Geothermal sites and systems have intrinsic and extrinsic values associated with them. These values must be considered separately or together when examining a geothermal site or proposal involving the use of a geothermal site. These values can be described as:

a) Scenic / Tourism
b) National Heritage
c) Cultural
d) Extractive
e) Therapeutic / Medicinal
f) Scientific / Vegetation

3.2 SCENIC / TOURISM

The settlement and subsequent development of parts of the Bay of Plenty owes a great deal to geothermal areas and activity. Sites of Maori settlement were associated with geothermal activity. With the increasing arrival of Europeans into New Zealand, the tourism potential of the geothermal activity was realised. In particular, the Pink and White terraces were the major drawcard of Victorian tourists. Following their destruction in the 1886 eruption of Mt Tarawera, the focus for tourist activity shifted to Rotorua. The Victorian penchant for "taking the waters" and the hospitality of the local Maori soon made Rotorua and surrounding areas a must on any tour of New Zealand. Geothermally related tourism developments continued to be developed on a major scale such as Tikitere, Waiotapu and Waimangu and at a lesser scale in areas such as Awakeri Springs and Sapphire Springs. The exploitation of geothermal resources for tourism continues to this day with the building of swimming pools in the Tauranga area to be filled with heated water from deep bores.

A breakdown of tourism figures reported in "Bay of Plenty Tourism Strategy 1991/92 (BOP Tourism Board)" were as follows:

i) International

Expenditure by international tourists is estimated to have earned the Bay of Plenty $133.7 million in 1987/88, $100 million in 1988/89 and $107 million in 1989/90. In 1987/88 (the latest available data), Rotorua earned an estimated $89.6 million from international tourism.

ii) Domestic

Total domestic tourist expenditure in the Bay of Plenty for 1988 was estimated at $220 million. Of this, Rotorua's share was approximately $52.4 million.

However, the actual contribution of geothermal areas and geothermal activities to the total tourist expenditure is hard to assess. The Rotorua Geothermal Management Plan (RGMP) contains the following comment:

"New Zealand is promoted internationally as a tourist destination on the basis of several key attractions. Rotorua is one of these and is promoted as a centre of thermal activity and Maori culture. Pohutu Geyser invariably features in promotional literature. Therefore, while tourists may not end up seeing the geyser or bathing in a mineral pool, these are key motivations for people going to Rotorua.

One of the most direct measurements of economic benefit from geothermal activity can be indicated by the number of visitors to Whakarewarewa. In 1986/87, there were 329,000 visitors to Whakarewarewa and this earned $2.25 million."

3.3 NATIONAL HERITAGE

The geothermal areas of New Zealand (whether they are in the Rotorua, the Bay of Plenty or other regions of New Zealand) are recognised by New Zealanders as part of that which makes New Zealand "different".

The RGMP reports " The geysers of Rotorua are a landscape feature which all New Zealanders would identify with as being part of the nation's heritage". It was partly this belief that prompted the Government to begin the Bore Closure programme.

3.4 CULTURAL

The Cultural value of geothermal resources can be assessed in terms of :

i) Maori;

ii) Social Environment.

3.4.1 Maori

The Maori perspective on geothermal issues is difficult to determine as so many perspectives and viewpoints exist. Indeed, the perspective on a particular geothermal issue of any given hapu/whanau will most likely derive from on-Marae debate. Most geothermal sites will, however, have traditional, historical or cultural associations for the local hapu/iwi.

As an example of the different viewpoints between Maori and others was the case of Crown water right 2635. Here, the geothermal fluid discharged into the river was seen as an undesirable pollutant by Council and objecting environmental groups but as natural and normal and maori by the local Maori (Savage Papakainga Trust).

The source of the geothermal energy, in the Maori tradition, lies within the legend of Ngatoroirangi. Here, Ngatoroirangi weakened and cold from his climb up Mt Tongariro called on his sisters in Hawaiiki to send fire. With the help of the fire gods, the fire was sent underground and where it came up upon its trip (Whaakari, Motuhora, Okakaru, Rotoehu, Rotoiti, Tarawera, Paeroa, Orakeikorako, Taupo and Tokaanu) thermal activity resulted.

Maori in the TVZ see the geothermal resources as their taonga (treasure) passed to them by Ngatoroirangi and perceive themselves as Kaitiaki (guardians) of those resources. They hold the resources in trust for the future generations. These in part form the spiritual values attached to geothermal resources. There were also practical uses and these included;

i) cooking;

ii) bathing;

iii) dyeing of flax fibre;

iv) therapeutic/medicinal use: ie Hongi remarked of using hot pools and mud baths to comfort and cure his wounded warriors after one of the Nga Puhi assaults on Te Arawa;

v) central heating: ie in some areas, whare could be constructed on heated ground and therefore adding considerably to comfort.

Many geothermal areas or features are regarded as Waahi tapu (sacred places) as a result of uses such as;

i) ritual: ie use of mud from certain pools removed tapu after battle;

ii) burial: certain hot pools and mud pools have historically been used as urupa (places of burial). Remains were interred here to prevent desecration by enemies. Such places still carry tapu.

The ownership of the geothermal energy resource was vested in the Crown by enactment of the Geothermal Energy Act 1953. Despite this, Maori still feel concern for the future of the geothermal resources in keeping with their role as kaitiaki of the taonga. The term taonga was used in the Maori version of the Treaty of Waitangi where the Article the second guaranteed rangatiratanga (chieftainship or governorship) of the whenua (land), kainga (living places) and taonga katoa (all inherited resources). Thus Maori continue to view the geothermal resources as being in their care and stewardship.

Grievances with what the Maori regard as misappropriation of the control of the geothermal resource by the Government (ie the 1953 Act) has led to a number of claims relating to the geothermal resource being lodged with the Waitangi Tribunal.

Regional Councils are likely to encounter a great unwillingness on behalf of the tangata whenua to enter into discussion on geothermal management. This is due to the Maori perception that the Regional Council are has no status in respect of the ownership and management of geothermal areas and resources because of the Treaty of Waitangi being a contract between the Crown and the Maori.

Manatu Maori (Ministry of Maori Affairs) has produced a discussion document "The ownership, management and development of the Geothermal Resource" which addresses the issues and suggests solutions. Three possible scenarios regarding the right of iwi to allocate use are identified.

i) Tribal regulation of the entire resource - involves the complete transfer of the three main rights (right to use, right to control or allocate and the right to economic gain or income) to iwi. Regional Councils would play no role other than to regulate the external effects of use of the resource, such as effects on the environment from development;

ii) Dual regulation - This would require obtaining permission from both existing authorities and the iwi. It would mean that an allocation decision is made twice - the iwi would lease the resource and the Regional Council would then approve that allocation decision if it found that the resource could be sustainably managed;

iii) Mixed system - Iwi would have exclusive management of certain defined areas, as well as an interest in the management of the resource generally. This option would involve the establishment of a Geothermal Commission consisting of representatives of both Treaty partners.

3.4.2 Social Environment

The presence of available geothermal water can lead to the development of a geothermally-orientated lifestyle and social environment. Rotorua has an significant number of elderly people who moved there to take advantage of the benefits of cheap heat, and mineral pool bathing.

Social gatherings and lifestyles tend to be based around the advantages of geothermal resources.

Destruction of or reduction in a currently available geothermal resource would have an intangible yet negative effect on the people of the geothermal area.

3.5 EXTRACTIVE

Geothermal areas, water and sites contain energy and minerals that may be commercially exploitable.

3.5.1 Energy

The energy of geothermal systems can be utilised in two ways:

i) direct use of heat;

ii) use of heat to generate electricity.

3.5.1.1 Direct use of heat

Direct use of the heat energy of geothermal resources in the Bay of Plenty ranges from glasshouse heating in the Tauranga Basin to industrial process heat at Tasman Pulp and Paper Ltd. Figure 3.1 provide a list of approximate minimum temperatures required of geothermal water and steam, necessary for a wide range of commercial applications.

3.5.1.1.1 Advantages and disadvantages of geothermal energy for process heat use.

Advantages

i) lower, more stable cost;
ii) low grade heat is already in a suitable form;

Fluid	Temperature	Process	
SATURATED STEAM	180	Evaporation of highly concentrated solutions Refrigeration by ammonia absorption Pulp and paper manufacture Drying of milk	Conventional Power Production
	170	Sulphur mining Drying of diatomite	
	160		
	150	Bayer Process of alumina extraction	
	140	Drying farm products at high rates Canning and bottling of food (esp. fruit and vegetables)	
	130	Evaporation in sugar refining Extraction of salts by evaporation and crystallisation	
	120	Most multiple effect evaporations, concentration of salt solutions, seawater Lucerne drying	
	110	Drying and curing of concrete slabs and blocks Most dairy processes, including cleaning	
	100	Drying of organic materials, seaweeds, grass, vegetables, etc. Wool washing and drying Drying of timber	
WATER	90		
	80	Space heating, domestic hot water heating Greenhouses by space heating	
	70	Refrigeration (lower temperature limit)	
	60	Animal husbandry, manure processing, cheese manufacture Thermophilic bacterial degradation	
	50	Mushroom growing, poultry hatching, brooding Balneological baths Greenhouses by combined space and hotbed heating	
	40	Soil warming	
	30	Swimming pools, biodegradation, fermentations	
	20	Hatching of fish Fish farming	

FIGURE 3.1 Approximate miniumum temperature of geothermal fluids necessary for some industrial processe

iii) resource is renewable (within limits);
iv) use of energy as direct process heat is four times more efficient than use for electricity generation;
v) plant operations need a minimum of supervision.

Disadvantages

i) contains non-condensible gases;
ii) corrosion;
iii) reliability of supply;
iv) environmental problems;
v) location.

3.5.1.1.2 Comparison of cost of geothermal energy to other energy sources

Table 3.1 compares the cost in 1982 dollars of producing one gigajoule (Gj) of energy from various energy sources. One gigajoule of energy is equivalent to the electrical energy required to heat 139 houses for one hour in winter. The table is derived from Dark 1982.

Table 3.1 Cost of production of energy

Energy Source	Gas	Coal	Electricity	Fuel Oil	Geothermal
$ / Gj	2.5	1.03	1.67	4.02	1.30 / 2.00

From the above table, it can be seen that geothermal energy is more cost efficient than gas and fuel oil, marginally equivalent to electricity and less cost efficient compared to coal.

Tasman Pulp and Paper Ltd is the world's largest user of geothermal energy for process heating with 16.3 percent of their energy requirements derived from geothermal energy.

3.5.1.2 Electricity generation

Following the recent installation of the Ormat station at Kawerau, interest has increased in investigating and utilising other geothermal fields in the Bay of Plenty region for electricity generation. The economical and efficient nature of these small generation plants make utilisation of smaller geothermal fields in the region attractive. The Bay of Plenty Regional Council currently has three applications before it for water rights associated with geothermally driven ORMAT power stations. These include the Kawerau field (Savage Papakainga Trust), the Taheke Field (Taheke 8C Trust), and the Tikitere field (Paehinahina Mourea Trust).

This section outlines the potential electrical generation capacity of geothermal fields in the Bay of Plenty region, as calculated from the most recent information.

