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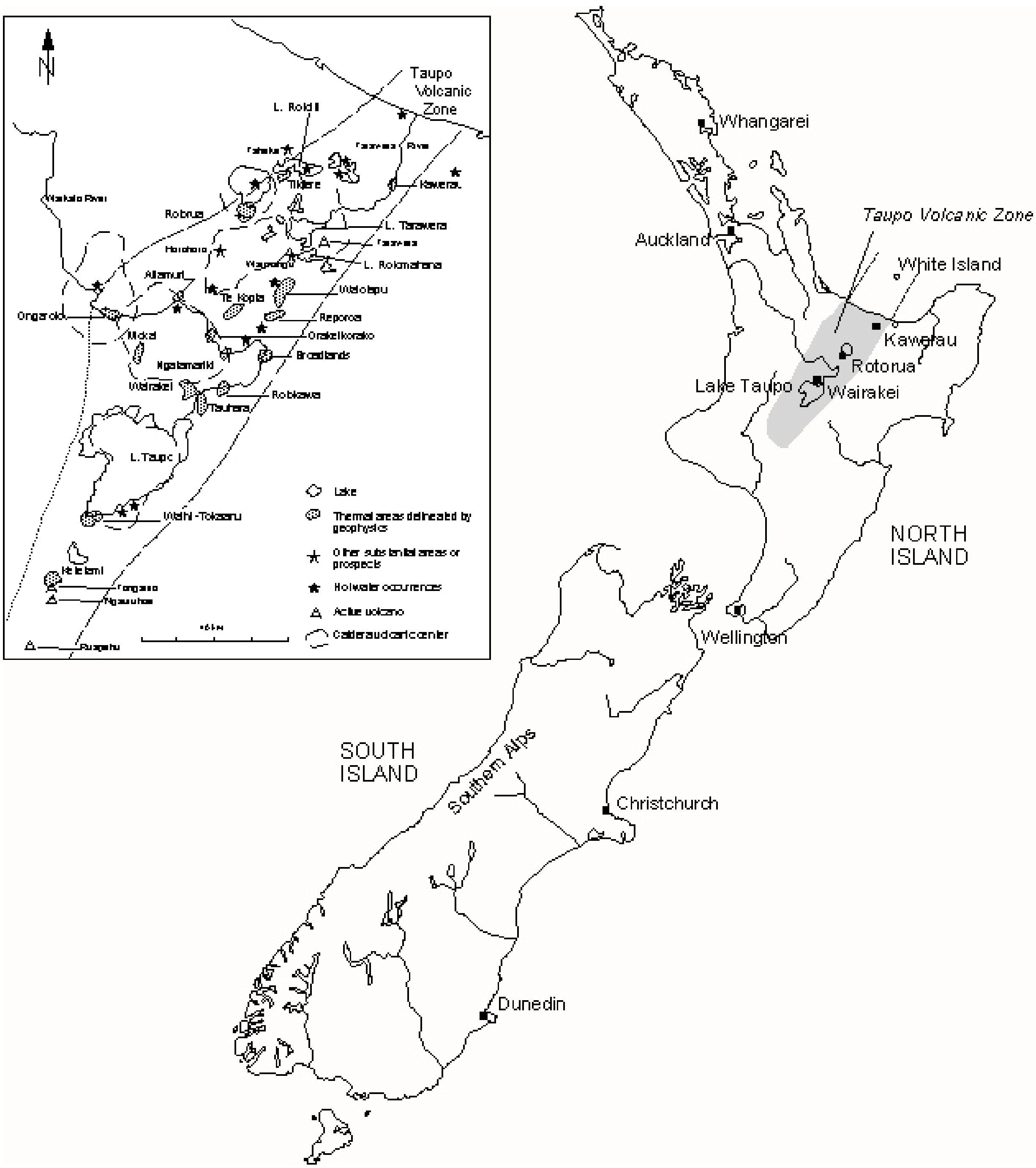
NEW ZEALAND GEOTHERMAL
Wairakei - 40 years



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A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

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A BRIEF HISTORY OF THE WAIRAKEI GEOTHERMAL POWER PROJECT

Ian A. Thain,
President New Zealand Geothermal Association

INTRODUCTION

November 15, 1998 marks the 40th anniversary of the commissioning of the first generator at Wairakei geothermal power station, in New Zealand. At that time it was only the second geothermal plant in the world to begin commercial operation and the first to exploit a wet geothermal resource. This paper briefly traces the development and operational history of this pioneering development and in particular the efforts made to keep the plant supplied with steam.

THE LARDARELLO INFLUENCE ON THE DEVELOPMENT

The impetus for the development of Wairakei came in 1947 from severe electricity shortages following two dry years which restricted hydro generation and a desire by the Government for the New Zealand electricity supply to be independent of imported fuel.

During World War II government scientists arranged for New Zealand army engineers serving with the British 8th Army, in the Italian campaign, to visit, inspect and report on the Lardarello geothermal power development in Tuscany. Unfortunately when the army engineers got to the plant in June 1944 it had been totally destroyed.

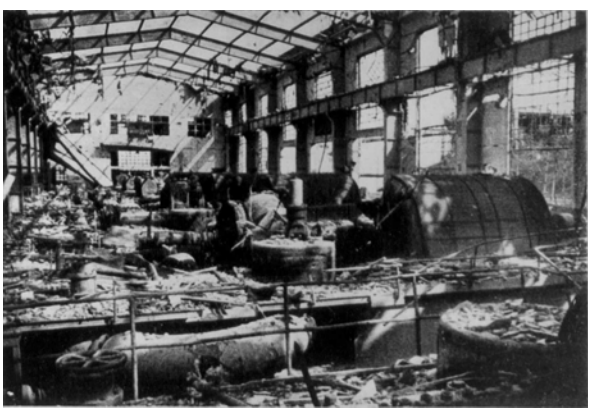

Figure 1. Destroyed Lardarello No 2 Station Turbine Hall.

In 1948 visits were again made by New Zealand engineers to Lardarello. This time they found rebuilt power plants producing over 140MW and the Lardarello No III station (142MW) in an advanced stage of construction.

While observations at Lardarello were important in providing the New Zealand engineers with an understanding of the overall approach to harnessing geothermal power, the dry steam resource was so different from the wet geothermal resource at Wairakei that its development would have to depend on exploiting technology designed in New Zealand.

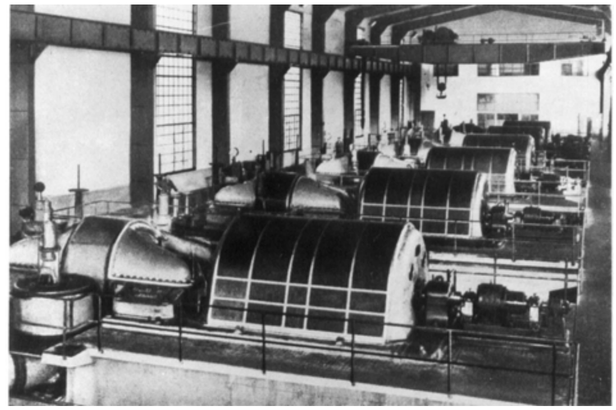

Figure 2. Rebuilt Lardarello No2 Station Turbine Hall.

Perhaps Lardarello`s most important contribution to the Wairakei development was its success and the enthusiasm the Italian engineers displayed for this type of power plant, because there is no doubt that these factors strongly influenced the New Zealand decision to proceed with a geothermal power development at Wairakei.

INVESTIGATION AND PROJECT DEVELOPMENT (1949 to 1958)

In 1949, a project development team was established and drilling together with scientific investigations proceeded rapidly so that by late 1952 steam capable of producing 20MW of electric power had been proven by shallow drilling (300m). Prospect of greater output from deeper drilling was also confidently predicted and larger drilling rigs were ordered. Important metallurgical research, into the corrosion effects of the Wairakei geothermal brine, were also completed about this time and these showed that mild steel could be used for the geothermal above ground systems without suffering any major corrosion effects. . Mishaps during this early development period were few, but when they did occur, it helped if one had a good turn of speed.

The initial project at Wairakei was conceived as a combined power station and a heavy water plant. This was to be a joint venture between the New Zealand Government and the United Kingdom Atomic Energy Authority (UKAEA). Conceptual designs were progressed and in late 1954 funding was approved to build a plant capable of producing 47MW of electric power and 6 tonnes per year of heavy water. However, principally because of major cost increases in the cost of the heavy water plant the UKAEA pulled out of the project in January 1956. As contracts for the turbine generators had been let in mid-1955 and their fabrication well advanced, it was

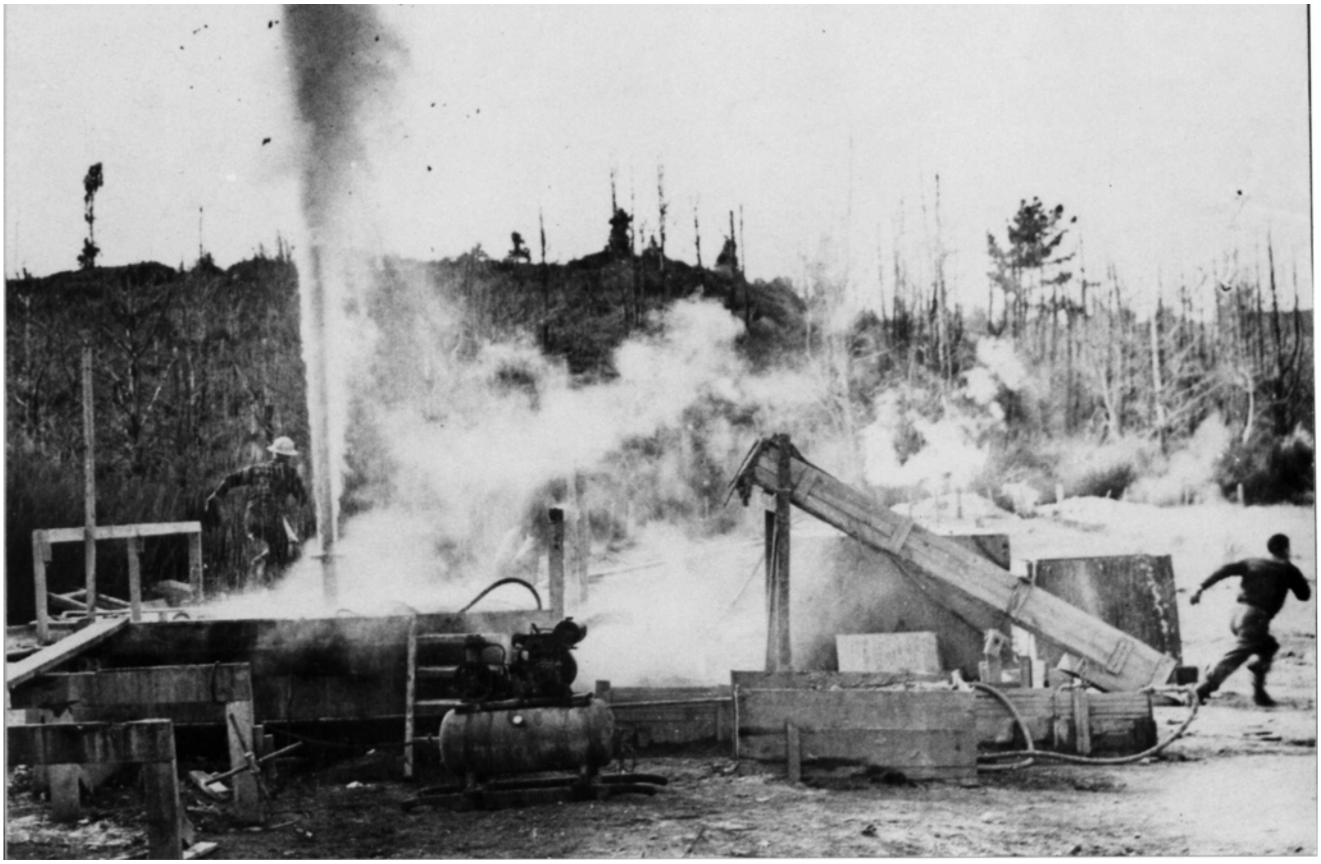

Figure 3. **Techniques and safety standards have improved significantly since the early 1950`s but still present is the pioneering element exemplified by this early Wairakei photograph.**

decided to proceed with the existing power plant design and to incorporate two intermediate pressure (IP) 11MW turbines generators in place of the heavy water plant. The Wairakei "A" station project initially was to consisted of two high pressure(HP)6.5 MW units; two intermediate pressure (IP) 11.2 MW units; and three low pressure (LP) condensing 11.2MW units giving an installed capacity of 69MW. The inlet pressure on the LP units was just above atmospheric pressure.

Meanwhile on the steamfield the larger drilling rigs had been very successful in winning more high pressure fluid at the greater depth. A two pressure system was evolved to tap the field; high pressure (HP) which produced flashed steam at the well head of around 13.5 barg (196 psig) and intermediate pressure IP producing flashed steam at 4.5 barg (65 psig). As a result of the greater output two HP 11 MW units and an additional LP 11 MW condensing unit were added to complete the Wairakei "A" Station (Stage I) development. This enhanced Stage I design also incorporated a pilot hot water flash plant which was sited adjacent to the power plant building and was fed with separated water from five HP wells and two IP wells. The very successful tangential entry bottom outlet steam separator was developed. (Wairakei Separator).

Construction of Stage I was not that far advanced when proposals for additional generating capacity were approved because even more steam than expected had been found. This resulted in the development of the Wairakei "B" Station which consisted of three mixed pressure (MP) condensing 30 MW generating units. The steam supply to the MP units consisted of 3.5 barg (50 psig) at inlet with pass in steam at slightly above atmospheric pressure (2 psig) to the machines LP cylinder. This brought the total installed capacity of the Wairakei development to 192.6MW.

A further extension of the "B" Station was allowed for in the design which would have consisted of two more 30 MW mixed pressure units.

The Power Station is located adjacent to the Waikato River from which it draws once through water for the direct contact condensers. The centre of steam production is approximately 3.5 km (2.2 miles) from the power station and steam is transmitted to the station via three 760mm (30 inch) and five 508mm (20 inch) diameter pipelines.

On 15 November 1958 the first set in the "A" Station was synchronized to the national grid. The remaining machines and plant of the "A" and "B" developments proceeded at regular intervals, the last machine being synchronized to the grid in October 1963.

SETTING THE PLANT TO WORK AND DEVELOPMENT SHORTFALLS (1958 to 1968)

The setting to work of the power plant caused unexpected draw down and a rapid pressure decline of steamfield output. Secondly, the pilot hot water scheme had to be abandoned, for whilst it had operated successfully for a short period, the wells which were connected to it change to become dry steam producers and the plant became starved of separated water. At this time no consideration was given to connecting additional wells to it as it was thought that they in turn would change with time to become dry steam producers.

With the commissioning of the "B" Station 30MW units it became necessary to drill more production wells to make up for the rapid drop in well output. Production drilling continued through the early and mid 1960`s and the peak power of 173 MW was achieved in 1965, some 19 MW short of the installed capacity. However, this drilling was ended shortly afterwards when it was realized that the effort was yielding ever diminishing returns.

From 1958 to 1968 the "at depth" reservoir pressure of the Wairakei field dropped from 58.6 bar g (850 psig) to 40 bar g (580 psig). [The reservoir "at depth" pressure being obtained from a selection of wells measured at a depth of 275 m (900ft) below sea level.]

The field management strategy adopted in the late 1960`s was to:

- hold mass output from the field at the current production level of around 50 million tonnes per year;

- to sacrifice HP machine output by progressively reducing HP well head pressure in order to maintain fluid flow and thus ensure that the IP, MP, and LP machines were fully supplied with steam at design pressure;

- to implement measures which would make more efficient use of the total energy discharged from the field and improving the reliability of the generating plant.

PERIOD OF CONSOLIDATION (1969 to 1982)

The use of flashed steam from separated HP borewater was not abandoned with the demise of the pilot hot water scheme. The process was instead moved to the steamfield where double flash units were installed adjacent to HP wells. These units were initially designed to be portable so that they could be moved in the event of the wells changing to become dry producers as had happened with the pilot hot water scheme. The well head double flash process was very successful and in 1974 the scheme was extended to triple flashing so as to extract intermediate low pressure, 1.7bar g (25 psig) (ILP) steam by flashing separated IP borewater at steamfield located central flash plants. A major part of this project was the construction of an ILP steam pipe, of 1.22 m (48 inch) diameter to carry the 1.7 bar g steam to the power station. There the ILP steam was passed through pressure reducing valves to reduce the pressure to 0.05 bar g (2 psig) to make suitable for passing into the A Station LP machines and as pass in steam to the B Station MP Machines.

Over the next few years a policy of connecting previously unused wells and piping additional water to the flash plants to maximize the use of the flash plants and the new ILP steam transmission line was pursued. When Wairakei was commissioned only 4.5 percent of the total energy above 0 deg C was converted to electrical energy, with the optimizing of the triple flash system in the late 1970`s this conversion factor had been increased to over 8.5 percent.

By 1981 the HP had been progressively reduced to about 7 bar g (100 psig) and the shortfall in IP and LP machine generation had fallen below what was being generated by the HP machines. Studies showed that a net gain in generation would be achieved by completely decommissioning the HP system and derating all HP wells to IP conditions.

Derating the HP system was carried out in November 1982 and this involved both wellhead and major flash plant modifications plus the installation of flow balancing crossovers on the steam transmission lines. This exercise resulted in the installed capacity of the plant being reduced to 157.2 MW (Gross)

The main reactions of the Wairakei reservoir to exploitation up to this point in time had been:

- after an initial very rapid fall, the "at depth" pressure of the field had now become relatively stable, which indicates that the mass withdrawal from the field was being balanced by a similar amount of natural recharge;

- despite the near stabilization of the "at depth" pressure and mass withdrawal the apparent enthalpy of the fluid continued to decrease slowly, reflected by annual decline in fluid temperature of around 0.5 deg. C per year; indication the system was being slowly mined of its heat by the production process.

- the water level in the reservoir had been drawn down approximately 200m (650 ft)

After decommissioning the HP system it became field management policy to once again tap the field in order to sustain full load on the remaining installed plant.

FIELD MANAGEMENT AND STEAM WINNING (1982 to 1997)

In 1983 three additional existing wells, drilled in the mid 1960`s for a proposed new power development on the north western sector of the field known as the Te Mihi area, were connected into the Wairakei steam transmission system This required extending the steam collection system by a further 3 km (approx. 2 miles) further from the power station. The output from these three wells were expected to keep the Wairakei plant fully loaded until 1987/88. This however did not materialize due to the resultant increase in pressure drop within the extended steam transmission system pushing up production wellhead pressures. This caused the output of all production wells to decline marginally. As a result the net increase in steam supply to the station was only 50% of what had been expected.

In consequence by 1884, Wairakei was once again facing a steam shortage.

Faced with further steam winning, attention turned to the utilization of a dry steam reservoir trapped at shallow depth beneath an impermeable cap in the Te Mihi area of the field. The presence of a shallow vapor dominated reservoir in this area was initially inferred from precise gravity changes and from the direct measurement of steam pressures in the existing Te Mihi wells. This steam resource having formed as a result of the exploitation of the liquid resource and the resultant draw down in the fluid level by approximately 200m. The reduction in reservoir pressure causing boiling of the fluid.

This steam zone was found to have pressures of around 25 bar g (360 psig). Beneath the steam cap fluid at up to 260 deg. C temperature was found. This liquid being some 30 to 40 deg. C hotter than liquid found in the main production area of the field. Given the good production potential the first new production well to be drilled at Wairakei since 1967 was drilled into this steam cap in 1985. At a depth of only 390 m (1270 ft) excellent dry steam production was encountered.

Following the success of this dry steam well efforts over the next three years were devoted to defining the extent and production potential of the Te Mihi vapor reservoir. The most important parameter was to determine its size and to determine this a number of exploratory wells were drilled to probe the perimeter of the resource. From the data obtained it was estimated that the resource could sustain a production of around 500 tonnes per hour for many years. Based on these estimates a development plan was prepared.

This development plan entailed drilling a further three 330 mm diameter (13") wells and the construction of a 1 m diameter (40") steam transmission line approximately 2.5 km long (1.5 miles) to connect the new production area with the existing Wairakei steam transmission system. This project was completed in September 1988. Two of the wells encountered excellent production from the shallow dry steam resource; however, the third failed to find permeable conditions at the dry steam horizon and this was successfully deepened into the liquid zone. These new wells provided a steam surplus and were able to keep the plant fully loaded until 1994.

However, the dry steam production was not without problems. The gas content of this steam was significantly higher than flashed steam. The net result of this increase was to increase the content of the steam delivered to the power plant from 0.4 % to just under 1%. The steam driven gas ejectors on the four A Station LP machines were inadequate to handle this increase and the condenser vacuum deteriorated, resulting in a decline in output of around 10 to 12%. The B Station plant ejectors whilst able to maintain design vacuum conditions, it was achieved at the expense of an increase in ejector steam supply from 27 to 88 tonnes/hour. These problems were overcome by redesigning the ejectors and improving the cooling efficiency of the ejector inter cooler.

The second problem encountered with the dry steam wells was that they spasmodically discharged significant quantities of sub micron sized particles of quartz. This quartz generally appears when the wells are being returned to service following a shutdown. Whilst contained within the steam phase the quartz very effectively removed silica scale deposits from within the turbine steam path and the magnetite coatings from the steam lines causing blockage of the turbine casing drains. However serious damage resulted when the quartz mixes with steam condensate. This mixture cuts out and destroys condensate drain valves in a matter of days. As the quartz is so fine it is not possible to remove from the system by normal debris collection methods. This problem is being partly overcome by carrying out a sustained vertical discharge of the well before it is returned to service.

The last major steam winning project to be carried out at Wairakei entailed tackling the steamline pressure drop problem which was overcome by constructing a new 1 m diameter (40") pipeline from the power station to the steamfield. This effectively reduced the wellhead pressure on all the production wells causing the output of each to be marginally increased. This project was completed in 1995.

Ways of making more efficient use of the energy withdrawn from the Wairakei field has always had a high priority and this was further enhanced in 1996 when the pressure reducing valves which reduce the ILP steam to LP conditions were replaced by a steam turbine which produces approximately 4 MW of additional output.

This year further wells were drilled to tap the Te Mihi dry steam resource and these have been successful in keeping the plant once again fully loaded

Perhaps the biggest challenge facing Wairakei in the near future will be the renewal of its resource consents before 2001. Up until now Wairakei has operated under "existing use" consents which were issued in 1968. With the passing of the Resource Management Act in 1991 all "existing use" resource consent holders had until a certain date to seek renewal of their consents in accordance with the requirements of the new legislation

SUMMARY

Wairakei has been one of the most reliable generating facilities within the New Zealand electricity supply system. Since decommissioning the HP plant in 1982 the station has operated consistently with an annual load factor of over 90%. Maintaining this output has been achieved by on-going steam winning initiatives and it is likely that with careful management of the resource Wairakei will continue to operate well into the new millennium.

GEOTHERMAL RESOURCES IN NEW ZEALAND AN OVERVIEW

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TYPES OF GEOTHERMAL SYSTEMS

In many parts of New Zealand, the rocks at shallow depth (< 1 km) have high porosity and may contain up to 30% (by volume) of water. Usually, the pores and fractures are connected so that the water in the rock can move in response to pressure changes. Fractures have high permeability and allow water to move quickly from place to place.

The Resource Management Act (1991) differentiates between geothermal water and cold groundwater on the basis of temperature: water greater than 30°C is geothermal, that below 30°C is groundwater. This distinction has no scientific foundation–it is based solely on the concept that water above this arbitrary temperature is an energy resource–it is not possible to clearly separate geothermal water from cold groundwater on the basis of temperature alone.

New Zealand's geothermal waters can generally be separated (but not always), on the basis of their temperature, geological location and chemistry, into two main groups:

- ***Low-Temperature Waters*** with temperatures of between about 20°C (ambient) and about 100°C, associated with active faults.

- ***High-Temperature Waters*** with temperatures greater than 100°C, associated with areas of active volcanism.

These waters form convective, hydrological systems within the upper part of the crust which are driven by the heat sources. In both cases, in their natural state, these are dynamic systems–the hot water is continually being lost at the surface to rivers and being replaced from deeper in the earth.

LOW-TEMPERATURE TECTONIC GEOTHERMAL SYSTEMS

Low-temperature springs occur mainly in the northern half of the North Island and in a band through the central part of the South Island (Figure 1). In the North Island, low-temperature springs are found mainly in areas of recent tectonic activity (such as the East Coast), and in areas of extinct volcanism (such as the Waikato and Coromandel). In the South Island, low-temperature springs are found mainly near the Alpine and Hope Faults, and appear to be associated with greater than normal temperatures (up to 200°C) at shallow depth (<2 km) which result from recent tectonic uplift.

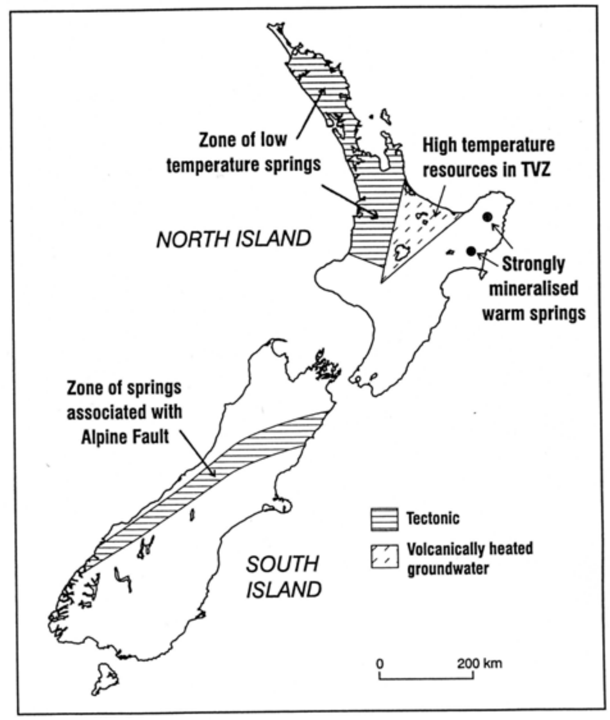

Figure 1. Distribution of geothermal waters in New Zealand.

Chemistry

The chemical composition of low-temperature tectonic geothermal waters is influenced mainly by the chemistry of the rocks the water has come into contact with, and the temperatures to which the water has been raised. Despite the relatively low discharge temperatures of South Island springs (40 - 60°C), their chemistry indicates that some of the waters have reached temperatures of over 100°C. The fluids within rocks with which the water interacts will also influence the chemistry. For example, the waters from Te Puia and Morere Springs on the East Coast of the North Island are highly mineralized. They contain high concentrations of sodium (Na) and chloride (Cl); probably, the result of mixing with fossil sea water from the underlying marine sediments.