The discussion is based on information supplied by the Geothermal Co-ordination Group of the D.S.I.R. The location of the geothermal fields under discussion is shown in Figure 3.2. The shape and areal extent of the fields, must be considered as tentative as in most fields exploration is incomplete.

Tables 3.2 and 3.3 are presented giving estimates of the capacity of local geothermal fields for electricity generation in terms of megawatts (one megawatt is the energy required by approximately 1000 one bar heaters). The distinction between the two tables is based on field temperatures: the fields with higher temperatures could be used to generate electricity using conventional steam turbines (such as at Wairakei) while the intermediate fields would be best exploited using binary cycle plants (such as the Ormat station). For comparative purposes, the Matahina Dam has a generating capacity of 72 megawatts.

In each of the tables, a uniform set of assumptions have been made and these are listed below the respective tables. In the high temperature fields, the final field temperature is taken as 180 °C as at this level, it becomes of no use for power generation using conventional turbines. The final field temperature of the intermediate fields is taken as 120°C as binary plant requirements are lower.

Most fields are represented by a number of field sizes and initial temperatures. The different field areas indicate uncertainty in interpretation of resistivity data. The initial temperature ranges used are derived from chemical geothermometry and/or actual measured bore temperatures. In recognition of these variable factors, generation capacity is presented in the tables for the various combinations of field size and initial temperature.

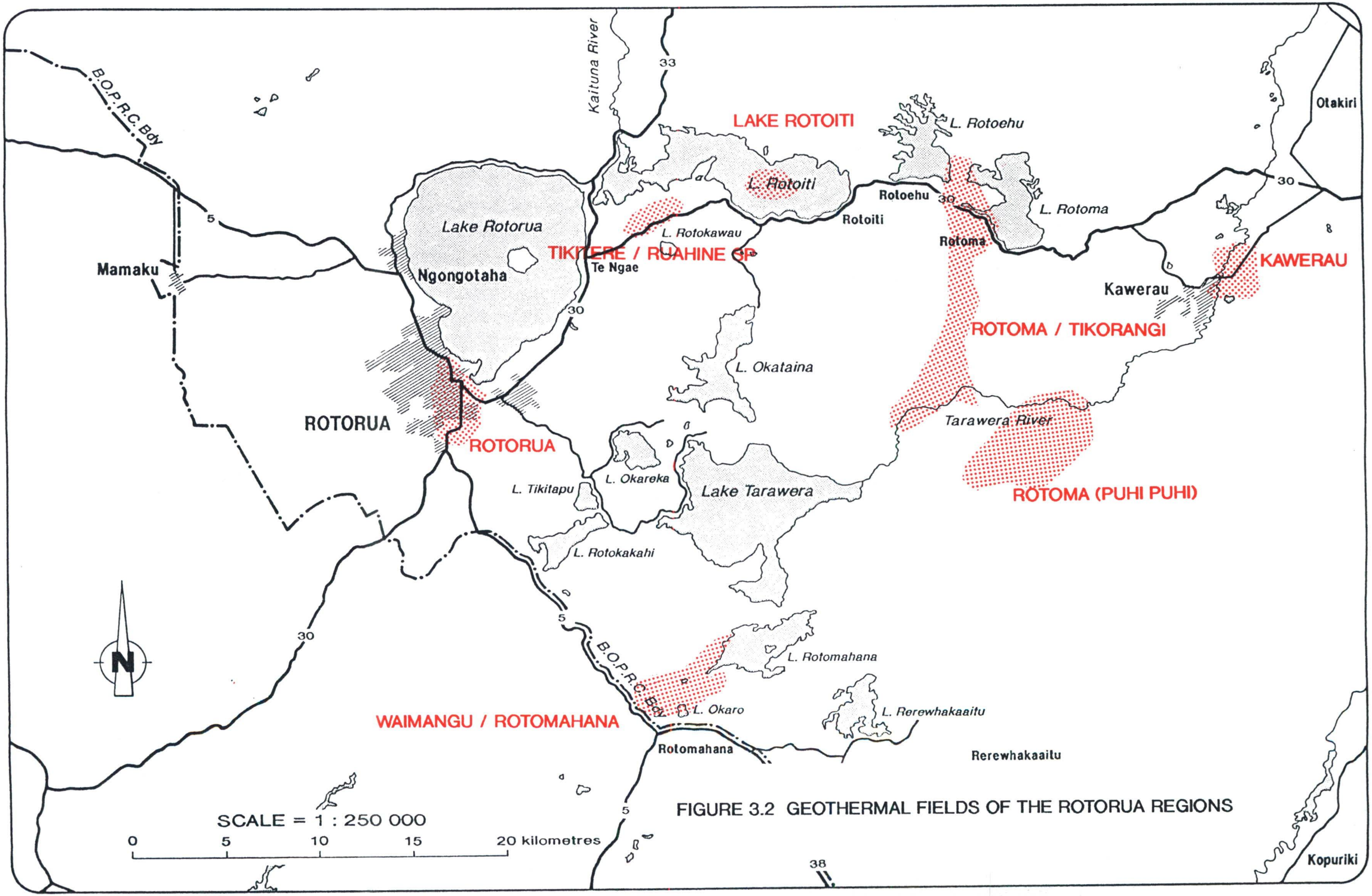

FIGURE 3.2 GEOTHERMAL FIELDS OF THE ROTORUA REGIONS

TABLE 3.2 High Temperature Fields

Field	Assumed Area (km2)	Initial Temperature (oC)	Generation Capacity (MW)
Kawerau	6	250	60
	6	310	110
	12	250	120
	12	310	230
Rotorua	10	250	100
	15	250	160
Waimangu/Rotomahana	22	260	260
	30	260	360

ASSUMPTIONS

Field Thickness	2 km
Mean Rock Density	2.6 t/m3
Rock Thermal Capacity	0.84 J/g/oC
Rock Porosity	0.15
Stored Heat Available	30 percent
Energy conversion efficiency	10 percent
No allowance for recharge	

TABLE 3.3 Low Temperature Fields

Field	Assumed Area (km2)	Initial Temperature (oC)	Generation Capacity (MW)
Lake Rotoiti	2	130	< 10
Rotoma/Tikorangi	10	200	40
	40	200	180
Rotoma (Puhi Puhi)	38	170	110
Tikitere/Ruahine Sp.	7	200	30
	12	200	50

ASSUMPTIONS

Field Thickness	2 km
Mean Rock Density	2.6 t/m3
Rock Thermal Capacity	0.84 J/g/oC
Rock Porosity	0.08
Stored Heat Available	15 percent
Energy conversion efficiency	8 percent
No allowance for recharge	

To convert available heat to electric capacity, it was assumed that the plant would operate for thirty years (and thus the available heat would be exhausted in that time) and that energy conversion efficiency from heat to electricity was per the percentages listed with the respective tables.

Using the above data, a minimum and maximum potential generating capacity for the region can be derived.

a) Minimum scenario : Minimum field size and lowest initial temperatures gives a generating capacity of 610 megawatts.

b) Maximum scenario: Maximum field size and highest initial temperatures gives a generating capacity of 1100 megawatts.

There is a significant electrical generation capacity associated with the known geothermal fields of the Bay of Plenty region. The significance of the resource is illustrated by Figure 3.3 which compares the Maximum scenario with existing installed generation capacity. It can be noted that the Bay of Plenty geothermal generating capacity;

i) is twice the generation capacity of New Zealand's largest dam, Benmore;

ii) is equivalent to all the hydro-electric generating stations on the Waikato river;

iii) represents 15 percent of the current total New Zealand installed capacity.

3.5.2 Minerals

The major exploitative minerals associated with geothermal resources are sulphur and trace minerals.

3.5.2.1 Sulphur

Active fumaroles are often characterised by encrustation of sulphur around the vents. They are formed by incomplete oxidation of hydrogen sulphide and by direct sublimation (WVA 1987).

Sulphur mining has historically occurred in a number of localities in the Bay of Plenty. These include White Island, Sulphur Bay and Taheke. Mining at White Island ceased following the death of eleven sulphur miners due to hydrogen sulphide poisoning.

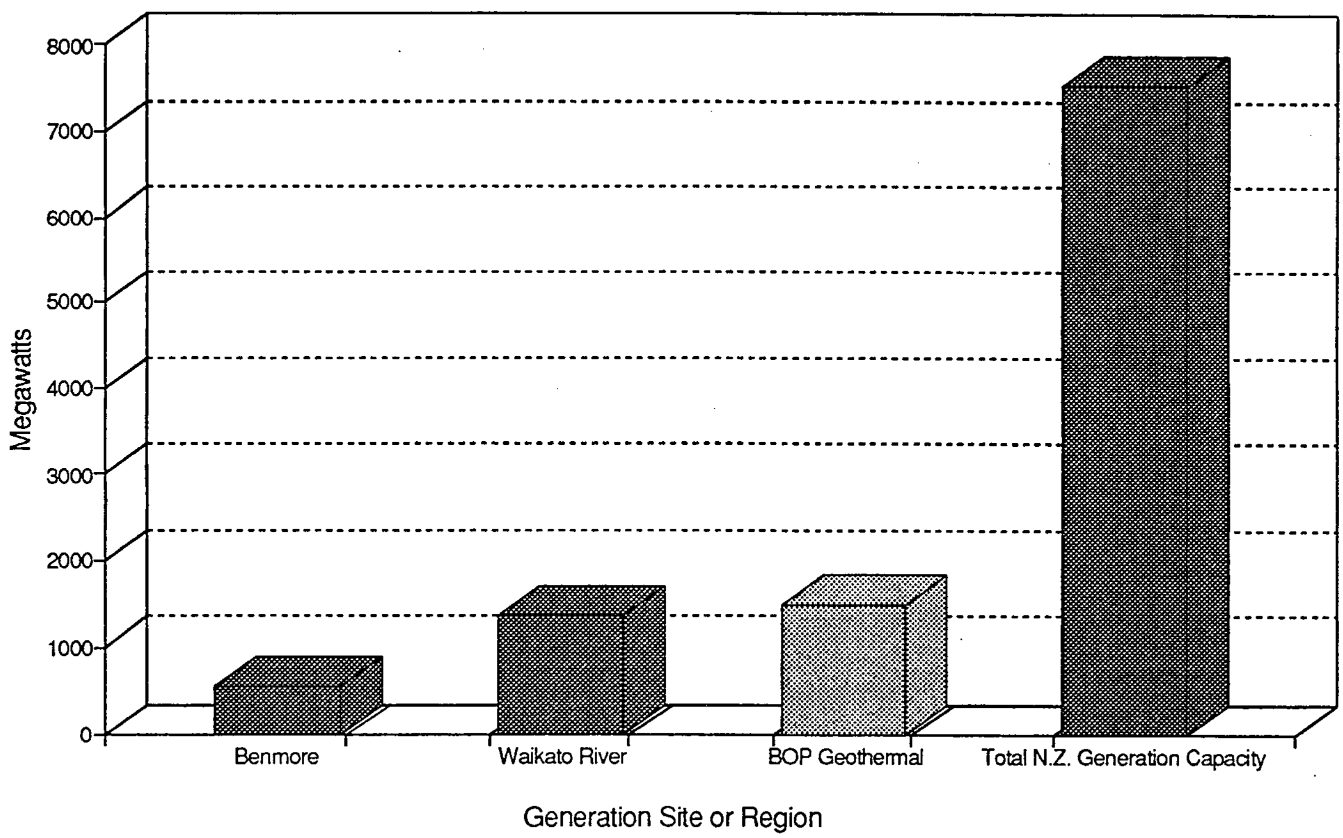

Figure 3.3 Electrical Generation Capacity of selected areas compared to the Total NZ Generation Capacity

3.5.2.2 Trace Minerals

The movement of geothermal fluid and long residence times within the reservoir rock results in dissolution of small amounts of various elements into the fluid.