Exploration and Use

There has been no systematic exploration for low-temperature systems in New Zealand. Those not already known to the Maoris before the arrival of Europeans have

Table 1. Some Examples of Direct Uses of Low-Temperature Geothermal Resources in New Zealand.

Location	Temperature ºC	Flow Rate (L/s)	Use
North Island			
Ngawha	40-50s	2	Bathing - commercial, mercury extraction in past
Kamo	up to 25s	<1	Bathing - past use by sanitarium and hospital
Waiwera	45-52s	-	Bathing - public, commercial, private pools
Parakai	up to 65s, d	12d	Bathing - 3 pool complexes, 4 motels, 5 private pools
Te Maire (Naike)	52-93s	10	Bathing
Hot Water Beach	54-63s	<2	Bathing - public and baths at Motor Camp
Te Aroha	59	<1	Bathing
Waingaro	37-54s	6	Bathing - public pool
Miranda	56s, 64d	7s	Bathing - commercial pool complex
Okauia	40d, 47s	<2	Bathing - commercial pool
Kawerau	up to 100	-	Industrial processing, greenhouse heating, electricity generation (binary plant), space heating
Awakeri	58-69s, 49-70d	50d	Bathing - commercial pools
Lake Rotokawa	45-52s, 29-99d		Space heating (motel, school, greenhouse)
Tikitere	30-99s	<1	Bathing , space heating, heating for greenhouses
Rotorua	up to 100s, d	-	Bathing (commercial pools and residential), space heating (domestic and industrial), timber drying, soil sterilization
Waikite	up to 99	1.5-3.5s	Bathing (commercial pools)
Golden Springs	40-50	9-40s	Bathing
Ohaaki	25-95	<20	Lucerne drying, heating of greenhouses (past)
Waiotapu			Timber drying
Wairakei	up to 100	-	Bathing, fish farming, space heating
Taupo-Tauhara	40-98s	20s	Bathing, heating greenhouses, domestic space heating
Tokaanu	19-98s	1-15s	Bathing (commercial and domestic pools), domestic heating
Morere	up to 62s		Bathing (commercial pool)
Te Puia	59-70s		Bathing (commercial pool - now defunct)
South Island			
Hammer Springs	32-43s, 50d	8d	Bathing (commercial pool)
Maruia Springs	up to 60s	2-5s	Bathing (commercial pool)

s = spring, d = drillhole. Data from Mongillo & Clelland (1984).

generally been found accidently by explorers, mineral prospectors, farmers, and trampers. It is unlikely that any new low-temperature geothermal springs of significant size or flow rate will be discovered; but, it is probable that additional localized areas of warm groundwater will be found.

At present, the main use of low-temperature waters in New Zealand is for bathing (Table 1). Public baths operate at Kamo, Waiwera, Parakai, Miranda, Te Maire, Waingaro, Hot Water Beach, Okauia (Matamata), Te Aroha, Tauranga, Awakeri, Te Puia, Morere, Hammer, and Maruia. A history of the use of some of these springs is given in the book ***Taking the Waters - Early Spas in New Zealand*** by Ian Rockel (1986).

HIGH-TEMPERATURE VOLCANIC GEOTHERMAL SYSTEMS

Only the upper parts of volcanic geothermal systems have been investigated by drilling. The deeper parts have been probed by geophysical techniques and their behavior is deduced theoretically from mathematical models or from scale models in the laboratory. A conceptual model of a volcanic geothermal system is that meteoric waters percolate down from the surface to depths of 5 - 10 km where they become heated by hot (up to 800ºC) volcanic rock, such as a magma body. Although such shallow bodies are believed to be the prime source of heat for high-temperature geothermal waters, no such body has yet been positively identified beneath any of the known volcanic geothermal systems in New Zealand, and their shape, size, depth and chemistry remain largely speculative. The waters become heated and interact chemically with the volcanic rock; then, being of lower density than the surrounding water, they rise in a plume, towards the surface through pores and fractures in the overlying rocks.

Once established, this plume is remarkably stable and the water rises vertically, seeking permeable paths to the surface. Although the temperatures may be several hundred degrees, the pressures at depth are such that the water does not boil. As the water rises, cooler water from the adjacent rocks may be entrained in the plume, reducing the temperature and diluting the concentrations of dissolved salts. Near the surface, a number of factors can complicate the flow: reduced pressures can cause local boiling, the geological structures in the rocks can channel flow, and surface waters can infiltrate the system.

Maori tradition has a different origin for the volcanic geothermal systems. Their legend is that when Ngatoroirangi (chief of the Te Arawa tribe) and Ngauruhoe (his slave), were exploring the Taupo Volcanic Zone they climbed the slopes of Mount Tongariro and were close to dying from the cold. Ngatoroirangi called to his sisters, Kuiwai and Haungaroa, in Hawaiki across the Pacific Ocean, to send heat to resuscitate them. The sisters heard his cry for help, and with the fire gods Pupu and Te Hoata, set out underground to bring heat. In the search for their brother, they stopped and came to the surface to look for him at places on the way. Their route led from Whakaari (White Island), puia Moutohora (Whale Island), Okakaru, Rotoehu, Rotoiti, Tarawera, Paeroa (Waikite), Orakeikorako, Taupo, and Tokaanu, to Tongariro. Where they stopped, the heat burst out as thermal activity, and remains as ngawha (overflowing pools), puia (volcanoes, hot springs), and wairiki (hot springs).

At the surface, the volcanic geothermal systems are characterized by groups of thermal features within an area of 5 to 15 km^2. The natural discharge of energy from these features can be considerable. Before exploitation, Wairakei Geothermal Area discharged more than 600 megawatts (MW) of heat, with one feature alone (Karapiti Blowhole) discharging 12 MW.

High-temperature waters are associated only with active volcanism and in New Zealand are confined to the northern and central parts of the North Island (Figure 2). A list of the larger, known volcanic geothermal systems is give in Table 2.

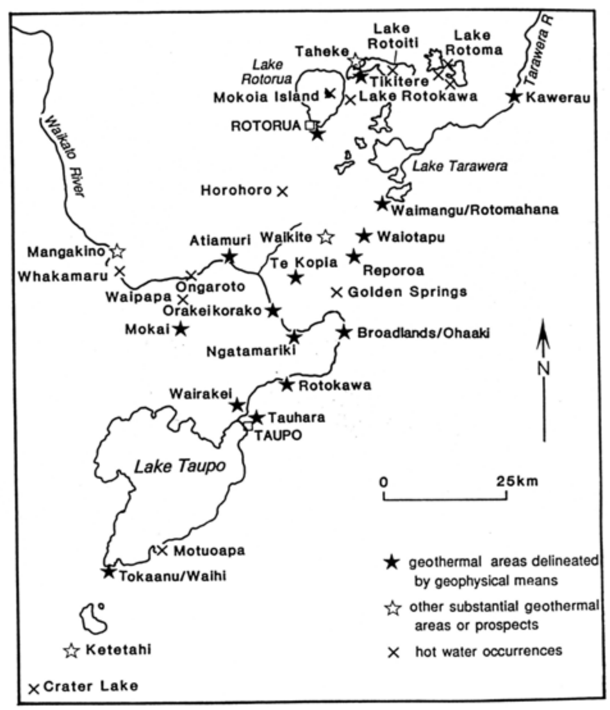

Figure 2. **Map of the central part of the North Island showing the location of the known high-temperature volcanic geothermal systems (Hunt & Bibby, 1992; Mongillo & Clelland, 1984).**

Age of the Volcanic Geothermal System

Measurements of heavy isotopes of hydrogen (deuterium and tritium) present in geothermal waters suggest that the circulation time for high-temperature geothermal waters in New Zealand is longer than 100 years, but less than 12,000 years. Cooling of the source body eventually causes the system to decay and die, and geological evidence suggests that individual systems may exist for up to half a million

Table 2. **New Zealand's High-Temperature Volcanic Geothermal Systems (Allis and Speden, 1991; Lawless, et al., 1981).**

System	Approx. Area (km^2)	Temp. ^{O}C	Status	No. of Drillholes	Available Energy (PJ)
Horoboro	5	220	f	1	400
Keteahi	?		u	-	?
Kawerau	10	250	c	32	1 300
Mangakino	5	220	f	1	400
Mokai	15	280	f	6	2 700
Ngatamariki	10	260	f	4	1 400
Ngawha	15	230	f	15	1 400
Ohaaki	10	260	c	46	1 400
Orakeikorako	5	260	p	4	?
Reporoa	5	230	u	1	500
Rotorua	5	220	u	-	400
Rotokawa	15	280	c	10	2 700
Taheke	5	230	u	-	500
Tauhara	15	240	f	5	1 900
Te Kopia	5	240	f	2	500
Tikitere	10	230	p	-	900
Tokaanu	10	250	u	-	1 300
Waikite	5	230	u	-	500
Waimangu	10		p	-	?
Wairakei	15	230	c	135	1 400
Waiotapu	10		p	7	?

Temperature: Inferred average temperature over 3 km depth range.

Status: p = protected for tourist use; c = commercial exploited; u = un-investigated; f = some feasibility studies made

PJ = Petajoule = 10^{15} joules

years. Epithermal mineral deposits, such as found at Ohakuri and in the Coromandel region, are the fossil remnants of previously active volcanic geothermal systems.

Relation to Cold Groundwater

Hot geothermal fluid may mix with and warm the cold groundwater, and if this occurs in a topographically high area where the groundwater is flowing naturally towards a topographic low, the resultant warm water or *outflow* may be carried a considerable distance from the area of the geothermal system. At Mokai, hot geothermal water rising from the Mokai geothermal system meets and mixes with the groundwater flowing down slope, and the resulting warm water is carried laterally about 10 km to emerge in the bed of the Waikato River as the Ongaroto Springs (39^{o}C). Outflows are sometimes very large and hot, and have been mistakenly though to indicate the presence of a geothermal systems below the place where they emerge, until drilling or geophysical measurements show that only a thin layer of hot water is flowing near the top of a zone of cold groundwater.

USE OF GEOTHERMAL RESOURCES

There are several ways in which geothermal energy is used in New Zealand:

1. Direct use - the heat is used directly (e.g., space heating, heating of swimming pools, drying and processing agricultural products.

2. Conversion to another form of energy (e.g., production of electricity).

3. Recovery of minerals (e.g., recovery of silica, lithium, boron, etc., from the waters).

The greatest use of geothermal water in New Zealand is for generating electricity. When a deep geothermal well is discharged, the emerging fluid is a mixture of liquid water (about 80% by mass) and steam. The steam is separated and piped to the power station. The water, together with condensed steam from the power station, is disposed of either by putting it into a nearby river or by pumping it back into the ground.

Figure 3. Geyser, Whakarewarewa, Rotorua.

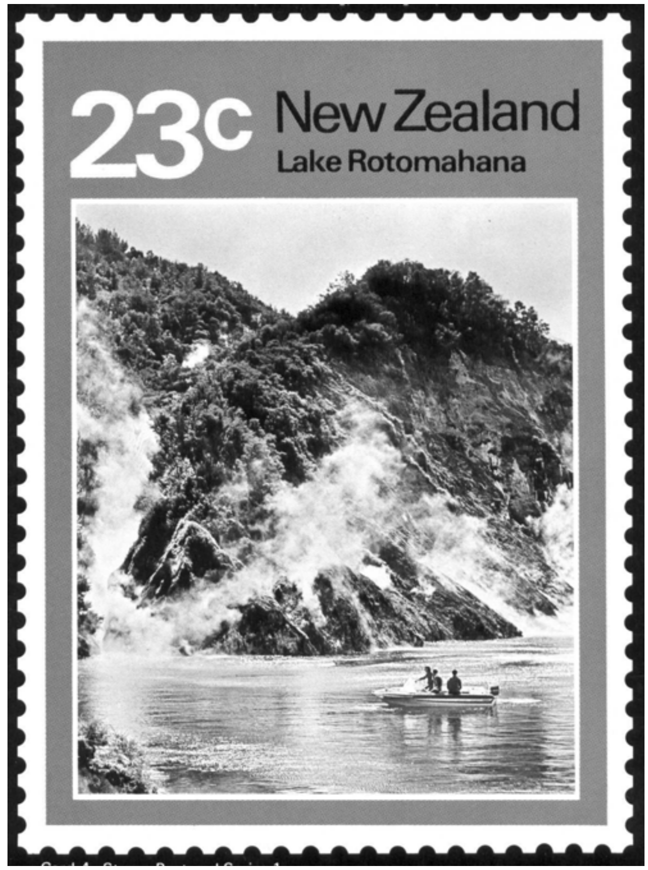

Figure 4. Lake Rotomahana (from Post Office Philatelic Bureau Stamp).

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DOMESTIC AND COMMERCIAL HEATING & BATHING ROTORUA AREA

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INTRODUCTION

Geothermal resources in the Rotorua area have been put to a number of practical uses, many of which are described in this article.

The use of the geothermal resource in this region has a long history, well and truly pre-dating European settlement. The earliest uses were for bathing, washing and cooking, these being made possible by the existence of suitable natural features.

Today, geothermal is applied to a variety of domestic and commercial heating and other purposes. It is used for both the heat it can provide and the "mineral" water content of the fluid; however, geothermal is not available over the whole city.

Increasing usage during the post-war decades was linked to the apparent decline natural activity at Whakarewarewa. In the 1980s, the government implemented a control program that, amid other things, resulted in the closure of wells within 1.5 km of Pohutu geyser.

CURRENT USES OF THE GEOTHERMAL RESOURCE

Parklane

This is a housing development with a geothermal group heating scheme. There are 13 units on this site, which share a well with six other dwellings on adjoining properties. Sixteen of the total are supplied with a circulating supply of hot water from a single heat exchanger. The other three receive geothermal fluid and have their own, smaller heat exchanger arrangements. This is a relatively early example of a scheme that distributes secondary water rather than recirculating geothermal fluid. The heat is used for space heating, domestic hot water heating, and, in some cases, heating small pools.

This system is quite successful and relatively neat, with much of its distribution piping underground. However, there are a number of design weaknesses which have contributed to piping corrosion, internal and external, and difficulty in getting adequate circulation to some users.

Queen Elizabeth Hospital

Queen Elizabeth Hospital is an example of institutional use of geothermal. Geothermal fluid is used not only for space heating and domestic hot water heating; but, the water phase is taken for therapeutic purposes.

Millennium Hotel

Commercial use of geothermal occurs in a number of hotels and motels, and other facilities. The Millennium Hotel is a case in point. Here geothermal is used for space heating, domestic hot water heating, pool heating (in this case, a medium-sized swimming pool and a number of spa pools, all using fresh water). High-temperature hot water is also generated for cooling purposes and, perhaps the most interesting of all, there is an absorption chiller for the air-conditioning.

Aquatic Centre

The Rotorua District Council's Aquatic Centre is another good example of the use of geothermal on a relatively large scale. This complex has two indoor pools and a larger outdoor pool. All three are heated. In addition, geothermal energy is used for space heating and for domestic hot water heating.

All of the geothermal fluid is passed through a single plate-type heat exchanger, which heats the secondary water, which is a circulating system of town water. This, in turn, supplies all the various heating services.

In this case, because of the high capacity of the geothermal heating system, the domestic hot water (DHW) supply (used for showers and hand basins) is heated on an as-required basis, avoiding the cost of installing a large storage calorifier. The cold mains water feed is passed through a small heat exchanger fitted with an automatic temperature control. There is a small buffer tank in the circuit, sized to absorb the swings in temperature in the hot water that occur when there is a big change in the demand.

Figure 1. Aquatic Center indoor pool.

The ventilation system for the pool building has been designed to minimize chlorine odor and keep the internal atmosphere as pleasant as possible. To achieve this, a relatively high air flow rate, once-through system has been provided. No air is recirculated. The incoming air is heated to maintain the building's internal temperature. A heat pipe, heat recovery unit has been incorporated to significantly reduce the high heat losses that would otherwise occur. The hot, moist, chlorine-laden air being extracted gives up most of its heat as it passes through the heat recovery unit, which uses it to preheat the incoming air. This unit recovers about 75% of the heat in the exhaust air. The heating of the fresh air is completed by a heating coil through which low-temperature hot water (LTHW) is circulated.

OTHER EXISTING USES

Space heating generally refers to the provision of comfort heating in an occupied building. Another variant is in-building heating for commercial purposes such as glasshouse operations. The Rotorua District Council nursery in the Government Gardens is a case in point.

Space heating is virtually always accomplished by the use of a LTHW system. This is a system in which a heat source–in this case hot geothermal fluid–is used to heat "clean" secondary water. "Low" temperature in this context does not mean cold. It refers to a heating system operating at a relatively low temperature, typically less than 100ºC. The secondary water is circulated through a heat dissipating device, usually flat panel-type radiators, but sometimes fan coil units, unit heaters or bare pipes.

Domestic hot water (DHW) means hot tap water, used for normal washing and sanitary purposes, in dwellings and other premises. DHW heating is a natural adjunct to space heating where geothermal is employed as heat is normally available throughout the year. This is not always the case with LTHW heating systems which are fueled by gas or coal since they are often only put into service during the heating season and the DHW is heated by electricity to assure a year-round supply.

Pool heating is one of the major uses of geothermal. Pools either contain town water which is heated by geothermal, as at the Aquatic Centre, or geothermal water ("mineral" pools).

The Polynesian Spa is no doubt the best known example of direct mineral pools. The pools shown here are built around natural springs with the inflow coming up through the sandy bottom of the pools. Other pools in this complex, use piped-in mineral water.

Figure 2. Polynesian Spa outdoor pools with temperatures from 34 - 44ºC.

Cooking has been a use of geothermal heat from pre-European times. There are still to be seen households with small, enclosed steam boxes outdoors which are used for steaming food.

Therapeutic uses - the reputed therapeutic benefits for geothermal waters has long been exploited. In fact, it was intended early in Rotorua's existence that it should become a spa in the European fashion. The Bathhouse, opened in 1908 complete with the latest balneological equipment and related treatments then in vogue in Europe, was built for this purpose.

The Bathhouse is now the city museum; but, hydrotherapy still continues at Queen Elizabeth Hospital, to which these treatments were transferred in the 1950s. At QE, geothermal water is used for the usual space heating and DHW heating services. Part of the effluent (that is to say, the partially cooled geothermal water) is collected and cooled further, and degassed in a concrete vat, and then piped to the Hydrotherapy Department.

Figure 3. Rotorua Bathhouse, opened in 1910–now a museum.

SYSTEMS, PROCESSES AND EQUIPMENT

Wells

Two systems of heat extraction are used:

- fluid removal and re-injection
- downhole heat exchangers.

The former are by far the more common, there being about 240 operative in this area, of which about 100 are for domestic systems. Wells of this type typically can have maximum outputs of the order of 1 to 3 MW (thermal).

Referring to the extraction and re-injection system, supply wells in Rotorua can be classified as self-starting, self-sustaining, and pumped.

Self-starting wells will, when shutdown, maintain a pressure against the stop valve and will flow again when the valve is opened.

Self-sustaining wells do not maintain a positive well-side pressure when shut down and do not flow of their own accord when the shutoff valve is opened. Flow is induced by introducing compressed air into the well. Once a flow has been established, it will then continue without further assistance. The majority in Rotorua are of this type.

Pumped wells cannot be induced to flow without assistance and have to be continuously pumped or air assisted. The ususal process is to air lift the fluid. This is sensible in that the operating conditions of temperature and fluid contamination are very severe for mechanical pumps. However, the continuous introduction of air into a well has long-term corrosion implications.

The vast majority of wells in Rotorua have 100-mm diameter production casings; although, sizes from 65 to 125 mm do exist. The smaller sizes are often larger wells which have been repaired by fitting a sleeve inside the casing. Wells in Rotorua are typically about 100 m deep, ranging from about 45 to 190 m. Aquifer temperatures vary from about 125 to 175°C.

Distribution Systems

Distribution of the geothermal energy can be either by piping the geothermal fluid to each user or by employing a central heat exchanger and piping a circulating supply of low-temperature hot water (LTHW). Both types of systems are used. Systems can be a hybrid of the two.

Figure 4 is a schematic diagram of a well conceived system of the second type (LTHW distribution), which is quite close to the Parklane system referred to earlier.

The principal features are:

- A single heat exchanger supplies LTHW to a number of users,
- The geothermal effluent goes to a deep injection well,
- The flow of geothermal is controlled to maintain the secondary water supply temperature constant,
- The temperature control valve is on the outgoing side of the heat exchanger,
- The isolation valves are fitted, to enable the user's system to be shutoff from the main system,
- Space heating is by radiators fitted with thermostatic valves,

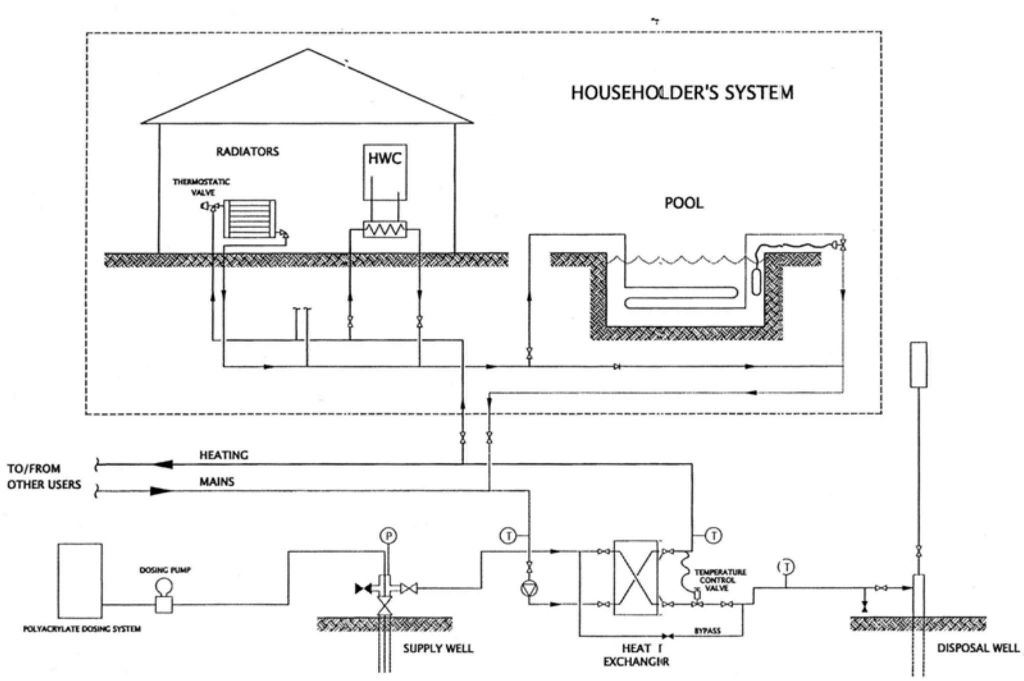

Figure 4. Group heating scheme - based on the reticulation of low-temperature hot water.

- The DHW cylinder has it own heat exchanger, or equivalent (such as pipe coil in hot water cylinder),
- The DHW system incorporates a mixing valve (not shown) which limits the water supply to a safe temperature,
- The pool, if any, is heated by the lower temperature, return side of the user's systems; thus, lowering the temperature of the return water and enabling more heat to be extracted from each kilogram of primary fluid, and
- The pool has a thermostatic control valve to maintain its temperature constant.

A system may have more than one heat exchanger, each serving a proportion of the users.

What this type of system des not do, is provide mineral water for pools or cooking. If raw geothermal fluid is required, then there can be either a separate geothermal fluid line to those users who want it or, alternatively, a geothermal distribution-only type system adopted, with each user having his own heat exchanger and LTHW system.

Heat Exchangers

The heat exchangers used these days are commonly of the plate type.

These heat exchangers have a very high capacity for their size. The main heat exchanger for the Aquatic Centre, for example, occupies less than one square meter of floor space, but can transfer several thousands kilowatts. They are also relatively easy to disassemble and clean.

Not all plate heat exchangers are suitable for geothermal duty and the manufacturer's recommendations should be sought when specifying or procuring them. Fatigue cracks have occurred in plates of an unsuitable design as a result of vibration induced by the two-phase geothermal flow. The plate seals also need to be correctly chosen. High-temperature seals are required for geothermal applications.

The alternative is the shell-and-tube type. These were once the standard, but are not now so common. For households and small systems, these were generally very simple, fully welded units with only a small number of internal tubes.

OTHER ISSUES

Hazards

The first is the presence of hydrogen sulphide gas in the geothermal fluid. H_2S is what gives Rotorua its characteristic smell. In small concentrations, it is easily smelt. In larger concentrations, it may not be detected and can be fatal.

It is not permitted to use geothermal fluid in plant in an enclosed space without ventilation or in a habitable space. Hydrogen sulphide is heavier than air. A small leak in a piping system will lead to the escape of gas and its accumulation at low levels in rooms, ducts, trenches, and the like. There have been fatalities as a result of H_2S escape.

Pools using geothermal water direct need to be fitted with a gas separator to ensure most of it is removed before the water gets to the pool. The pools enclosure also needs to be thoroughly ventilated.

A particular problem was the use of uncontrolled domestic hot water systems. Systems delivering water at near to boiling point were not uncommon at one time and, again, very unfortunate accidents have resulted. Fortunately, this is now easily fixed as there are relatively simple and low-cost thermostatic mixing valves on the market which control the water temperature to a safe level. These are mandatory in new installations.

Calcite Precipitation

Calcite (calcium carbonate) precipitation is frequently a feature in the operation of geothermal systems in Rotorua. This phenomenon occurs where CO_2 comes out of solution from the geothermal fluid. Precipitation, therefore, tends to occur in production wells in the zone where the fluid flashes to steam. For the same reason, it is important that where a throttling device (such as a control valve) is installed in the primary circuit, that it is fitted on the downstream side of the heat exchanger. Not only should flashing not occur at the lower temperatures prevailing there, but the solubility of calcite is greater at lower temperature.

Precipitation is sometimes suppressed by the dosing the supply well with polyacrylate. Systems where this is done have a small bore stainless steel pipe inserted into the well, so that the liquid polyacrylate is injected in the boiling zone by means of a small dosing pump.

Costs

Costs vary widely from installation to installation and the following figures should be taken as a guide only

Domestic group schemes - These figures refer to the installation of new heating schemes (NZ$ 1.00 = US$ 0.50).

The typical costs of the elements of a group heating scheme are:

Well - supply or re-injection	NZ$ 24,000 each well
Installation of household heating system	NZ$ 8,000 - 16,000 per household
Central distribution system	NZ$ 2,000 - 4,000 per household

Normally, two wells will be required for a group heating scheme: one for the supply and the other for reinjection. Commercial or institutional systems may require more wells, to achieve the required capacity or for backup. For a group scheme, the cost of the wells will be shared among the users.

Installation costs for individual dwellings will be less where LTHW is distributed from a central system than for those on a primary geothermal fluid supply, since individual heat exchangers and some control elements are not required. However, a connection charge, to the central system will be greater because of the greater complexity and cost of that system.