Small quantities of ore-grade base and precious metals are being deposited in geothermal systems. Hedenquist (1986) reports that metals such as gold, silver, mercury, antimony, thallium, tungsten, lead, zinc and copper are enriched within the upper 1000 metres of the Taupo Volcanic Zone. Arsenic, antimony, mercury, thallium, gold and silver are found enriched in sulphide-rich siliceous precipitates around hot springs. Tungsten- rich precipitates are actively forming in Waimangu (WVA 1987).
Browne and Lloyd (1986) report that metallic scales found on orifice plates at Kawerau contained up to six percent gold and 20 percent silver.

Geothermal waters contain significant quantities of silica (ie up to 1208 g/m^3 as SiO_2). Technology for silica extraction has now been developed to an advanced state by Tasman Pulp and Paper Ltd and Victoria University (Harper 1991). Tasman intends to use the extracted silica to enhance the quality of its newsprint.

Thain and Harper (in press 1991) have reviewed the gross revenue available from minerals in New Zealand geothermal fields. Five minerals were identified.

- i) Precipitated amorphous silica;
- ii) Lithium metal;
- iii) Arsenic trioxide;
- iv) Boric acid;
- v) Precipitated calcium carbonate.

The gross value of these minerals for Wairakei, Ohaaki, Kawerau and Ngawha was estimated to be NZ$39, NZ$15, NZ$10 and NZ$70 million respectively (Harper 1991).

3.6 THERAPEUTIC / MEDICINAL

Mention (see Section 3.4.1) has been made of the therapeutic and medicinal use to which the Maori put geothermal features and fluid.
While many of the geothermal areas in the Bay of Plenty may be used informally for therapeutic or medicinal use, only the Rotorua geothermal field can be considered to have formal development for these uses.

As mentioned in the Section 3.2 (Tourism), the spas were a factor in Rotorua City's early development. The use of mineral pools in Rotorua is wide spread for relief of rheumatic, asthmatic, skin afflictions and other illnesses. The medical effectiveness of mineral pool bathing is difficult to prove scientifically, however, those that utilise it firmly believe in it's curative and ameliorating properties.

Queen Elizabeth Hospital relies totally on geothermal energy for hot water, heating, steam raising for laboratory, theatre sterilising and supply of geothermal fluids to the hydrotherapy unit (RGMP). Queen Elizabeth Hospital currently have a water right for extraction of geothermal fluid under consideration by Council.

The RGMP contained the following comment on the benefits of Geothermal Energy in Hospitals:

> "Hospitals require a reliable supply of energy for heating and hot water 24 hours a day, 365 days a year. Geothermal is a source of energy which lends itself to continuous use. Economic and engineering advice is that the use of the resource is more efficient when it is being used 24 hours a day.
>
> Continuous heat is a factor in making people who are sick, comfortable. The maintenance of heating at body temperature in operating theatres and post operative or recovery rooms is an important safety factor for patients lives."

3.7 <u>SCIENTIFIC / VEGETATION</u>

Unique opportunities exist in geothermal areas for study of rare physical features, activities and flora and fauna. Active high temperature geothermal fields are rare in the world.

3.7.1 <u>Scientific Rating of Geothermal Areas of the Bay of Plenty</u>

Houghton et al (1980) established a classification scheme for ranking geothermal sites on the basis of their scientific and nature conservation value.

3.7.1.1 Basis of rating categories

Category A Areas containing New Zealand,s unique and outstanding hydrothermal features that must be completely preserved if a representative selection of features is to be retained.

Category B Areas with a selection of outstanding thermal features. Recommended for protection from exploitation until geothermal energy demands exceed energy available from Category C areas.

Category C Areas already irreversibly spoiled by exploitation and/or those with no recognised unique geological or geophysical features.

3.7.1.2 Geothermal areas of the Bay of Plenty by rating

Class A Whakarewarewa
Waimangu
Whakaari (White Island)

Class B Tikitere

Class C All other Bay of Plenty geothermal areas.

3.7.1.3 Explanation for areas in Class A

Whakarewarewa

i) geysers and extensive sinter deposits. Rates with Iceland and Yellowstone Park;

ii) mud volcanoes;

iii) actively growing sinter terraces;

iv) actively forming geyserite.

Waimangu

i) only large system formed in historic times and as a result of a volcanic eruption.

ii) 93 year history is well documented;

iii) only intense hot chloride system as yet unaltered;

iv) features unique quasi-cyclic behaviour in change in levels and outflow from lakes;

v) amplitude (up to 12m) of level change in Inferno crater has no parallel;

vi) unique association of thermal vegetation.

Whakaari

i) White Island is the best example in New Zealand of a highly acidic hydrothermal system caused by interaction of magmatic gases and groundwater;

ii) the very high temperature fumaroles and acidic stream are unique hydrothermal features.

3.7.2 Vegetation

Vascular plant communities are not usually found in geothermal waters due to the high total dissolved solids and toxic element content. Swamp fern (*Cyclosporus interruptus*), whose roots can go into hot water, fringe hot springs. Also large foliose rhodophytes (red alga) and *Compsopogan hookeri* can also occur in geothermally influenced, but not hot waters.

Prostrate kanuka (*Kuzea ericoides var. ericoides*) is dominant in most geothermal areas. Acidic geothermal sites generally favour heathlike plants such as manuka (*Leptospermum scoparium*), mingimingi (*Leucopogon fasciculatus*) and prickly mingimingi (*Cyathodes juniperia*)
On less acid sites, the vegetation is usually more diverse. Frost intolerant species such as thermal ladder fern (*Nephrolepis sp.*), thermal umbrella fern (*Dicranopteris linearis*) and soft fern (*Christella sp.*) are restricted to the Taupo Volcanic Zone in New Zealand. Other plants such as swamp fern (*Cyclosarus interruptus*), fern ally (*Psilotum nudum*) and a comb fern (*Schizaea dichotoma*) grow in warmer northern areas as well as thermal areas.

At soil temperatures in excess of 50°C, mosses, liverworts, lichens and arching club moss can survive where other plants can not.

3.7.2.1 Examples of vegetative associations in geothermal areas

Whakarewarewa

dwarf mistletoe (*Karthsella salicornioides*);
blueberry (*Dianella nigra*);
Sun orchids (*Thelymita longifolia, T. pauciflora, T. carnea*);
Bearded orchids (*Calochilus spp.*);
Green onion orchids (*Microtis parviflora, M. unifolia*).

Whakarewarewa is too acidic for tropical ferns. Rare sedge (*Kimbristylis squarrosa*) survives. Also pohutukawa, kamihi and toru thrive close to the geysers.

Waimangu

Giant hypolepis (*Hypolepis dicksonioides*) found only at Waimangu, Lake Tarawera (Hot Water Beach) and Mokoia Island. Diminutive ferns (*Cheilanthes distans, C. humilis*) and comb fern (*Schzaea bifida*) are also present with the two *Cheilanthes* only found at Waimangu.

Ohinemutu

Ohinemutu once had many "geothermal" species however many are now exinct or very rare.

Thermal areas are also havens for introduced sub-tropical plants such as blue morning glory (*Ipomoea indica*) and buffalo grass (*Stenataphum secundatum*). Species normally associated with the coastal environment such as oioi (*Leptocarpus similus*), sea rush (*Luncus maritimus*) and shore lobelia (*Lobelia anceps*) can also be found in thermal areas.

3.7.3 Micro Algae of Thermal Areas

In thermal areas, many different kinds of bacteria live together in dense mats together with blue-green algae. The colours of the algal carpets are considered to enhance the beauty of the thermal areas.

The type and presence of species is determined by temperature and sulphide tolerance ie sulphide rich clear alkaline-chloride water

55 - 80°C archebacteria
35 - 65°C blue-green algae or cyanobacteria
20 - 45°C diatoms
16 - 37°C green and red algae and *Euglenas*

Sulphide waters up to 50 $g.m^3$

Oscillatoria amphigranulata

Usually the algal mats are composed of only a few species; *O. amphigranulata* or *Phormidium valderium* interspersed with *Synechococcus lividus, Synechocystic aquatilis* or *Cyanothece exima*. The green cushions are usually formed by *Mastigocladus laminosus*. In Waimangu, as an example of succession of species due to changes in chemistry of geothermal water, *Cyanidium calderium* fringes acidic waters but as the water becomes more alkaline, *P. valderium and M. lami* take over.

Diatoms found in geothermal areas and geothermally influenced water are: *Eurotia sp., Frustulia sp., Nitzchia sp., Nedium sp. and Pinnularia sp.*

Warm nutrient rich thermal waters can also permit growth of potentially fatal amoebae such as *Naegleria fowleri* and *Acanthamoeba sp.*

CHAPTER FOUR

IMPACTS AND GEOTHERMAL MANAGEMENT

4.1 INTRODUCTION

Exploitation of geothermal resources is not without hazards or problems. These potential impacts must be taken into account when considering development of a geothermal resource. The major impacts can be described as;

a) Destruction or change of surface features;
b) Subsidence;
c) Hydrothermal eruptions;
d) Discharge of contaminants;
e) Destruction or modification of fauna and flora;
f) Conflict between uses.

4.2 DESTRUCTION OR CHANGE OF SURFACE FEATURES

Excessive withdrawal of geothermal fluids may lead to reduction in pressures within geothermal systems. This reduction in pressure may seriously affect surface features such as geysers and boiling springs which rely on such pressure to maintain their activity. In concert with pressure reduction there may be a change in the temperature dynamics of the geothermal system. This may be due to greater influx of colder groundwater and/or change from boiling to non-boiling. The nature of these changes can range from springs simply ceasing to play to radical changes in chemistry and appearance.

New Zealand once had five active geyser fields: Whakarewarewa, Orakeikorako, Rotomahana, Wairakei and Spa (Taupo). Today, only Whakarewarewa continues to exist. Orakeikorako was quenched by Lake Ohakuri which formed behind Ohakuri hydroelectric dam. Wairakei and Spa ceased as result of geothermal fluid withdrawal for the Wairakei geothermal power station. Rotomahana was extinguished by the eruption of Mt Tarawera. Prior to the Bore Closure programme, the prognosis for the continued existence of the Whakarewarewa geyser field was poor. Bradford (1991) concluded that pressures in the Rotorua geothermal field are recovering and this has lead to a consequential increase in certain surface features in Whakarewarewa (notably heat and chloride flows from Lake Roto-a-tamaheke). Figure 4.1 illustrates this increase.

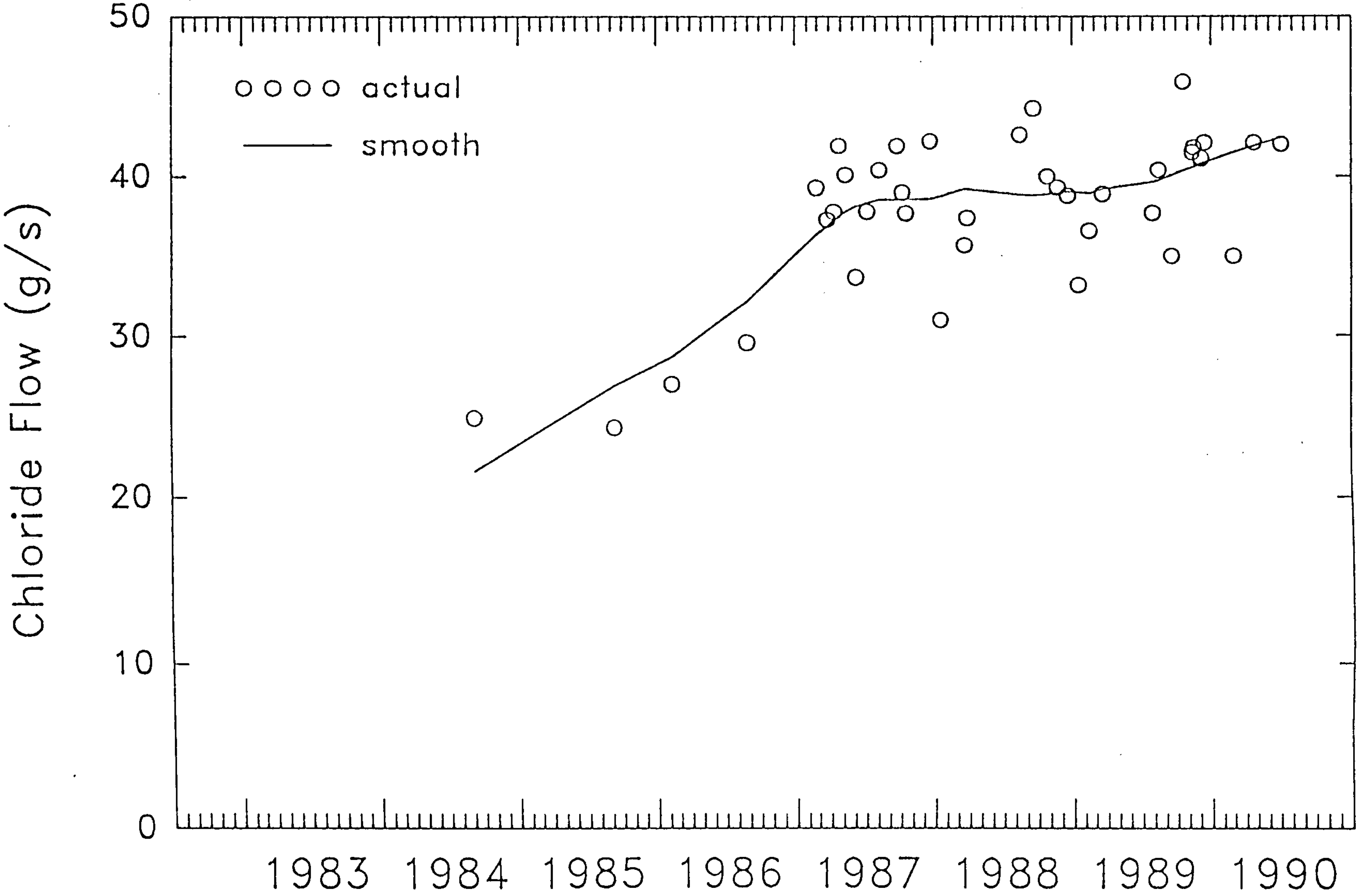

FIGURE 4.1 CHLORIDE FLOW FROM ROTO-A-TAMAHEKE (Bradford 1991)

4.3 SUBSIDENCE

Withdrawal of geothermal fluid can lead to subsidence problems in the surface area above the geothermal field. Fluids held in fractures and pore spaces of geological formations actually help support the weight of overlying materials. When the fluid is removed, the support is also removed and this may result in subsidence at the surface. Subsidence can be major as in the case of parts of the San Joaquin valley in California where excessive groundwater withdrawal led to approximately 9 metres of subsidence. Subsidence in the Wairakei geothermal field has been of a similar order with greater than 10 metres of ground lowering measured in some places. This equated to a maximum subsidence rate of 450 mm per year during the 1970's decreasing to 350 mm per year in the late 1980's.

Subsidence in the Bay of Plenty is minor in comparison. The Kawerau Geothermal Field has an area of anomalous subsidence centred on the Onepu Hills. Within the anomaly, three local maxima (Lake Rotoitipaku, northern end of the airfield and southern end of the airfield) occur where subsidence rates reach 20 mm per year. Elsewhere, the subsidence rates are mostly in the range 5 - 7 mm per year, compared to background values of 1 - 2 mm per year (Allis 1991). Subsidence within the Kawerau Field is of particular concern due to the effect on the alignment and adjustments of the sensitive paper making machinery operated by Tasman Pulp and Paper Ltd and Caxton Paper Ltd.

4.4 HYDROTHERMAL ERUPTIONS

These may occur at any time and at any locality within a geothermal field. They are the result of water at boiling point experiencing a fall in pressure or coming in contact with rock at higher temperatures. Steam generation then occurs at a very high rate. The expansion of the steam can contain enough energy to throw rocks high in the air.
(Glover and Watson 1989). Hydrothermal eruptions are most likely to occur in areas where the geothermal aquifer is at or close to the surface.

Hydrothermal eruptions occur periodically in Rotorua. When these occur in residential areas, eg West Ohinemutu, significant damage to land and property can result. With the rising pressures within the Rotorua geothermal system and changing groundwater characteristics, hydrothermal eruptions may become more frequent (A Cody pers. com).

4.5 QUENCHING OF RESOURCE

Excessive withdrawal of geothermal fluid from an area may lower pressures and alter the balance between the hot geothermal fluid and the colder surrounding groundwater. In this case, continued exploitation may lead to sufficient cold groundwater inflow to quench the geothermal area. There is evidence of this occurring in the fringe area of the Kawerau Field.

4.6 DESTRUCTION OR MODIFICATION OF FAUNA AND FLORA

As described above (see Section 3.8.2), geothermal areas can have unique associations of flora and fauna. Reference was also made to the once rich 'geothermal' flora species to be found at Ohinemutu and of which many species are now extinct or very rare.

The flora and fauna associations to be found at Waimangu need full protection.

4.7 DISCHARGE OF CONTAMINANTS

Geothermal fluid, by its very nature, contains a high total dissolved load. Potentially toxic trace elements such as lithium, boron, arsenic, and mercury can be found at concentrations hazardous to living organisms. The subsequent discharge of such fluids to the surface water streams may have an undesirable result on the flora and fauna of the streams. Rivers such as the Tarawera have had concerns raised as a result of waste geothermal fluid being discharged into the river.

The polluting action of geothermal fluid may be associated with either the heat of the fluid, the chemistry of the fluid or the gases associated with it.

4.7.1 Heat

The discharge of geothermal fluids to surface waters can significantly alter the thermal characteristics of the surface water. Most species have a temperature tolerance range and the increasing water temperature may induce behavioral problems, stress and mortality. A significant change in the thermal characteristics of the water body will result in a change in the flora and faunal associations of that body.

Physical parameters such as the dissolved oxygen content of the surface water is significantly affected by change in thermal characteristics. This can reduce the assimilative capacity of the water body.

The discharge of geothermal fluid (approximately 24,000 tonnes per day) to the Tarawera River at 80°C is estimated to increase the temperature of the river by 1.3°C at a mean river flow of 13 m^3/second and a initial river temperature of 20°C (BOPCC 1985).

4.7.2 Fluid

Boron, lithium, ammonia and arsenic concentrate in water. Mercury generally concentrates in the gas phase but has the most toxic effect through ingestion in water.

4.7.2.1 Boron

Certain plants have a very low tolerance to boron. It is an essential element up to a certain concentration (dependent on plant type) and phytotoxic thereafter. Kiwifruit is thought to be particularly sensitive to boron. Field trials into kiwifruit sensitivity to irrigation water containing boron are currently taking place on the Rangitaiki Plains. Early results have been inconclusive (D Sheppard pers. com).

Boron concentration data from Rotorua wells suggest that levels range between 1.4 and 10.8 g/m^3. The mean daily mass discharge of boron (in geothermal waste water) being discharged to the Tarawera River from the Kawerau field was reported as 1164 kg/day for the period 1988 to 1990.

4.7.2.2 Lithium

The concentration of lithium in natural geothermal discharges in the Bay of Plenty region is generally in the range 0.5 to 3.0 g/m^3. Concentrations of lithium in wells around Rotorua ranged from 0.1 to 4.4 g/m^3 (DSIR 1985).

4.7.2.3 Mercury

Mercury is highly toxic and bioaccumulatable. The major threat of mercury to humans is accumulation in fish and shellfish which is then passed up the food chain. The mercury content of geothermal waste fluid from the Kawerau field has been measured ranging from <0.17 to 1.18 grams per day (Sheppard 1991).

Mercury concentrations in the sediments of Lake Rotorua are reported to be higher than those of lakes which have no geothermal input (Munster 1982).

4.7.2.4 Arsenic

Arsenic is a cummulative poison, highly toxic to man, and has been associated with epidermic complaints, kidney disorders, cancer and death. Adverse effects have been associated with long term ingestion of 0.2 - 1 g/m^3. Arsenic data from Whakarewarewa suggests that levels range from 0.05 to 0.7 g/m^3 (DSIR 1985).

4.7.2.5 Ammonia

Ammonia acts as an algal and microbial nutrient in waters. Concentrations of NH_3 in Rotorua geothermal wells ranges from < 0.1 to 0.89 g/m^3 (DSIR 1985).

It is believed that the ammonia content of geothermal fluid contributes significantly to the nitrogen load of a number of lakes in the Bay of Plenty. As an example, Vincent et al (1986) estimates that the contribution of NH_4-N from hot springs contributes 41.6 tonnes per annum of the 62.8 tonnes total NH_4-N annual budget of Lake Rotoiti. They further estimate that overall hot springs contribute 26 percent of the total nitrogen budget.

4.7.3 <u>Gas</u>

4.7.3.1 Hydrogen Sulphide

This is the geothermal related gas which causes most problems in the Bay of Plenty. Hydrogen sulphide (H_2S) is extremely toxic to humans. At concentrations of 0.01 to 0.1 mg/m^3, it has that characteristic Rotorua smell but at concentrations of 1-10 mg/m^3 loss of smell occurs and eye irritation can result. At above 150 mg/m^3 respiratory complaints and death may result (Rolfe 1980).

Concentrations of H_2S in geothermal gas in the Rotorua area ranged from 5.5 to 493 mmole/100 mole (DSIR 1985).