For each user on a new scheme, the minimum cost will be about NZ$ 12,000, covering a share of two wells, a share of the distribution network, central heat exchanger and related equipment, and the user's own in-house equipment costs. The cost could well be considerably greater.

Running costs are likely to be of the order of NZ$ 20 - 40 per month, say $300 per year.

The monthly operating charge can vary significantly, depending on how the operating syndicate structures its charges and what items it covers. Charges need to recover well clean outs (about NZ$ 1,000 a time) which may be required very few months or at intervals of several years, general maintenance, well inspection costs and, if applicable, doing chemical costs. In addition, charges may be levied for long-term equipment replacement or for capital recovery.

Comparison with electric heating - A comparison with electricity, normally regarded as a high-running cost option, is instructive. An all-electric home, operated modestly and economically, is likely to spend NZ$ 1,200 per year on power, of which about $700 will be for water heating and space heating. On the (unlikely) basis that a geothermally-heated home used the same amount of energy, then:

Cost of geothermal system	NZ$ 12,000
Annual running cost	NZ$ 300
Electricity cost	NZ$ 700
Annual savings in operating cost	NZ$ 400
Rate of return	3.3%

Clearly, a geothermal user, not having to pay a unit charge for geothermal heat, will consume more energy. However, even if the consumption was four times that of the ordinary electricity user, the return on capital is still only about 13%.

A geothermal system for domestic heating is not, generally, a sound investment when the full cost of installing a new complete heating scheme has to be paid; although, it should be noted that each situation needs to be judged on its own merits. If pool heating is required, for example, the economics changes significantly.

The situation becomes less clear when considering a property in which geothermal is already installed. In this case, the premium, if any, that one pays for such a property, becomes the capital cost element. Valuers will add about NZ$ 2,500 to 3,000 to the value of a typical property, and up to $5,000 for a very large dwelling if geothermal heating is installed.

Large-scale users - The economics can be very different for large-scale users. In many cases, particularly with institutional users, fossil fueled heating systems will be of the low- or medium-temperature hot water type, similar to a geothermal system. In the one case, the secondary system will be heated by a boiler and the other with a heat exchanger; but, the secondary circuit system will be the same.

The equipment costs will be of a similar order of cost, unless of course, boiler plant is also installed to provide backup capacity.

Apart from the plant maintenance costs and minor items such as bore inspections, the energy costs are zero.

Of the large users in Rotorua, the Aquatic Centre has annual maintenance costs for its geothermal system of NZ$ 20,000. If natural gas were used to provide the energy, the estimated gas cost would be around $150,000. Another major user has heating plant maintenance costs of around $5,000 per year and achieves a similar energy cost savings, conservatively estimated at NZ$ 140,000 per annum.

SUMMARY

- Geothermal has been successfully used in Rotorua for many years,

- Geothermal energy is principally used for heating: space heating, domestic hot water and fresh water pool heating.

- Mineral pools, using geothermal water direct, are also a significant use,

- Most systems obtain the energy by using a well to extract geothermal fluid (water, steam and non-condensable gases), which is passed through a heat exchanger to heat fresh water and is then reinjected, preferably to the geothermal aquifer.

- Historically, geothermal heating systems, small-scale systems in particular, were simple and relatively primitive and had low-energy efficiency,

- The use of geothermal is being greatly improved by the use of appropriate designs and automatic controls, both in terms of energy use efficiency and the effectiveness, benefit and safety of the results,

- For households and small installations, geothermal heating has a high capital cost and the economics are poor, and

- For large installations, the capital costs are more akin to fueled heating systems. The unit incremental cost of the heat obtained (over and above the fixed costs) is very small. There is, therefore, little capital cost penalty for using geothermal, but potentially major savings in running costs. The economics of large systems can be excellent.

KAWERAU GEOTHERMAL DEVELOPMENT: A CASE STUDY

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DEVELOPMENT HISTORY

The Kawerau geothermal field covers an area of 19 to 35 km^2. Fluid temperatures exceed 310°C. Drilling began at the end of 1952, using experience gained at the Wairakei geothermal field. A significant area of the field to the south and east lying within the resistivity boundary is virtually unexplored. Production is currently limited to an area of about a square km located just north of the mill (Figure 1).

The steamfield is owned by the New Zealand Government (who under New Zealand law, owns all geothermal resources). The steamfield is managed by the engineering firm Connell Wagner, with day-to-day operations and maintenance being contracted to Downer Energy.

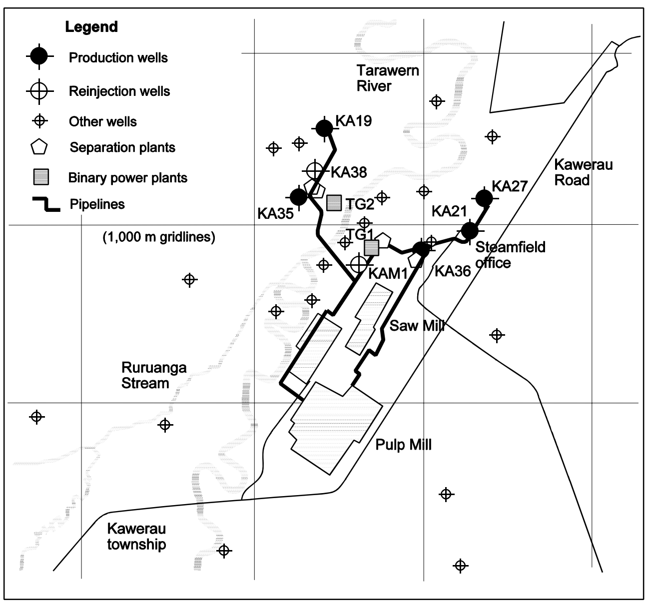

Figure 1. Kawerau geothermal steamfield.

Mill

The Tasman Pulp and Paper Company Ltd. mill is sited at Kawerau, partly because of the presence of the geothermal steamfield. The steamfield has been supplying geothermal steam since 1957.

Geothermal provides 30% of the mill's process steam and 5% of electrical energy. Steam flow is up to 320 t/h with a total annual supply of about 2.3 million tonnes; that is a mean flow of around 265 tonnes/hour. The peak flow is equivalent to 40 to 45 MW(e).

Geothermal steam is the cheapest external energy source at Kawerau. (The cheapest fuel is "black liquor" and timber waste). The geothermal steam price is determined on the basis of the next cheapest energy option, with benefits being shared between supplier and user.

Geothermal steam is used both directly in the mill processes, and in heat exchangers. Electricity is generated in an 8-MW turbo alternator (T/A), with the exhaust steam being further used to heat process water. The T/A is used to balance process steam flows, so does not have a high-load factor.

An interesting by-product of the geothermal process is the condensed steam. All the condensate from within the mill is collected, after having the non-condensable gases stripped out it, is used to provide high-quality boiler feed water. The ammonia naturally present in the steam provides a built-in corrosion inhibitor, so that dosing with amines is no longer required (Carter and Hotson, 1992).

Other Uses

High-pressure steam is also supplied to the Fletcher Challenge Forests sawmill for drying timber in kilns. In line with increasing demand for kiln dried lumber, Fletcher Challenge Forests propose installing a further five geothermal-heated kilns and converting the non-geothermal kilns to geothermal (Figure 2).

Some of the separated geothermal water is used to generate electricity in two "binary cycle" electricity generating plants with a total capacity of about 6 MW(e). Small quantities of steam are also used for greenhouse heating.

OPERATIONAL ASPECTS

Characteristics

Production of steam from the steamfield is a continuous operation: 24 hours per day, 360 plus days per year. Currently, five wells are producing and two are used for reinjection. Other wells are used for monitoring on a continuous or periodic basis.

Steam is supplied for process heat and to power a turbo alternator. Unlike a power plant providing base load, the mill operation fluctuates, so the steamfield has been designed for load following. Changes in demand can be very sudden with changes in the pulp and paper process–although, the demand is smoothed to some extent by the turbo alternator, which usually runs off maximum load.

Pressure is controlled by venting steam when demand decreases, as it is not possible to throttle the wells in the short time required. Well are, however, throttled if demand is to be reduced for some period, to reduce the amount of steam lost through the steam vents. Resource consents are required for discharge to atmosphere–a condition of the consents is to minimize venting. This arises from the requirement to maximize efficient use of the geothermal resource. In

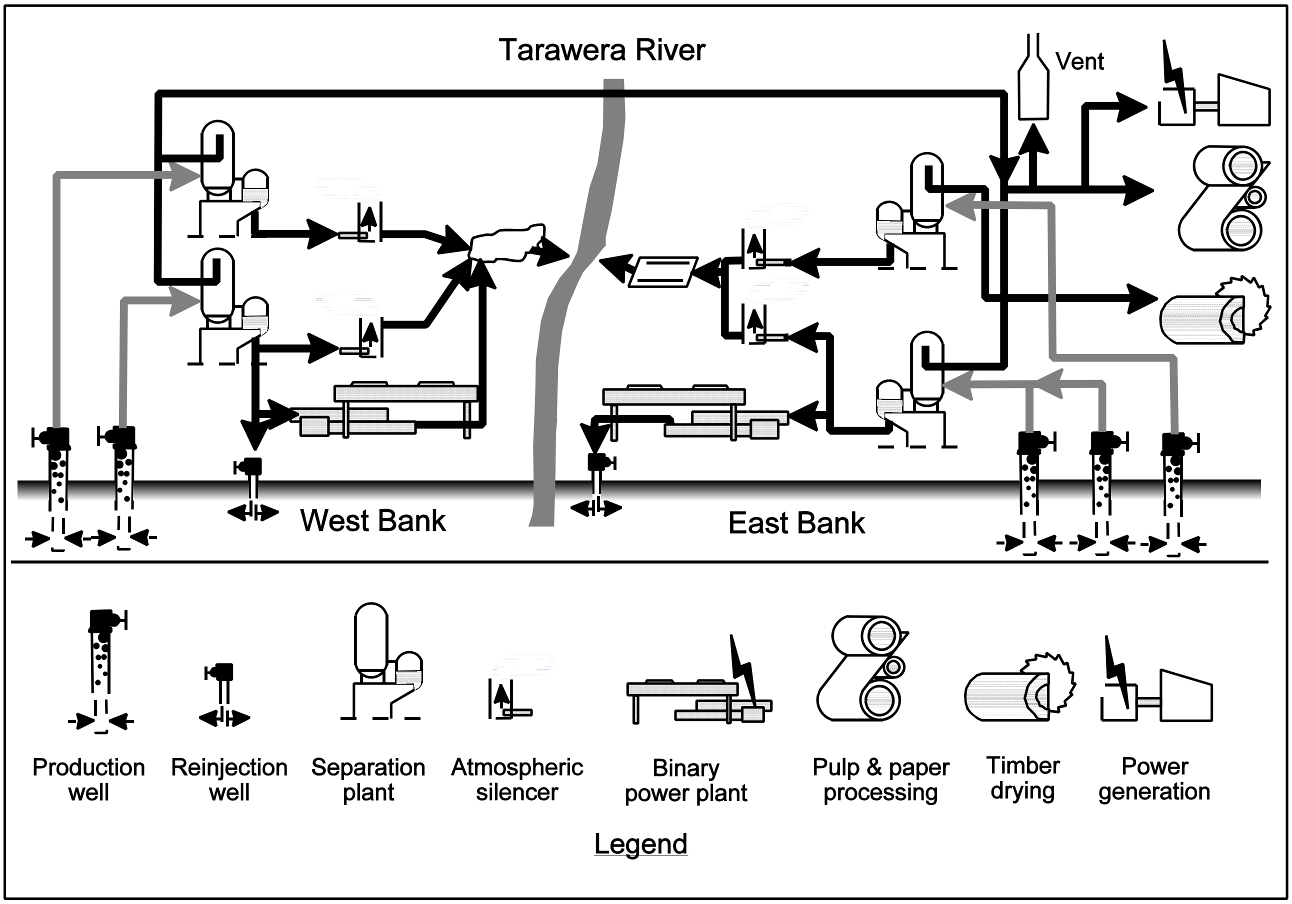

Figure 2. Kawerau geothermal steamfield schematic.

addition, the steamfield owner receives no payment for steam vented.

Control System

The steamfield functions are monitored by a Distributed Control System (DCS). This fills a primarily monitoring role of operational aspects such as steam flows and pressures. It also monitors environmental and reservoir parameters, such as geothermal water discharges and reinjection flows, and temperatures.

The DCS raises alarms, the major ones of which dial up a pager to alert the duty steamfield operator that attention is required.

Three of the production wells can be remotely throttled through the DCS to assist with load following. Other aspects are automatically controlled at a local level, such as the water levels in the separation plants. The automatic control functions are being extended to provide greater efficiency in operation.

Plant Maintenance

Steamfield plant inspection and maintenance is integrated with mill maintenance and "marine" inspections to minimize disruption to the steam supply. (Marine inspections are annual safety inspections of pressure vessels carried out by the statutory authority.)

The mill has biennial total shuts lasting three or four days. Consequently, no steam is required an all wells are shut in. Inspection and maintenance of essential or unique items is carried out during this time. Other items of plant, such as the separation plants or production wells, are taken out of service sequentially–coinciding with programmed reductions in mill demand whenever possible.

The two staff, in addition to operating the steamfield, schedule and supervise maintenance which is done under contract.

Wellbore Scaling

An operational problem with the Kawerau production wells is a tendency for calcite scale to form, restricting flow in the well. In the worst affected well, this caused a run down of about 70% output over a year. The scale can be effectively removed with a drilling rig; but of course, production is reduced through most of the year and there is a significant cost involved in the drilling operation. Two forms of well clean out have been employed: pulling the liner, or reaming it in-situ. Traditionally, the slotted liner has been reamed, then withdrawn from the well. The slots have been cleaned on the surface. More recently, the liner has been cleaned in place by jet washing. This is a quicker operation and is more effective in some wells.