Because H_2S is denser than air, it accumulates and concentrates in low areas with poor ventilation. This situation has caused a number of deaths (Munster 1982).

On contact with air, H_2S oxidises to SO_2. Both gases are highly corrosive and are particularly severe on metals such as copper and lead. Corrosion and subsequent failure of electrical equipment is a real problem in geothermal areas.

Cope (1981) investigating the effect of sulphur gases on exotic pine forests concluded that the impact of geothermal H_2S is very local and confined to within a few hundred metres of a thermal area.

4.7.3.1 Radon

Radon (Rn) is present in both water and air but is most toxic by inhalation and is associated with leukaemia in man. Radioactive decay of the element produces lead and polonium. Long term exposure to polonium can cause lung cancer (Munster 1982).

The threat posed by these gases make it imperative that consideration be given to adequate design of new structures in geothermal areas.

4.7.4 <u>Options for disposal</u>

Disposal of spent geothermal fluid has traditionally had three options:

a) Natural watercourse. This leads to concerns about the toxic effect on the flora and fauna of the receiving water. It is worth noting that many of the streams and lakes of the Rotorua region receive significant amounts of geothermal inflow (Timperely 1986). This may relate to drainage from geothermal areas and/or direct discharge of geothermal fluids into the water body through bank or bed. The Tarawera system is an interesting example. Geothermal input to the river derives from springs and geothermal flow in Lake Tarawera, geothermal input from streams draining the Okataina Volcanic Complex (ie Mangakotukutuku), natural input from the surface features of the Kawerau geothermal field and geothermal waste discharge from the Kawerau geothermal field.

   This type of disposal contributes to the mining of geothermal resources as no fluid is returned to the geothermal reservoir.

b) Ground Soakage. This was the most common form of geothermal fluid disposal in the Rotorua geothermal field. The hot fluid (often in excess of 100°C) was discharged to ground soakage and then infiltrated to the shallow groundwater. This was a waste of useful heat, elevated local groundwater levels and contributed nothing to maintenance of the geothermal aquifers. A result of the bore closure programme has been the decline of up to 9 metres in shallow groundwater levels in parts of Rotorua (ie Arikikapakapa) now that the number of bores and hence discharge to groundwater has reduced considerably (Grant-Taylor pers com).

c) Reinjection.

i) Deep reinjection. This method returns the spent fluid to the geothermal aquifer and helps to maintain pressures in the aquifer.

ii) Shallow reinjection. Reinjection at depths above the geothermal aquifer. This method while removing the polluting effect of the fluid from the surface may result in contaminating a potentially potable groundwater aquifer.

Deep reinjection is usually considered the best option for disposal of geothermal fluid. It has substantial technical problems however including permeability of receiving formation material, calciting of reinjection bore, reversal of flow (ie a reinjection well may boil and become a production well) and possible quenching of geothermal aquifer by reinjection of cooler waters.

4.8 INTERCONNECTION OF FIELDS

While geothermal fields may appear separated by many kilometres at the surface, they may be interconnected at depth. Exploitation at one site could lead to effects at another site. There is a precedent already in New Zealand where geothermal fluid withdrawal at Wairakei resulted in geysers failing in the Taupo field, some seven to ten kilometres distant.

There is a current belief (Nairn 1981) that many of the major geothermal fields of the Bay of Plenty are interconnected or at least are connected to the same deep heat source. The geothermal fields of Tikitere, Rotoma, Rotomahana, Rotoiti, Waimangu, Waiotapu and Kawerau ring a geological structure known as the Okataina Volcanic Complex. It is believed that this Complex, at depth, is the heat source for the geothermal fields listed above.

Therefore any large scale development at any of the fields (such as a geothermal power station) must be considered in relation to connections to the other fields.

Waimangu and Waiotapu geothermal fields share a common heat source. The boundary between the Waikato Regional Council and the Bay of Plenty Regional Council passes between the two fields. Any future consideration by either Council concerning development at one of the fields must be taken in consultation with the other.

4.9 CONFLICT OF USE

The multiple values of geothermal resources inevitably leads to conflict of use.

The Rotorua geothermal field and the decline of Whakarewarewa is a classic case of conflict of use. Here, the scientific, cultural and scenic/tourism value of the geothermal resource at Whakarewarewa was in conflict with the residential and commercial value of the resource. One argument reasoned that without hot mineral pools, many of the motels would lose guests and therefore the local economy revenue would decline and actions such as the bore closures to protect Whakarewarewa was precipitous. Yet the continued future supply of those guests probably depended on the healthy displays of geothermal features at Whakarewarewa.

The Resource Management Act by assigning high priority to Maori perspective on geothermal resources will in the future raise the profile of the Maori cultural value of geothermal resources. This may in turn create new conflicts of use in previously non-conflict geothermal localities.

The greatest conflict of use that will be faced by Council will be that of energy (ie electricity production) versus other values. The volumes of fluid extracted and subsequent requirements for disposal make geothermal power stations the single greatest potential effect on any geothermal field. Evidence of subsidence, water pollution and destruction of natural surface features is clearly supplied by the example of the Wairakei geothermal power station.

The most recent example of conflict of use is demonstrated by the Kawerau geothermal field. Here, two energy producers are in conflict with the existing energy extraction (for industrial process heat and electricity generation) in opposition to the Savage Papakainga Trust who also proposes to utilise geothermal fluid for electricity generation.

CHAPTER FIVE

DATA SUMMARY OF BAY OF PLENTY GEOTHERMAL SITES

5.1 INTRODUCTION

The purpose of this section is to provide a concise listing of the pertinent information relating to the known geothermal localities of the Bay of Plenty. The information has been uplifted from "Concise Listing of Information on the Thermal Areas and Thermal Springs of New Zealand" by Mongillo and Clelland (1984). An update of this publication is currently awaiting approval by Ministry of Commerce for publishing. Where updated information or references are available, information from Mongillo and Clelland has been revised. A recent concern relating to the distribution of geothermal information has been the non-publication of material on grounds of potential commercial sensitivity.

5.2 DESCRIPTION OF GEOTHERMAL FIELDS

The location of geothermal localities in the Bay of Plenty is shown in Figure 5.1. For each identified geothermal locality, the following information is presented:

- i) Location (NZMS 260 coordinates);
- ii) Type of scientific investigations carried out;
- iii) Description of natural features;
- iv) Characteristics of natural features;
- v) Type and number of wells drilled;
- vi) Field data eg stored heat;
- vii) Current usage;
- viii) Environmental aspects or problems;
- ix) Named features associated with localities;
- x) References of investigations and data.

The intention of the listing is not to provide all known information about a geothermal locality, but to present the key facts and references to further more detailed information. The geothermal localities have been subdivided into geothermal prospects, areas and fields. The definition of these are:

Geothermal Prospect : is identified by the presence of natural geothermal features and/or cursory scientific studies, which

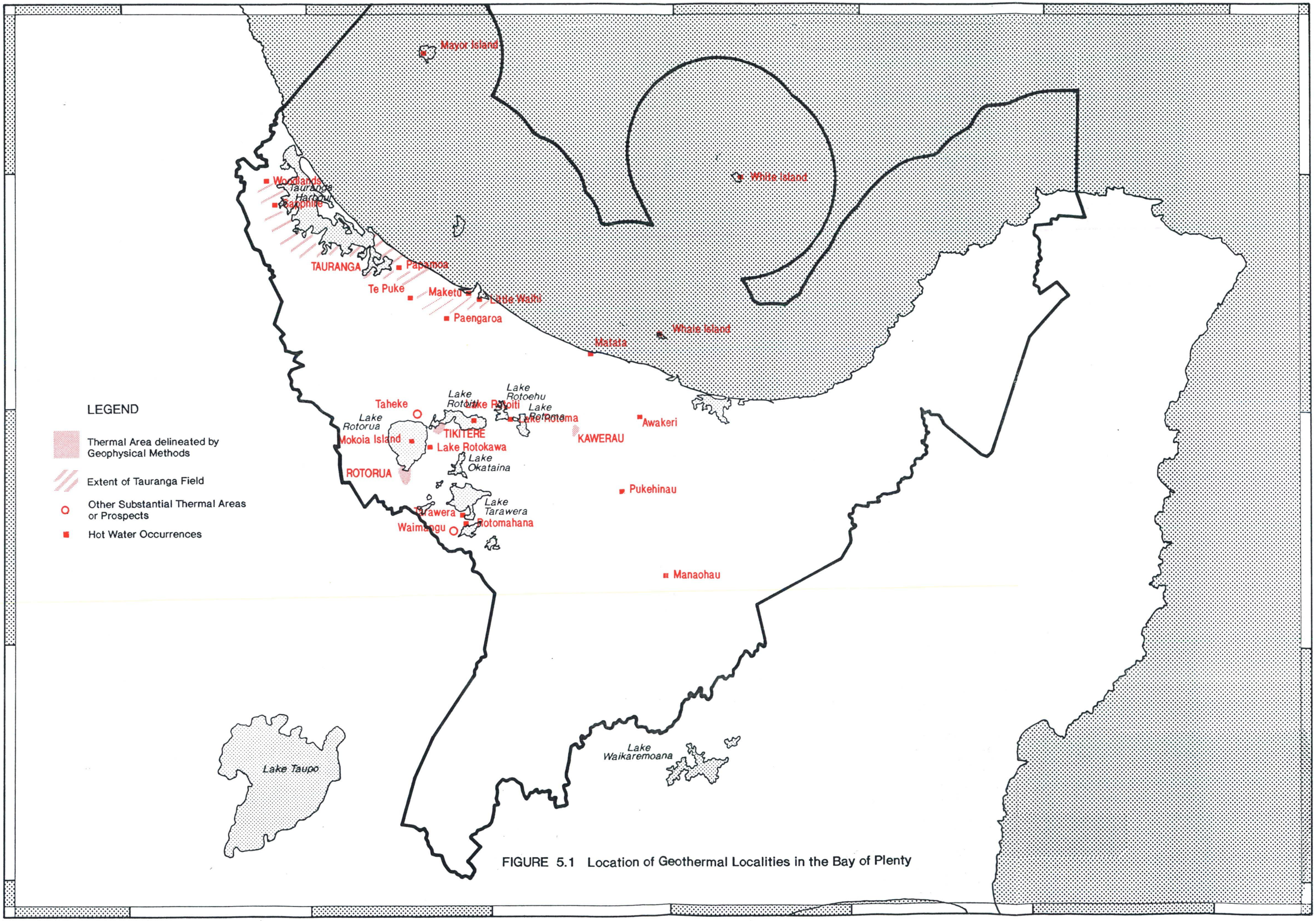

FIGURE 5.1 Location of Geothermal Localities in the Bay of Plenty

indicate the possible presence of a geothermal resource at depth;

Geothermal Field	:	is defined by the extensive scientific investigations which have been conducted, in particular, detailed resistivity surveys: and by the drilling and testing of deep drillholes. The energy content and productive potential of the locality have been reasonably assessed;
Geothermal Area	:	this is intermediate between a field and a prospect. Generally, no deep wells have been drilled and scientific studies, while often extensive, are incomplete.