Monitoring

Extensive monitoring is carried out. This includes monitoring of environmental impacts such as heat and chemicals discharged to the Tarawera River and subsidence. It also includes extensive reservoir monitoring. Information from this is used to prepare and update a model of the geothermal reservoir. This in turn is used to predict future changes in the reservoir from different resource management strategies –such as increased production or reinjection into different locations (White, et al., 1997).

HOW THE STEAMFIELD HAS REACTED TO DEVELOPMENT

Wells

The years of production have had little effect on the reservoir itself, pressure decline in the deep reservoir is less than measurement error; though, there has been some decline in temperature (Allis, 1997).

Not every management strategy is successful; but, the less successful are useful for learning more about the resource and development techniques. (Kawerau was using geothermal steam a couple of years before Wairakei, and these fields were the first wet geothermal fields to be developed in the world.) Cold groundwater inflows caused the demise of some of the earliest wells with their relatively shallow casings. Wells are now drilled and cased through the volcanic strata overlying the basement to prevent the intrusion of cooler water. Wells drilled in this manner have been very successful. KA19 is now into its 27th year of production, still producing over 70 t/h of steam.

KA21 has been producing for over 20 years and puts out well in excess of 100 t/h of steam-equivalent to 18MW electrical. KA27 has produced for 17 years, KA35 for 10 years and KA36 for 5 years. However, well KA28 which was linked into the system in 1986, was retired two years later owing to a long-term cyclic reductions in output.

Reinjection

Unlike all current or future geothermal field developments in New Zealand, where reinjection will be incorporated into the process from the start, waste water at Kawerau has been traditionally discharged to the Tarawera River. Reinjection has been under investigation for about 12 years, including reservoir studies and field trials.

Reinjection, commenced in 1991, has increased up to peak flow rates in excess of 300 t/h. However, the annual average is about 250 t/h or about a quarter of the separated water. Separated water from the separation plants is piped under pressure to the reinjection wells. Currently, there are two separate systems, with a reinjection well on each bank of the Tarawera River, receiving water from an individual separation plant.

The east bank reinjection flow is passed through binary generating plant "TG1 prior to reinjection; this removes heat from the water. Injection temperature being around 110 to 130^{o}C. The flow to the west bank reinjection well is not used in binary plant; so, the reinjection temperature is higher–about 180^{o}C. However, part of the flow from the separation plants on the bank is used in binary generating plant "TG2."

The injectivity of the first well, KAM1, has declined over time. The well now swallows about 60 t/h compared to about 130 t/h when first commissioned. It is believed that this decline is caused by deposition of super-saturated silica within the formation. On the other hand, reinjection well KA38 increased in swallowing capacity over the first three years–increasing from about 100 t/h to over 200 t/h. Its injectivity has since remained over 200 t/h.

Although reinjection has the potential to provide recharge to a system where mass extraction has resulted in pressure drawdown. At Kawerau, pressure drawdown over the period of field development is negligible. The task is to minimize the effect of the cold front spreading from the reinjection wells and affecting production wells.

The existing system of shallow reinjection has caused small changes in the shallow receiving aquifer as observed in monitor wells near the first reinjection well, KAM1.

It is possible that shallow reinjection may cause increased flows of geothermal water to the surface–possibly in the areas of natural springs which ceased flowing in the 1960s and 1970s; however, this has not yet been observed.

Subsidence

Ground subsidence is a concern at Kawerau because of the extreme sensitivity of the paper making machinery to tilt. Consequently, subsidence is monitored intensively.

Interestingly, the area of maximum subsidence does not coincide with the area of production however, but is more to the northwest. A maximum subsidence rate of 25 mm per year has been detected in the original Onepu hot springs area. The rate of subsidence over most of the steamfield is lower, generally between 5 and 10 mm per year or less (Allis, 1997).

Wellbore Scaling

As an alternative to removing calcite scale with a drilling rig, a well anti-scalant system has been developed. This has the double benefit of reducing annual maintenance costs while increasing steam availability. (The cost of anti-scalant is dependent on how frequently the tubing needs to be replaced; but even if it were necessary to replace the tubing annually, an anti-scalant system would be cost-effective.)

Trials to develop a suitable system having been going on for about eight years. At the time of the original trial in 1989, systems were widely used internationally; but, none were suitable for higher temperatures–270^{o}C (Robson and Stevens, 1989). Suitable chemicals were developed for Kawerau and an anti-scalant system was installed in KA35. This showed promise, but mechanical problems with the tubing that injected the chemicals to a depth of about 1,000 m in the well caused the trial to be abandoned.

About two years ago, a system using a new type of amoured tubing was installed in well KA19. The new anti-scalant system operated for over a year with no run down in steam output. Despite some further mechanical problems, this success justified installation of a similar system in KA35. This well also showed no decline in output following installation.

FUTURE DIRECTIONS

Improvements in Operating and Maintenance Methods

The steamfield operation undergoes continual improvements in methods. Many of these are quite small, some major and some more experimental.

Automation of control functions is being extended. For example, control of the venting system will reduce steam lost through venting. Automatic control of separator vessel water level is now incorporated in all separation plants. This prevents steam being lost through the separated water system.

Wellhead pipework has been rebuilt to improve flow characteristics, but also to reduce maintenance costs and reduce down time.

Two wells now have anti-scalant systems installed to reduce well rundown. These are still in the trial-stage as not all mechanical problems have been solved.

Steam Supply Expansion

The reservoir has considerable potential for expansion. The geothermal reservoir has been modeled in detail, using computer numerical models, to predict the future effects of production and reinjection over the next 30 years. The modeling indicates that doubling production will only slightly increase cooling in existing wells. Shallow reinjection (as is being used currently) does not alter this conclusion (White, et al., 1997).

Currently, steamfield equipment is located in a small area of the field, to the north of the mill, with production and reinjection wells and separation plant located on both banks of the Tarawera River (Figures 1 and 2). Other existing wells may be incorporated into the system in the future, either to makeup the steam supply as existing production wells decline in output, or to increase the supply.

Further Reinjection

The strategy is one of staged development, monitoring the effects of each stage before proceeding. Care must be exercised in the location of further reinjection to avoid affecting the temperature of production wells and to avoid contamination of groundwater aquifers. However, the success with reinjection so far indicates that it may be possible to increase the reinjection flow rate.

Separated water resulting from any increment in steam production is likely to be disposed of by reinjection, with constraints of avoiding damaging the resource and contaminating groundwater.

CONCLUSIONS

the Kawerau geothermal steamfield has provided a consistent energy supply to the Tasman Pulp and Paper mill over a long period. It is predicted that producing steam at twice the current rate would be well within the sustainable capacity of the reservoir. However, it is necessary to continually improve steamfield efficiency and cost effectiveness to remain competitive with alternative fuels such as natural gas.

An effective automatic monitoring and control system has been developed. This system reduces manpower requirements and gives both better control and better knowledge of the resource.

ACKNOWLEDGMENTS

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Figure 3. Main building of Tasman Pulp and Paper Co.

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TIMBER DRYING AT KAWERAU

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BACKGROUND

Traditional methods of drying timber in New Zealand were largely reliant on stacking the sawn timber in layers with spacing pieces outdoors, and letting the sun and wind do the work over a period of a few weeks in summer and much longer, if ever in winter. Some timber was pre-dried in the open air and then "topped-off:, i.e. brought down to the required moisture content in the controlled atmosphere of a drying kiln. Older types of drying kilns in the USA were of the "wigwam" or conical type.

This procedure had certain limitations: (1) variability of moisture content from top to bottom and side to side depending upon the exposure, (2) the temperature in the kiln and the final moisture content of the lumber could not be well controlled in the older type drying kilns, (3) sun checking would occur at the top of the stack in the open air, and wide boards would curl or twist, and (4) increased handling cost and prolonged drying period requiring material to be held longer in inventory.

About 40 years ago, a number of the larger sawmills began building timber drying kilns. These were typically enclosures constructed from brick, concrete and concrete masonry and would accommodate 20 to 50 m^3 of stacked timber. The enclosures or chambers were heated by steam and heat exchangers. Operating temperatures were low by today's standards typically 60 to 70ºC (80ºC maximum) which resulted in timber taking up to 2-3 weeks to dry from green sawn state.

At that time, the timber resources was mostly Native species and the slow drying process was ideally suited as it allowed the moisture to be extracted without subjecting the timber to cell damage and stress. About 20 years ago the technology developed with the introduction of "dehumidifying" drying processes which basically used reverse cycle refrigeration techniques similar to air conditioning to removed the moisture from the timber.

The percentage of timber dried from the total sawn was relatively small and demand for the dried project was such that a premium could be charged which made the drying process a very profitable business. It was obviously the quickest and <u>simplest way to add value to the timber</u>, and still is today.

RADIATA PINE

With the rapid decline in the availability of Native timber species and a large plantation grown Radiata Pine resource becoming available, the drying process needed to change. Radiata Pine has quite different characteristics to the native species being lower density full of knots and in particular having a very high moisture content (up to 130% by weight). New Zealand's timber industry is now dependent on this new resource.

The Radiata Pine, however, has some serious disadvantages compared to most other timbers used in similar situations: (1) it is of low density and variable in density through the log, (2) it has very high moisture content when harvested, (3) it is of relatively low strength, and (4) it is subject to fungal and insect attack if not treated.

The Forest Research Institute have developed techniques and processes which solve many of the problems listed above, and are list in order as follows: (1) grading of sawn timber, (b) kiln drying schedules, (c) measuring and being able to guarantee strength, and (4) a number of preventative treatment processes. The most important single factor is kiln drying the timber in order to be able to supply a completely predictable product.

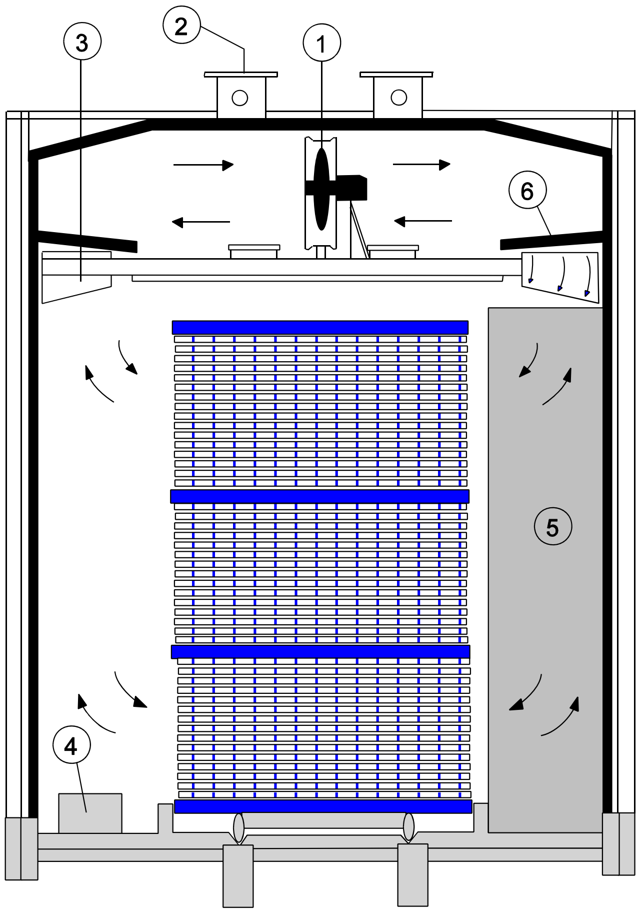
KILN DETAILS

The two main reason for drying lumber is to set the sap and prevent warping. The sap usually sets at 57 to 60ºC and warping is prevented by establishing uniform moisture content through the thickness of the wood, which is best achieved in a kiln. The drying rate varies with the species of wood and decreases (time increases) with thicker sizes.

Kiln drying techniques have developed to the extent that different drying regimes are followed depending on the end use of the timber. For timber used in structural applications the appearance is not important provided that the timber is strong straight and stable. These parameters can be achieved by firstly grading the timber correctly then drying at elevated temperatures which allow drying in 24 hours or less. Often some form of timber treatment process will follow drying.

For timber that is required to further processing into products such as flooring, cladding joinery and furniture the timber must be dried in a way that precludes apparent defects which detract from appearance. For finger jointing and laminating to produce building components it is of critical importance to have timber dried accurately with moisture content varying between pieces by no more than ±1%.

In basic terms a timber drying kiln is simply a large oven which can be heated up and have the enclosed heated air circulated to draw the moisture from the timber and exhaust it to the atmosphere. By far the most popular method of providing the energy in recent times has been to supply hot water at high pressure and temperature to an enclosed system with heat exchangers in the kilns and fans distributing the air at velocities ranging from 5 m/s to 8 m/s and with kiln temperatures ranging from 80 to 140°C. The operation of the kilns can be completely automatic. Steam can also be used as a heat source. Using geothermal energy, the cost is estimated to be between NZ$2.00 to NZ$4.00 per m^3 (US$1.00 to 2.00). This is usually less than half the cost of other fuel sources, however, geothermal energy is not available everywhere.



1. Adjustable Pitch Aluminium Fan
2. Aluminium Ventilator
3. Aluminium Side Air Baffle
4. Water Trough for Humidification
5. Adjustable Aluminium Vertical End Air Baffle
6. Bi-Metallic Estruded Aluminium Finned Heat Exchanger Tubes

Figure 1. Typical New Zealand drying kiln (courtesy of Tekwood Ltd.).

KAWERAU DRYING KILN

The geothermal drying kiln associated with the Tasman Pulp and Paper Plant at Kawerau is operated by Fletcher Challenge Forest. This kiln uses 10 bar geothermal steam at inlet temperature of 180°C which produces 150°C temperature in the kiln. Radiata Pine in batches of 80 to 100 m^3 is moved into the kiln on three rail-mounted trucks. Each layer of lumber is separated by spacing pieces about 2 cm thick. In the kiln the moisture is reduced from 150 to 10% in 20 hours. Two-meter diameter fans produce 9 m/s air across pipe heat exchangers. The circulation direction is reversed by computer every 1.5 hours. The lumber is then put through a cool-down period for two hours and finally reconditioned for six to eight hours at 90 to 100°C , which changes the moisture content from 10 to 20%. This creates a uniform moisture content throughout each piece of lumber. A bacteria mat is used to clean the hydrogen sulfide from the geothermal steam after it has been run through the heat exchangers and before disposal.

Figure 2. Stacked lumber ready to be dried.

Figure 3. Reconditioning of the dried lumber.

The typical lumber dried is rough 2 x 4 (5 x 10 cm) in dimension, however, wider material requires a lower temperature of 120°C and longer time. The dried product is stained by sap on the surface, which is removed in the finish planing operation. Prior to using geothermal energy, lumber was dried at 70°C for four days - a much more costly operation. The entire procedure is monitored and controlled by computer. The final product sells in New Zealand for US$ 150 to 200 per m^3 - adding 50 to 100% to the price of green lumber. Kiln drying costs about US$20 per m^3 of which the geothermal energy is about 5 to 10% of this cost. About 80% of the product goes to the domestic market.

GEOTHERMAL GREENHOUSES AT KAWERAU

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INTRODUCTION

Geothermal Greenhouses Ltd was established in 1982 by a small group of Tasman Pulp and Paper Company employees who saw an opportunity to utilise geothermal steam available in the Kawerau geothermal field. The operation produces capsicum (bell pepper) for local and export markets and is located entirely within the production steamfield at Kawerau. Heating for the greenhouses is provided by a small flow of geothermal steam taken from a two-phase pipeline, fed by several deep geothermal wells.

The greenhouse operation is small, with a permanent staff of five, including a share holding manager. Marketing and packing of the crop is handled by a separate company. Total greenhouse area is 5250 m^2, consisting of 3600 m^2 in an early timber frame fan ventilated single plastic covered design built in 1982, and an area of 1650 m^2 in a modern fan ventilated twin skin steel and aluminium framed greenhouse built in 1994. Heating requirements are relatively high compared to other greenhouses in New Zealand, due to the high minimum night and day temperatures needed for the crop grown, and the cool Kawerau climate.

The primary utilisation of geothermal steam at Kawerau is as a heat source for the Tasman Pulp and Paper Company mill, which uses approximately 300 tonnes/hour of steam, mainly to generate clean steam for paper drying. High temperature lumber drying kilns are also supplied with geothermal steam at the same site. Steam supplied to the greenhouse is a very small part of total steam production. Although the greenhouse is independently owned and operated it would not exist without the paper mill, since steam production would not be viable for the greenhouse operation alone. Without geothermal heating the climate at Kawerau would preclude heated greenhouse operation, as freezing night time temperatures occur during winter. Geothermal heating has allowed the high sunshine levels found in the Bay of Plenty area to be used to advantage without the problem of frost being a major factor.

Carbon dioxide, which is a very effective growth stimulant for plants, is used in the greenhouses. Studies have shown that as CO_2 concentration is increased from a normal level of 300 ppm (mmol/kmol) to levels of approximately 1000 ppm crop yields may increase by up to 30% (Ullmann, 1989). Bottled carbon dioxide is utilised at a rate of about 50 kg per day, to provide CO_2 levels of 800 mg/kg when the greenhouse is closed and 300 to 350 mg/kg whilst venting. In England and the Netherlands CO_2 levels of 1000 mg/kg are often used (Ullmann, 1989) and similar concentrations are desired at Kawerau, but current costs of 0.60 NZ$/kg for bottled CO_2 are too high.

Geothermal greenhouse heating offers an opportunity for utilisation of the carbon dioxide present in the geothermal fluid. The main difficulty is that plants react adversely to hydrogen sulphide which is mixed with the CO_2 in the steam. Even very low H_2S concentrations of 0.03 mg/kg can have negative effects on the growth of plants (National Research Council, 1979). Therefore, purification of the available CO_2 would be required before it could be used in the greenhouses. Some work on this subject was presented by Dunstall and Graeber (1997).

GREENHOUSE CONSTRUCTION

Two fan ventilated greenhouses are currently in use in Kawerau. The older greenhouse, built in 1982, covers 3600m^2 and is timber framed with a single plastic cover. This greenhouse provides a relatively large night time heat load, as capsicum has a relatively high temperature requirement (Table 1).

Figure 1. Older greenhouse with Capsicum (green peppers) plants and heating pipes (bottom one is condensate return)

The second greenhouse covers an area of 1650 m^2, and is a modern design fan ventilated twin skin stainless steel and aluminum framed greenhouse built in 1994. The twin skin dramatically lowers heat load requirements in this greenhouse, compared to the older design.

Table 1. Minimum growing temperatures for several greenhouse crops

Crop Type	Minimum Night Temperature (ºC)	Minimum Day Temperature (ºC)
Tomato	15	18
Capsicum	18	20
Aubergine	20	25
Roses	16	18
Carnation	10	18

* Higher temperatures may be required with high CO_2, humidity and light levels.

Figure 2. New greenhouse with manager, Brian Foster.

CROP AND GROWING SYSTEM

Geothermal Greenhouses grows its capsicum crop in a specially graded pumice, fertilised and watered using a hydroponics method. The irrigation system is controlled by solar sensors, dispensing nutrients at a rate dependent on the uptake rate in the plants. Mature plants grow to a height of approximately 3.5m, at which point they are discarded and the growing process is restarted from new seedlings.

A high quality crop is grown, with a crop yield of over 20kg/m^2 annually for red and yellow capsicums, and 30kg/m^2 annually for green capsicums. This compares very well with a target figure of 25kg/m^2 annually, given in 1994 by the New Zealand Ministry of Agriculture and Fisheries.

The greenhouse climate is controlled using a MAXSYS greenhouse computer control system, with humidity control and a CO_2 enrichment system. The MAXSYS system is a commercial crop management system designed for New Zealand climate, and gives crop production rates which are about twice that of traditional type greenhouses.

HEATING SYSTEM AND CONTROLS

Steam for the greenhouse is supplied from the a two phase line fed by several wells in the north eastern part of the bore field. The primary separator for this two phase fluid is some 500m distant, so a small separator mounted to one side of the two phase line is used. Flows to the greenhouse are quite low, so steam can be tapped from this small separator and the remaining water returned to the two-phase line. The steam supply is at 270ºC and a pressure of 15 bar in the two phase line, but a pressure control valve reduces this to 5 bar in the 50mm greenhouse steam supply line, which is buried in a shallow trench. Estimated annual energy usage is about 700,000 kWh, with an energy cost of about NZ$4900. The unit energy cost is therefore NZ$0.007/kWh, or about NZ$5.50 per tonne of steam. The steam flow is not metered; instead a flat rate is charged each year, based on historical condensate flow data.

Figure 3. Separator on two-phase line with pressure control valve.

Fast growing crops in heated greenhouses are very vulnerable to a loss of heating, so a backup supply is required. At Kawerau, several wells supply the two-phase line so a shut down of any individual well for maintenance does not affect the greenhouse. The most vulnerable part of the system is probably the short buried steam supply line from the pressure control valve to the greenhouse. To date, this has not caused any problems.

The pressure control valve maintains a constant 5 bar inlet pressure to the system. Motorised valves connected to temperature controllers in the greenhouse then determine the flow of steam admitted to distribution headers, which in turn supply a network of 25mm diameter heating pipes. Condensate and residual steam from the heating pipes flow to atmosphere. The black steel heating pipes are installed above the crop, supplying heat to the air and radiant energy to the plants. Wet and dry bulb sensors (PT100) are used for humidity and temperature control as part of the MAXSYS system.

Data is not available for the original costs of the heating system, but based on data collected during the 1994 upgrade of the 1650m^2 unit, installed costs are estimated at NZ$8.30 per m^2, including pressure control valves, temperature control valves, pipework and installation costs. Total costs for the heating system are therefore around NZ$44,000 capital cost + NZ$4,900 annual running cost. Assuming a 20 year equipment life the discounted cost (12% discount rate) is NZ$0.036/kWh ($0.029 equipment + $0.007 energy). Some comparison with other fuels is then possible.

Heating a similar greenhouse with electricity in the Franklin district (an intensive crop growing area) would cost about 11c/kWh (7c energy + 4c installation), based on a heating requirement in Franklin of 110 kWh/m^2 annually. compared to 133 kWh/m^2 annually in Kawerau. This is a $38,000 yearly saving to the geothermal greenhouse, but at least part of this saving is offset by transportation costs, as Kawerau is much further from major domestic markets and ports of export.

Most heat is lost from greenhouses by air leakage and wind effects due to poor construction. Modern plastic covered greenhouses may use as little as 30% of the heat needed for an older glass covered greenhouse. Typical heat loss rates at Kawerau are 3.5W/m^2K in plastic greenhouses compared to 12W/m^2K in glass covered greenhouses. The new twin-skin plastic greenhouse achieves these low heat losses without loss of solar light transmission required for plant growth. Heat loss rates impact heavily on greenhouse profitability.

OPTIMUM GROWING CONDITIONS

Plants grow and develop most efficiently when the environment is controlled with specific day and night temperatures. Generally, higher crop yields are obtained at higher temperatures and the cost of supplying additional energy for heating must be balanced against the increase in yield expected. Low marginal cost forms of energy, such as geothermal, give higher optimum temperature conditions than high marginal cost system such as electricity.

Most crops respond to 24 hour mean temperatures, provided the variation in temperature over that time is not too extreme. This means that electrically heated greenhouses can tolerate lower temperatures during times of high tariff, and operate at higher temperatures during low tariff times to compensate. The Kawerau greenhouse is not constrained in this manner, but could be operated in this way if the steam supply shared with another operation was critical at certain times of the day.

Humidity control has a very significant beneficial effect and often it is humidity control, rather than dry bulb temperature, which controls greenhouse conditions. Fungus disease control is highly dependent on the humidity level. Continuous air movement through the leaves of the plants is also important to control fungus, by eliminating moisture from the leaf surface. The reduction in cost and risk associated with chemical sprays substantially offset the additional expense involved in a more sophisticated control system. Improving fruit quality and yield result in increased profitability.

Air leakage rates have a severe impact on economics when CO_2 enrichment and humidity control are used, since these factors are much more expensive to control and provide than dry bulb temperature. At Kawerau the annual cost of providing bottled CO_2 is higher than the geothermal energy cost. Best growth rates are achieved when humidity, CO_2 enrichment, and temperature are all controlled in a low loss greenhouse. High temperature only translates to high growth rates if the level of CO_2. is also high. Without additional CO_2 higher temperatures will stress the plants.

It is interesting to note that the steam supplied to the greenhouse each year for heating purposes contains almost exactly the quantity of bottled CO_2 used each year (Geothermal & Nuclear Sciences, 1992). With appropriate treatment, the geothermal steam might ultimately be as valuable for its CO_2 contribution as for its heating value.

OTHER FACTORS AND FUTURE TRENDS

A number of proposals for geothermal heating of New Zealand greenhouses have been studied over the past 15 years or so. In most cases the relatively mild New Zealand climate has greatly reduced the advantage obtained from geothermal heating. High capital costs are difficult to recover when energy costs are quite low. In addition, the geothermal areas are further from markets than traditional greenhouse areas and transport costs have been high.

However, the size of new greenhouse developments has increased dramatically in recent times, from a typical size of 2000m^2 to 10 to 50 times larger. The heating demand has consequently risen by a similar factor, as these new export oriented units are developed. With falling transport costs, and with more intensive heating and crop production rates, geothermal greenhouse heating is becoming more attractive.

The use of geothermal carbon dioxide for growth stimulation of plants might be possible if a purification process is used to reduce the initial hydrogen sulfide content. This would greatly increase the attractiveness of geothermal energy in greenhouses where a steam source is available. The CO_2 could be worth as much as the energy in the Kawerau operation. However, a cheap purification process is needed.

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DRYING OF FIBROUS CROPS USING GEOTHERMAL STEAM AND HOT WATER AT THE TAUPO LUCERNE COMPANY

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INTRODUCTION

Background

Taupo Lucerne Limited was formed in 1972 to develop the use of geothermal steam and hot water for drying fibrous agricultural crops. The plant is located at Broadlands, approximately thirty (30) km norteast of Taupo in the central North Island of New Zealand, on a four (4) hectare site adjacent to the Ohaaki Geothermal Power Development (Figure 1). The Ohaaki power development is operated by ECNZ (Electricity Corporation of New Zealand) who supply the Broadlands Lucerne Company with all geothermal fluids. High pressure steam (8 bar) is separated onsite, supplied as two-phase fluid from the stations production well system. Separated hot water from the Ohaaki power station's reinjection system is also utilized.