Warm and hot springs are also included in the data summary. The geothermal localities and springs are listed in alphabetical order.
Where estimates of stored heat are provided, the calculations for the estimate is the same basis as that described in Tables 3.2 and 3.3.

5.2.1 Awakeri Hot Springs

Location: V15 : 2849200E/6347800N
Located about 3 km southwest of Awakeri railway station.

Scientific Investigations: Geological survey; chemical analyses and temperature measurements of spring and well waters; resistivity survey; seismic and inconclusive magnetic surveys.

Natural features: Hot springs.

Characteristics of natural features:

Springs:

Number: three hot springs (2 naturally occurring and one created by excavation).

Temperature: 58 - 69°C

Discharge: has declined since wells were drilled and produced from.

Heat Output: from original two springs, approximately 0.4 MW.

Wells drilled:

Investigation (general):

Number: four wells drilled (now cemented up).

Investigation (detailed): Hole M1
Depth: 104 m
Temperature: 48°C
Flow : artesian at Approximately 0.5 - 0.6 l/s

Production:

Number: six holes producing
Temperatures: 56 - 70°C
Total flow: artesian at approximately 50 l/s.
Depth: deepest well 98 m.
Water: weakly mineralised, neutral chloride bicarbonate

Field data: Temperature: maximum = 70°C

Use:

Present : springs and wells supply hot mineralised water for swimming baths.

Potential: probably low-grade heat source: could expand bathing facilities.

Environmental aspects:

Reserve: Pukaahu Hot Springs Recreation Reserve.

Named features/areas associated with field:

Within field: Pukaahu Hot Springs.

References: Glover (1968a)
Healy (1951)
MacPherson (1944)
Modriniak (1945)
Ministry of Energy (1983)
NZ Gazette (1941)
NZ Geological Survey (1974)

5.2.2 Kawerau Geothermal Field

Location

Located at Kawerau; on both sides of the Tarawera River.

Scientific Investigations: Geological survey; petrological studies; chemical analyses and temperature measurements of spring and drillhole fluids; shallow ground temperature studies; shallow and deep resistivity surveys; gravity and magnetic surveys; subsidence monitoring; analysis and interpretation of well measurements; corrosion studies; environmental investigations; stable isotope studies; production/reinjection study; industrial development; computer modelling of geothermal reservoir.

Natural features: Hot and boiling springs; steaming ground; hydrothermal explosion crater; gas vents; sulphur deposits.

Characteristics of natural features:

Springs:
- Size: cover an area about 1 kilometre long.
- Temperature: up to boiling.
- Waters: high in sulphate.

Steaming ground: Amount : 2 small areas

Wells drilled:

Investigation/production:

Number:	27 wells drilled, 7 presently producing.
Depth range :	433 m (KA5) - 1617 m (KA31).
Temperature range :	120°C (KA5) - 310°C (KA29)

Field data :

Area :	12 kms
Temperatures:	maximum = 310°C; production = 250°C.
Stored heat available:	7,700 PJ (T = 310°C).

Use :

Present : a shallow well supplies hot water to heat public recreation hall; Tasman Pulp and Paper Ltd utilise 7 wells for generating electricity (0.3 PJ/year) and industrial heat processing (0.9 PJ/year).

Potential : field is capable of expanding production.

Environmental aspects :

Subsidence : has been observed and is presently being monitored.

Reserves : Parimahana Scenic Reserve.

Other : possibility of hydrothermal eruptions.

Named features/areas associated with field :

Within field : Onepu Thermal Springs.

Reference :

Allis, 1982a
Allis, 1990.
Allis, 1991.
Bixley, 1991.
Browne, 1978.
Drew, 1982.
DSIR, 1962.
Finlayson, 1982.
Grant, 1982a
Healy, 1951.
Henly and Brown 1982.
Lawless et al., 1970.
Macdonald et al., 1970.
Mongillo, 1984a.
Ministry of Energy, 1983.
Ministry of Works and Development, Temperature Surveys.
Nairn, 1981.
Nairn, 1982.
NZ Gazette, 1979, p. 222.
New Zealand Geological Survey, 1974.
Sheppard, 1991.
Stewart, 1982.
Steward and Sheppard, 1980.
Wilson, 1982.

5.2.3 Lake Okataina Springs

Location: V16 : 2810900E / 6333600N
Located on the eastern shore of Lake Okataina, south of Oruaroa.

Scientific Investigations: Geological surveys; temperature measurements, gas analyses.

Natural features: Gas discharges; warm water seepages.

Characteristics of natural features:

Seepages:	Location:	occur in lake shore beach sands.
	Temperatures :	30 - 36°C
Gas discharges:	Occurrence:	bubbles rise in lake
	Composition:	mainly carbon dioxide.

Wells drilled: none.

Use: none.

Other information: none.

References : Nairn, 1981.

5.2.4 Lake Rotoiti Geothermal Area

Location: V15 : 2810500E / 6345400N
Located about 19 kms northeast of Rotorua City, in Centre Basin of Lake Rotoiti.

Scientific Investigations: Bathometry; heat flow surveys; gravity, magnetic and resistivity; chemical analyses of Moose Lodge well; environmental study; lake hydrodynamics studies; stable isotope studies; temperature measurements.

Natural features: gas bubbles; high heat flow in Centre Basin area; hot sediments.

Characteristics of natural features:

Heat flow:

Location:	high heat flow in Centre Basin.
Area:	approximately 2 km^2
Temperatures:	sediments = 130°C.
Thermal gradient:	in sediments = 63°C/m.
Heat flow:	total in lake estimated at 140 MW.

Wells drilled:

Moose Lodge (about 1 km west of Centre Basin):

Number:	1 well drilled.
Depth :	218 m.
Temperature:	maximum = 39°C.

Field data: no details.

Use :

Present : none known.

Potential: could be a large field

Environmental aspects:

Fluid disposal: geothermal effluent should not be discharged into Lakes Rotoiti or Rotoehu.

Other: an increased heat flow and reduced gas flow into the lake could affect fish life; the field maybe connected to the Tikitere Field.

Named features :

Within field : Centre Basin

References:

Coulter, 1981.
Colter and Spiegel, 1981.
Houghton et al., 1980.
Lyon, 1977.
Nairn, 1981.
NZ Geological Survey, 1974.

5.2.5 Lake Rotokawa Geothermal Area

Location: U16 : 2801100E / 6338100N
Located approximately 8 km NE of Rotorua City.

Scientific Investigations: Geological survey; resistivity survey; gravity and magnetic surveys; chemical analyses and temperature measurements of fluids from hot springs and drillholes; stable isotope studies.

Natural features: Hot springs.

Characteristics of natural features:

springs: Temperatures: 45 - 52°C.
Waters: slightly acidic and chloride.

Wells drilled:

Production: Number : eight shallow wells.
Depths : less than 45 m (for seven wells); 90 m (for one well)
Temperature range: 29 - 99°C.
Discharge : all wells discharge without pumping.

Field data

Area : Appears small

Use:

Present: Hot water for heating motel, glasshouse, school and swimming pools.

Potential: Sufficient for medium grade heat required by small industries.

Environmental aspects: May be connected to Rotorua Field.

Named features:

Within field: Maori Bath (artificial pool); Bubble Bay Spring.

References:

DSIR, 1974
Drolia et al., 1981.
Houghton et al., 1980.
Lyon, 1977.
NZ Geological Survey, 1974.

5.2.6 Maketu (Hot Springs) / Little Waihi

Location: V14 : 2813600E / 6375900N
The hot springs are located on the south side of Maketu Estuary.

Scientific Investigations: Temperature measurements of spring and well water; resistivity survey; chemical analyses of water from DSIR well and spring gas; 1 metre depth temperature survey.

Natural features: Warm springs.

Characteristics of natural features:

Springs:

Number	: 7 springs known.
Temperature range	: 44 - 49°C.
Gas	: marsh gas.

Wells drilled:

Production:

Little Waihi well

Temperature	: 30°C.
Flow	: artesian (0.3 l/s)

DSIR well

Depth	: 132 m.
Temperature	: 42°C.
Flow	: artesian

Artesian bore:

Temperature	: 39°C.
Flow	: artesian (0.08 l/s)

Use : not known.

References: Clelland, 1982.
Macdonald, 1982.
Rishworth, 1969.

5.2.7 Mangakotukutuku Springs

Location : V16 : 2819500E / 6336300N
Located about 18 kms west southwest of Kawerau, in the Mangakotukutuku Stream valley.

Scientific Investigations: Geological surveys; temperature measurements; chemical analyses.

Characteristics of natural features:

Springs: Temperatures: 12 - 24°C.
Waters : weakly mineralised.

Wells drilled: None.

Use: None.

Other information: Sodium/potassium geothermometer suggests deep fluid temperatures greater than 150°C.

Reference: Nairn, 1981.

5.2.8 Matata Geothermal Prospect

Location: V15 : 2840600E / 6361000N

Scientific Investigations: Regional resistivity survey.

Natural features: none known

Characteristics of natural features: none known

Wells drilled: none.

Field data: Existence inferred from resistivity anomaly.

Use: none.

5.2.9 Mayor Island Hot Springs

Location : U13 : 2800500E / 6429800N
Springs are located below high tide water level on the north and west coasts of the island.

Scientific Investigations: Geological survey; flow estimates.

Natural features: Warm springs.

Characteristics of natural features:

Springs : Flowing at a trickle.

Wells drilled: none known.

Use: none known.

References: Healy, 1948.
Petty, 1972.

5.2.10 Ngakuru Geothermal Prospect

Location: U17 : 2786600E / 6291700N

Scientific Investigations: Regional resistivity survey.

Natural features: none known

Characteristics of natural features: none known

Wells drilled: none.

Field data: Existence inferred from resistivity anomaly.

Use: none.

5.2.11 Papamoa Hot Spring

Location : Exact location not known.

Scientific Investigations: none known.

Use: none known.

References: Lawless et al., 1981.

5.2.12 Rotorua Geothermal Field

Location: Located in and underlies much of Rotorua City.

Scientific investigations : Geological surveys; resistivity surveys; gravity and magnetic surveys; hydrothermal activity mapped and described in detail; chemical analyses and temperature measurements of streams, hot springs and drill holes; aerial IR survey; spring and geyser monitoring programme; 1-m depth ground temperature survey; historical study; study of usage; botanical studies; mathematical modelling.

Natural features: Hot and boiling springs; geysers; bubbling mudpools; fumaroles; steaming ground; sinter deposits.

Characteristics of natural features :

Major activity : Whakarewarewa

Minor activity : Ohinemutu, Kuirau Park and Arikikapakapa

Springs/pools:

Number	: 500.
Temperatures	: up to boiling.
Waters	: acid-sulphate, some neutral chloride.
Gas	: discharged.
Odour	: strong hydrogen sulphide smell.

Geysers : Only remaining geyser field in New Zealand.

Sinter:

Area: Extensive siliceous sinter deposits associated with geysers and springs.

Wells drilled :

Production:

Number:	approximately 900 shallow wells have been drilled in an area of 1 km^2.
Depth range:	60 to greater than 220 m.
Depth:	most in range 90 - 120 m . a few greater than 220 m.
Temperatures:	less than 160°C (at 90 - 120m); one well at Whakarewarewa is 194°C(135m)
Discharge:	mostly alkaline-chloride water.

Field data :

Area : 10 km^2
Temperatures : maximum = 250°C; production = 150°C.
Stored heat available : 3,400 PJ (?)

Use :

Past:	Approximately 5000 tonnes of sulphur was mined from Sulphur Bay in early 1900's; old tourist attraction and bathing area.
Present:	Major tourist attraction; domestic and commercial heating and hot water supplies; source of water for swimming pools and mineral baths; hot house horticulture and soil sterilisation; kiln timber drying; large hotel air conditioning.

Environmental aspects :

Natural activity:	was under extreme stress prior to Bore Closure programme. Heat and chloride flow indicate system is recovering.
Reserves:	Whakarewarewa Reserve; Arikikapakapa Golf course Reserve; Rotorua Thermal Motor Camp Reserve; Kuirau Park Recreation Reserve; Rotorua City Recreational Reserve.
Other:	best location for thermal ferns

Named/features/areas associated with field:

Within field: Whakarewarewa; Puarenga Stream; Kuirau Park; Ohinemutu; Arikikapakapa; Pohutu Geyser; Mokoia Island; Waipa; Ngapuna; Government Gardens.

References :

Bradford, 1987.
Bradford, 1990.
Bradford, 1991.
Bradford, Cody and Glover 1987.
Bradford, Timpany and Murray 1986.
Cody and Lumb 1991
DSIR, 1974.
Given, 1976.
Given, 1984.
Glover, 1967a.
Glover, 1988
Grant and Bradford, 1983.
Grant and Donaldson, 1980.
Grant and Lloyd, 1980.
Iles, 1982.
Lloyd, 1975.
Mongillo, 1984a.
New Zealand Geological Survey, 1974.
NZ Gazette: 1908, p.849; 1947, p 1920; 1964, p. 1809;1975. p.776;
Simpson 1985
Thompson, 1980.
Wood, 1983.

5.2.13 Sapphire (Katikati) Hot Springs

Location : T14 : 2748100E / 6377800N
Located 5 kms southwest of Katikati.

Scientific investigation: Geological survey; temperature measurements and chemical analyses of waters.

Natural features: Warm springs.

Characteristics of natural features:

Springs:

Temperature : 36°C.
Gas : carbon dioxide evolved from spring bottom.
Existence : now filled in.

Wells drilled:

Number : 1 well drilled.
Depth : 61 m.
Temperature : 39°C.

Use:

Present : used for swimming pools.

Other information:

Reserve : Sapphire Hot Springs Reserve.

References:

Petty, 1972.
NZ Gazette, 1976, p. 1570.

5.2.14 Tauranga Geothermal Field

Location : Located in Tauranga Basin on north and east side of Kaimai range.

Scientific Investigations: Geological survey; chemical analyses of hot spring and drillhole waters; temperatures of hot springs and drillholes; 1 metre depth temperature survey; seismic survey (along Kaimai Tunnel line); temperature gradients in many drillholes.

Natural features : Hot springs.

Characteristics of natural features:

Springs:	Temperature range :	22 - 39.3°C.
	Flows :	believed to be small.

Wells drilled:

Production:

Number	: in excess of 100 producing wells.
Depth	: 60 - 450 m.
Temperature	: 20 - 54°C.
Discharge	: ranges from artesian flow (about 2 l/s) at 30°C to 127 l/s under pumped conditions.
Water	: slightly mineralised and of chloride-bicarbonate type.
Contamination	: seawater contamination in some wells.

Field data:

Thermal gradient : 2 - 4 times normal for whole area.

Use:

Present: Public and private swimming baths

Potential: Temperatures are too low for steam generation; could probably support extensive domestic and commercial heating and use in low grade heat industries.

Environmental aspects:

Reserve: Mt Maunganui Thermal Pool Domain.

Named features :

Within field: Welcome Bay Springs; Te Puna Springs; Mt Maunganui Hot Springs.

References:

Healy, 1984b
Ministry of Energy, 1983.
NZ Geological Survey, 1974.
Simpson, 1987.
Simpson and Stewart,1987.
Stewart, Downes, McGill, Taylor and Whitehead 1984.
Thompson, 1980.
NZ Gazette, 1889, p. 116; 1983, p. 2462.

5.2.15 Pukehinau (Waikokopu) Hot Springs

Location: V16 : 2848500E / 6323400N
Located near Urewera National Park adjacent to Waikokopu Stream at Pukehinau Stream confluence.

Scientific Investigations : none known

Natural features : Warm spring

Characteristics of natural features: none known

Wells drilled: none known

Use : none known

Other information : Located on Maori land.

References:

Department of Lands and Survey, 1983.
Lawless et al., 1981.

5.2.16 Rotoma Geothermal Area

Location : V15 : 2821900E / 6345500N
Located about 26 km northeast of Rotorua City.

Scientific Investigations: Geological survey; gravity survey; chemical analyses of spring waters; spring flow and temperature measurements; stable isotope studies.

Natural features: Warm springs; warm stream; seepages; warm sinter/sulphur pans; patches of sulphur and alum deposition; extensive hydrothermally altered ground; fumaroles.

Characteristics of natural features:

Springs:

Temperatures	: 27 - 50°C.
Flows	: 11.3 - 53.1 l/s.
Water	: chloride-bicarbonate type.

Fumaroles:

Size	: small
Temperatures	: 90°C.

Sulphur deposition :

Number	: few patches of active deposition.
Temperatures	: up to 97°C.

Wells drilled :

Prospecting holes:

Number	: 5 sulphur prospecting holes drilled.
Depths	: 30 - 70 m.
Temperature	: 120°C at 30 m depth.
Eruption	: steam erupted from one well at 30 m depth.

Production :

Location	: wells at Stillwater Lodge.
Discharge	: pumped to produce.
Temperature	: 35°C
Water	: bicarbonate type.

Field data:

Area :	5 km^2 (?)
Temperature :	134°C.
Stored heat available:	not known.

Use:

Present : wells pumped at Stillwater Lodge to obtain bicarbonate water.

Potential : though little known at present, power generation potential could be considerable.

Environmental aspects:

Fluid disposal: undesirable to discharge geothermal effluent into Lake Rotoehu.

Named features:

Within field: Waitangi Soda Spring; Otei Hot Spring; Tikorangi Springs.

References:
Hochstein, Yamada, Kohpina and Doens, 1987
Bromley, Bottomley and Pearson, 1988
Ministry of Energy, 1983.
Nairn, 1981.
NZ Geological Survey, 1974.
Taylor et al., 1977.

5.2.17 Taheke Geothermal Field

Location: U15 : 2804900E / 6351900N
Located about 20 km north northeast of Rotorua City.

Scientific Investigations: Geological survey; chemistry of spring waters and gases; temperature measurements; gravity, heat flow, magnetic and resistivity surveys.

Natural features: Fumaroles; sinter pans; deposits of crystalline sulphur; small springs; seepages.

Characteristics of natural features:

Springs/pools:

Temperatures:	57 - 97°C.
Flow:	total from main thermal area = 6 - 18 l/s
Water:	extremely acidic.
Gas:	large amounts of gas (carbon Dioxide and hydrogen sulphide) being discharged.

Fumaroles:

Temperatures (steam): up to 99°C.

General activity:

Type: acid-sulphate steam heated.

Wells drilled: none

Field data:

Area:	2 km^2
Natural heat flow:	12.8 MW (relative to 12°C.)

Use:

Present:	Hot water used for bathing; small amounts of sulphur have been mined.
Potential:	Unknown.

Environmental aspects:

Other:	No apparent problems; may be connected to Tikitere Field.

Named features: None known.

References: DSIR, 1974.
Espanola, 1974.
NZ Geological Survey, 1974.
Sheppard and Lyon, 1979.

5.2.18 Tarawera Geothermal Area

Location: V16 : 2810300E / 6323400N
Located 19 kms southeast of Rotorua City at Te Rata on the southern shore of Lake Tarawera.

Scientific Investigations: Geological survey; chemistry of springs; gravity survey; spring temperatures and flows measured.

Natural features: Hot springs; fumaroles; warm ground.

Characteristics of natural features:

Springs:

Temperatures:	37 - 90°C.
Total discharge:	approximately 100 l/s.
Waters:	near neutral with moderate chloride.
Deposits:	depositing iron.

Fumaroles:

Temperatures:	55 - 70°C.

Wells drilled: none.

Field data: none.

Use:

Present: Springs used for bathing.

Potential: Field appears small and not significant for electricity generation.

Environmental aspects:

Fluid disposal: Undesirable to increase flow of geothermal fluids into Lake Tarawera.

Other: Field may be connected to Waimangu Geothermal Field.

Reserves: Lake Tarawera Scenic Reserve.

Named features:

Within field: Te Rata Bay (Hot Water Beach) Hot Springs; Te Puha; Tarawera Fumaroles.

References: Houghton et al., 1980.
Nairn, 1981.
NZ Geological Survey, 1974.

5.2.19 Tikitere (Ruahine Springs) Geothermal Area

Location: U15 : 2806300E / 6373500N
Located about 16 kms northeast of Rotorua City and south of Lake Rotoiti.

Scientific Investigations: Detailed geological surveys; chemical analyses and temperature measurements of springs (water and gas) and deep wells; gravity, heat flow and magnetic surveys; resistivity survey; botanical survey; stable isotope studies.

Natural features: Hot and boiling springs and pools; seepages; steaming and highly altered ground; sulphur deposits; gas discharges.

Characteristics of natural features:

Hydrothermal activity:
Area: covers approximately 0.25 km^2.

Springs/pools:
number: several hot/boiling springs
temperatures: 30 - 98°C.
waters: acid-sulphate at higher elevations; chloride-bicarbonate at lower elevations.
flows: less than 1 l/s.
gas: large quantities of gas being discharged.

Wells drilled:

Shallow wells:
Hells Gate:
Number: six shallow holes.
Location: outside the 20 ohm meter contour.
Depths: 70 - 110 m.
Discharges: steam and hot chloride water.
Temperatures: estimated downhole = 140 - 190°C.

Haupara Bay area:

Number:	five holes.
Depths:	deepest = 330 m, others less than 220 m.
Temperatures:	74°C (195m), 39°C (218m), 91°C (330m).

Field data:

Area:	10 km^2
Temperature:	Estimated = 250°C.
Stored heat available:	6,230 PJ
Natural heat output:	Estimated about 120 MW (relative to 12°C).
Reservoir fluid:	Chloride-bicarbonate waters.

Use:

Past: About 5,000 tonnes of sulphur was mined from surface areas.

Present: Hot water from wells provides heating for mushroom growing, a holiday camp, and private baths; major tourist attraction at Hell's Gate.

Potential: Very promising, estimated power potential of 100 - 200 MW (similar to Broadlands field).

Environmental aspects:

Fluid disposal: Undesirable to discharge geothermal fluids into Lakes Rotoma and Rotoiti.

Natural activity: Exploitation could adversely affect surface activity at Hells Gate tourist area.

Other: Phreatic eruptions have occurred (1966).

Named features:

Within field: Parengarenga Springs; Manupairua Springs; Papakiore Bath; Hell's Gate Thermal Area; Maraeroa Springs; Otutarara Springs and Ruahine Springs.

References: DSIR, 1974.
Espanola,1974.
Given, 1978.
Houghton et al., 1980.
Klyen, 1970.
Lyon, 1977.
Ministry of Energy, 1983.
Nairn, 1981.
NZ Geological Survey, 1974.
Sheppard and Lyon, 1979.

5.2.20 Waimangu - Rotomahana Geothermal Area

Location: U16 : 2807900E / 6319200N
Located 22 km southeast of Rotorua.

Scientific Investigations: Geological survey; resistivity surveys; chemistry and temperature measurements of hot springs (waters); monitoring of flow and temperature of Frying Pan and Inferno Crater Lakes; study of hot spring flora and fauna; botanical survey.

Natural features: Hydrothermal explosion craters; hot and boiling springs; geysers; crater lakes; steaming cliffs; fumaroles; altered ground.

Characteristics of natural features:

Springs: Temperatures: up to boiling.
Fluid : alkaline chloride waters

Lakes:

Inferno Crater Lake:

Water: Discharges are acid sulphate.
Depth: Fluctuates cyclically by up to 10 m.
Temperature: 66 - 81°C.

Frying Pan Lake:

Water: Discharges are acid sulphate.
Flow : 120 l/s
Temperature: 56°C.

Field data:

Area: 12 km^2.

Temperature:	Maximum = 270°C.
Stored heat available:	5,400 PJ

Use:

Present:	Tourism.
Potential:	Not known

Environmental aspects:

Fluid disposal:	must avoid polluting Lakes Rotomahana and Tarawera.
Reserves:	Waimangu Scenic Reserve
Other :	Possible connection with Waiotapu; an active and unstable field; one of the best locations of geothermal vegetation in New Zealand.

Named features:

Within field:	Frying Pan lake; Inferno Crater; Echo Crater; Trinity Terrace; Southern Crater; Black Crater; Iodine Spring; Haumai Hot Springs.

References:
Given, 1976.
Given, 1984.
Glover, 1968b.
Houghton et al., 1980.
Lawless et al., 1981.
Ministry of Energy, 1983.
Nairn, 1981.
NZ Gazette, 1903, p.1201; 1910, p.3824 and 3825; 1922, p.1701.
NZ Geological Survey, 1974.
Scott and Lloyd, 1882.

5.2.21 Whale Island Geothermal Area

Location: W15 : 2859000E / 6364600N
Located eight kms offshore in Bay of Plenty, eleven kms north northwest of Whakatane.

Scientific Investigations: Geological survey; chemical analyses of spring waters; temperature measurements of springs and fumaroles; flora and fauna studies; 1 metre depth temperature survey.

Natural features: Hydrothermally altered ground; fumaroles; deposition of crystalline sulphur; sinter; hot water flows; hot and steaming ground.

Characteristics of natural features:

Springs : Location : occur near sea level.
Temperature: 98°C.

Sinter: Location : Sulphur valley
Type : Siliceous in composition.

Fumaroles: Temperatures: 57 - 100.8°C.
Deposits : Depositing sulphur.

Hot water flows: Temperature : 98.5°C.
Flow : 5 l/s.
Waters : sulphate rich.

Hot ground: Temperature: 45°C (at 15 cm depth) to 100°C (steam vents)

Wells drilled: none

Field data: none

Use:

Present: none.

Potential: Could possibly produce 5 - 10 MW electricity.

Environmental aspects:

Other: Maori occupation site.

Named features:

Within field: Sulphur valley.

References: Healy, 1948.
MacPherson, 1944.
NZ Geological Survey, 1974.

5.2.22 White Island (Whaakari)

Location : W13 : 2879900E / 6400200N
Located in the Bay of Plenty approximately 50 km northeast of Whakatane.

Scientific Investigations : Detailed geological surveys; botanical study; chemical analyses and temperature measurements of fumarole gases and hot springs waters and gases; soil survey; detailed surface mapping; microbiological studies; bird and mammal studies.

Natural features : White Island is an active andesitic volcano having the associated volcanic features:- hot springs and pools; fumaroles; sulphur deposits; hydrothermally altered ground; gypsum deposits; mounds of decomposed rock.

Characteristics of natural features:

Springs/pools:

Number: a few on crater floor.
Temperature : some boiling vigorously.
Waters : contain unusually high quantities of free acids and dissolved solids.
Gas : (mostly carbon dioxide) is evolved from springs and pools.

Fumaroles :

Size : Range from small to huge.
Temperature: 100 - 350°C.
Discharges : emit both wet and dry steam.
Deposits: some depositing sulphur, with some mounds up to 1.2 m high; molten sulphur around some steam vents.

Gas: emitted (mostly carbon dioxide with smaller amounts of sulphur dioxide, methane and hydrogen).

Gaseous emissions :

Composition: large quantities of sulphur dioxide emitted; hydrochloride acid fumes present.

Wells drilled: none

Characteristics of island: Area : 4.8 km^2

Use :

Past : mined sulphur and gypsum.

Present : private scenic reserve.

Potential : chiefly of scientific value.

Environmental aspects :

Reserve : The island is gazetted as a private scenic reserve.

Named features : Schuberts Fairy Fumarole; Noisy Nellie Fumarole; Little Donald Fumarole; Big Donald Fumaroles; Schubert's Earl King Fumaroles; The Seven Dwarfs Fumaroles.

Reference : Hamilton and Baumgart, 1959.

CHAPTER SIX

GEOTHERMAL MONITORING

6.1 GENERAL

The geothermal resource of the Bay of Plenty is poorly monitored at present. A number of fields are heavily monitored while the majority have no ongoing monitoring. Information known about the majority of geothermal localities is minimal (reference Chapter Five) and tends to relate to work carried out prior to 1980. In many cases, information dates back to the 1950's. It is perhaps appropriate that Council give consideration to a programme of updating key information (ie pressures, temperatures and discharge rates) relating to geothermal resources within its region.

6.2 CURRENT MONITORING

Geothermal fields currently undergoing some monitoring are:

- i) Rotorua
- ii) Kawerau
- iii) Waimangu
- iv) Tauranga

6.2.1 Rotorua

This is the only geothermal area where the Bay of Plenty Regional Council is directly involved in monitoring. This field, prior to the Bore Closure programme, was subject to extreme stress. A comprehensive investigation of the field and subsequent production of a management plan was undertaken. To aid in continuing assessment of both the field and management policies, a monitoring programme for the Rotorua field was established. This included monitoring of geothermal pressures, groundwater levels, temperatures, outflow from springs and other geothermal features in Whakarewarewa, chemistry of geothermal features, rainfall, barometric pressure, flows in the Puarenga Stream and regular assessment of the behaviour of the geothermal features.

Council staff now undertake hydrological measurement of the Puarenga Stream and discharges of various springs in the area. Assessment, measurement of flow and chemistry analysis of springs and geysers around Rotorua is also undertaken by Council staff. Remaining specialist monitoring (ie downhole temperature logging, chemical analysis, mathematical manipulation of data) is remains with DSIR.

6.2.2 Kawerau

Monitoring of this field is indirectly influenced by Council via conditions attached to water rights (Nos 20004 - 20009, 1617, 1619 and 2635) associated with geothermal exploitation of the field. Monitoring information collected includes ground subsidence monitoring and monitoring of the geothermal discharges to the Tarawera river (flow and chemistry). It is interesting to note that the right to geothermal fluid (No 1617) has no condition attached requiring monitoring and reporting of extraction rates and volumes.

The Crown also has a significant data collection programme operating within the field. Information from this programme has been sufficient to create a model of the Kawerau geothermal system.

6.2.3 Waimangu

This field has been monitored for twenty years by the DSIR. Monitoring includes flow, temperature and water level. The value of Waimangu is that it is unaltered and thus cause and effect can more easily be understood. Waimangu provides an excellent representation of natural behaviour (ie in response to rainfall) and therefore can be used to help understand behaviour in the Rotorua Field. Waikato Regional Council is currently negiotating with DSIR for the Waimangu information as their field Waiotapu is interconnected. DSIR and Waikato Regional Council has approached the Bay of Plenty Regional Council in regard to BOPRC continuing monitoring at Waimangu.

6.2.4 Tauranga

This field has upwards of 100 bores extracting low temperature (30 -35°C) water. The majority of these have water rights. The Regional Council currently monitors 6 bores, for water level and chemistry, within the field as part of the Non-Geothermal Groundwater Regional Monitoring Network.

6.3 FUTURE REQUIREMENTS

The potential for proliferation of ORMAT power station in the Bay of Plenty requires Council to put in place monitoring programmes at the more significant geothermal localities in the Bay of Plenty.

A minimum requirement for the granting of permits associated with development of a geothermal resource is a management plan which would contain comprehensive monitoring requirements. These would include monitoring of pressure, temperature, chemistry and production. For most of the sites where ORMAT technology could be applied, little is known about the ongoing sustainability of the resource. For this reason, permits should be granted for a short term so as to assess the impact of such commercial activities on the resource.

CHAPTER SEVEN

SUMMARY

The Bay of Plenty region has the highest concentration of geothermal resources in New Zealand. The majority of these resources are contained within the Taupo Volcanic Zone, an area of active volcanism with magma occurring at shallow depth. The surface expression of the geothermal resources range in nature from warm springs through boiling mudpools to impressive geysers.

Historically, legislation controlling the regulation and management of geothermal resources has been fragmentary and inefficient. The enactment of the Resource Management Act has redefined and reorganised the management of geothermal resources. Regional Council functions under the Act in respect of geothermal resources include preparation of management plans; preparation of objectives and policies in respect of use, development and protection of land and the control of the taking or use of geothermal energy. The Act also puts new emphasis on the position of Maori in respect of ownership and management of the geothermal resources.

Geothermal sites and systems have intrinsic and extrinsic values which must be considered when examining a geothermal site or proposal involving the use of a geothermal site. These values can be described as: scenic/tourism; national heritage; cultural; extractive; therapeutic/medicinal and scientific/vegetation.

Exploitation of geothermal resources is not without hazards or impacts which may impinge on the values listed above. The major impacts can be described as; destruction or change of surface features; subsidence; hydrothermal eruptions; discharge of contaminants; destruction or modification of fauna and flora and conflict between uses.

The level of information known about the individual geothermal localities varies greatly. Fields such as Rotorua, Waimangu and Kawerau have a wealth of information available including operational computer models (eg Rotorua and Kawerau), reflecting the scientific, cultural and commercial value of these fields. Whereas other sites are only recognised on the basis of resistivity anomalies and therefore little is known about them.
The majority of geothermal sites, however, have undergone some scientific investigation and have limited information available. This limited information is generally insufficient for management purposes.

The geothermal resources of the Bay of Plenty are poorly monitored with monitoring programmes currently in operation at only four fields: Rotorua, Waimangu, Tauranga and Kawerau. The Rotorua and Tauranga fields are the only fields where the Regional Council is directly involved in monitoring. The potential for proliferation of ORMAT power stations in the Bay of Plenty requires Council to put in place monitoring programmes at the region's more significant geothermal localities.

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