The drying facility provides a means of adding value to the lucerne (alfalfa) hay which is grown from November until April in this area. A number of contract growers provide feed stock for the plant. If the lucerne is cut, windrowed and collected quickly for drying, the retention of Vitamin A, protein and color will be high compared to the field dried product, resulting in a higher commercial value. Drying the corp at the point where it is grown reduces transport costs and, in this case, allows use of low cost geothermal fluids to provide the heat source. Product appearance is a very important aspect of fodder marketing, and the color of the product is one of its most important characteristics. In comparison to fodder dried conventionally in fossil fueled driers, geothermal driers operate at lower temperatures and do not expose the fodder to contamination by the products of combustion, resulting in a final product of higher quality (Lienau, 1990). Farming and forestry are the major industries in the area, since the raw material is readily and immediately available, round wood and timber is also dried at the plant. Sawn timber, fenceposts and poles are produced in the timber drying operation.

Geothermal steam and hot water is used as the heat source for all processes. Steam is obtained from a deep two-phase well in the adjacent Ohaaki steam field. Hot water is used after electricity has been produced from the initial flash by ECNZ, who operate the Ohaaki geothermal power station. Approximately four (4) tonnes of steam per hour is used for coagulation of the lucerne juice and operation of the round wood drying cylinder. Up to one hundred (100) tonnes per hour of hot water is used in the heat exchanger system for drying the fibrous lucerne material.

The fibrous lucerne material is dried in an air steam heated by geothermal hot water which is passed through finned tubular-type heat exchanger units. Initially, only dry separated geothermal steam was used in the plant, at approximately 175^{o}C (Freeston and van de Wydeven, 1979). In 1993, the system was converted by the installation of additional heating coils to use the hot water which remains after flash steam has been removed for generating electricity. Separated hot water is now used at 148^{o}C. The system is steam purged to prevent silica buildup in the heat transfer coils..

Products Produced

The following products are produced onsite:

<u>De-Hi</u>

Lucerne is direct harvested into the plant where it is steam heated and pulped. The stems and leaves of the plant are then crushed and squeezed to extract the juice. De-Hi is the remaining fibrous residue of the plant, which is dried and pelletized to form a stock food which is easily transportable, high in protein and has a long shelf life. Considerable volumes of this product are used during transportation of sheep and New Zealand's live sheep trade has been a major market for this product, which is also used by the poultry, deer and rabbit farming industries. Up to 3000 tonnes per annum are produced.

<u>Protein Concentrate (LPC)</u>

Lucerne protein concentrate (LPC) is the dried juice extracted from lucerne. This product is very high in protein (48% by weight) and is used in the egg industry as a feed supplement for chickens. The high level of xanthophyl in this product gives good color to the egg yolk without the addition of artificial carotene. An interesting emerging market for this product is the health food industry, where it is used as an ingredient in health drinks. Annual production is up to 200 tonnes of dried product.

<u>Dried Timber and Round Wood (Pinus Radiata)</u>

Dried timber and round wood is produced at the same site (Figure 1). At present, only one drying chamber is used. This chamber uses high pressure steam (10 bar) as the heat source and is run as a batch operation. The main market for this product is the local farming industry. Up to 1000 cubic meters of dried fenceposts, poles and sawn timber products are produced per month. Drying timber before use increases

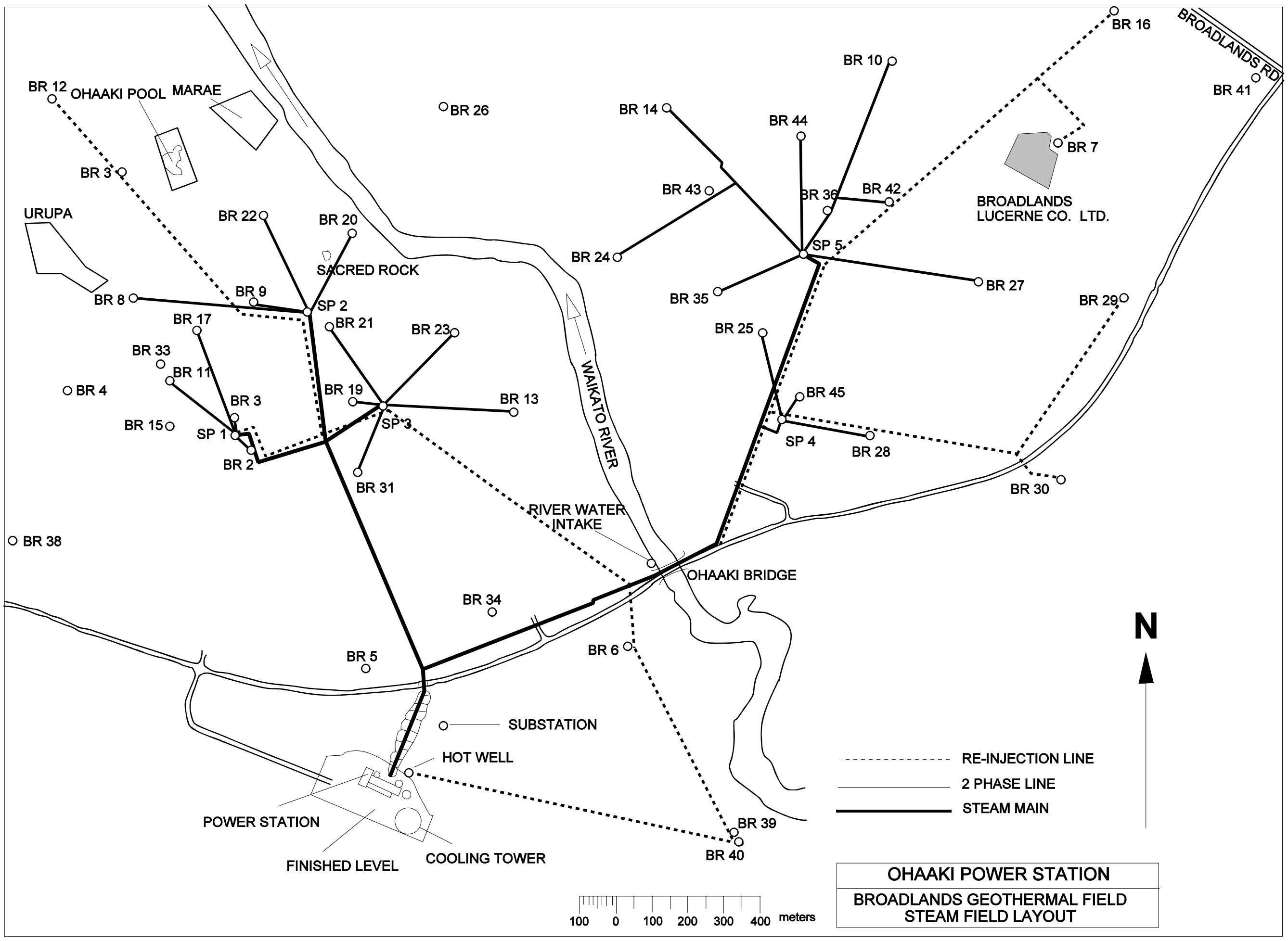

Figure 1. Location of the Taupo Lucerne Company within the Ohaaki steam field.

strength properties, resistance to biological attack, dimensional stability, and fastener retention. At the same time, it reduces weight, and consequently, shipping costs (Mujundar, 1987). Drying,, therefore, adds considerably to the value of this locally produced raw material.

PRODUCTION PROCESS

Steam Supply

When operations began in 1972, all of the heat for the operation was supplied from well BR27. Two-phase fluid was piped to the plant where separation of the steam and water took place, supplying approximately 14 tonnes per hour of saturated steam at a pressure of 8 bars and temperature of 170^{o}C.

In 1993, modifications were made to the air heaters to allow them to run on hot water from the reinjection system. Waste hot water from the Ohaaki Geothermal Station is reinjected at depth in a number of wells outside the field margins for waste disposal and reservoir pressure support. One of these injection wells, BR7, is located on the plant site and approximately 100 tonnes per hour of the hot water piped to this well is now tapped off before reinjection and used in the drying plant. The original high-pressure steam supply system was retained to supply the reduced steam demand.

Steam and hot water flows are shown in flow diagram form in Figure 2. A tee fitting at the wellhead of BR27 allows two-phase fluid at a wellhead pressure of 17 bars and an enthalpy of 1000 kJ/kg to be passed to an onsite separator at the lucerne plant, Ohaaki separation plant 5, or both. During the growing season, the well normally supplies both separation plants. Approximately, 30 tonnes per hour of fluid is passed to separation plant 5 where it is mixed with fluid from a number of other wells and flashed, first at 11.8 bars and then at 4.5 bars, to supply HP (high pressure) and IP (intermediate pressure) steam for the power station. The remaining separated water is then pumped to the reinjection system, of which BR7 is a part. Well BR27 produces approximately 30-40 tonnes per hour (5-7 MWt) of additional fluid which is piped to the onsite separator at the lucerne plant. This separator, originally used at Wairakei, is operated at a pressure of around 8 bars to provide the 4 tonnes per hour of steam (3.1 MWt) currently required. Water from the onsite separator is at a pressure and temperature unsuitable for reinjection; so, it is passed to an atmospheric silencer before surface disposal in a nearby area of steaming ground.

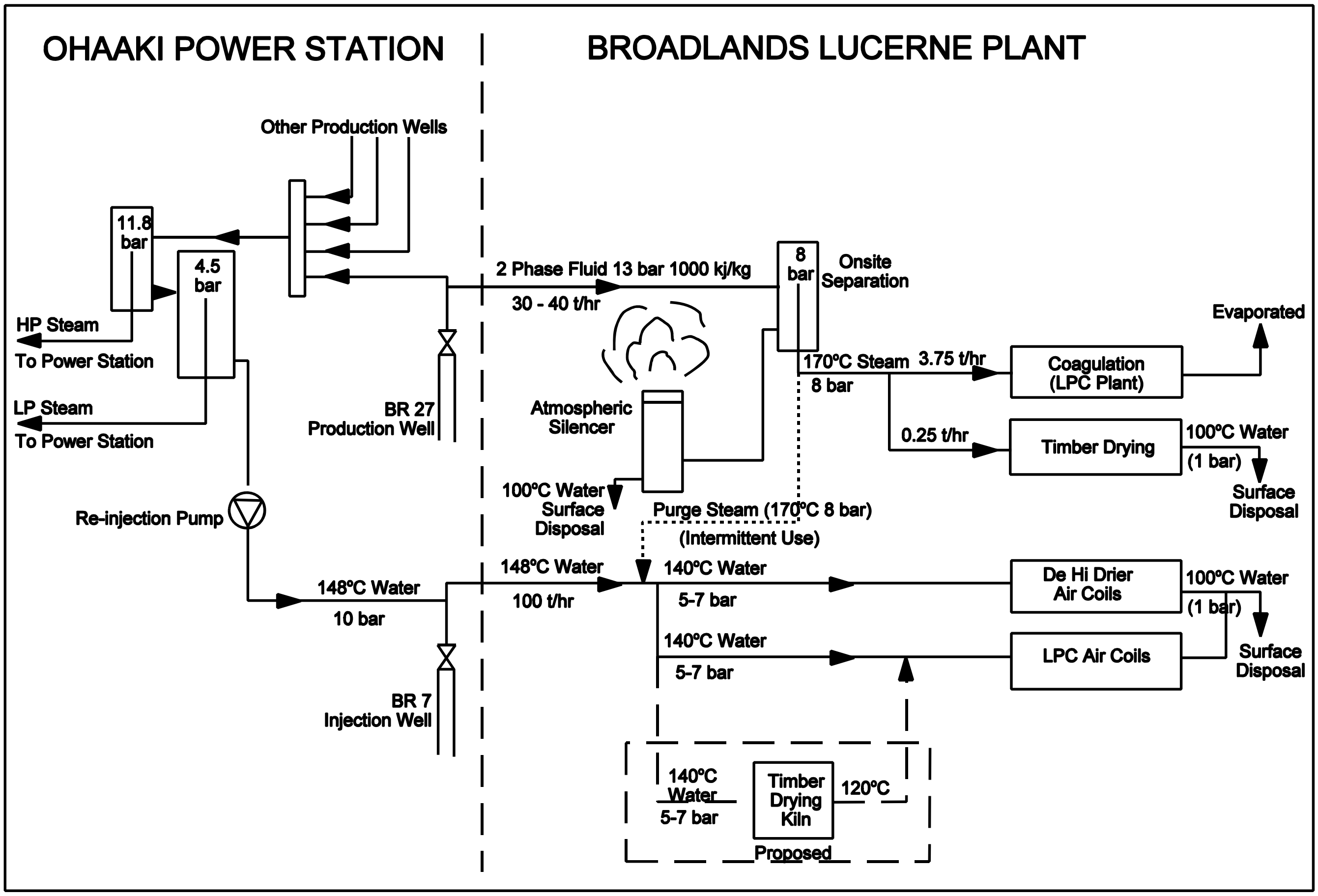

Figure 2. Flow diagram for steam and hot water supply to the Taupo Lucerne Company.

De-Hi Production

Originally, a fixed bed dryer was used for the production of the dried fibrous product (DE-HI) (Freeston and van de Wydeven, 1979). Hot air was passed over the product sitting on a mesh, in a batch operation; but, this plant was destroyed by fire in 1984. Instead of rebuilding to the same design, it was decided to convert to a continuous preumatic conveying dryer where the product is carried through the process steam by heated air, which then performs both drying and transport operations. Drying is done in three stages, with the product being cycloned at each stage to allow removal of moist air and the injection of fresh hot air (Figure 3). The complete drying cycle takes about tow to three minutes, and evaporates approximately 95% of the water originally present. This reduces the moisture content of the crushed plant material from an average of 68% to 10% by weight. An evaporation rate of up to 8000 kg of moisture per hour has been achieved; but, normal operation is around 6000 kg per hour.

The fibrous product is then passed to a hammer mill and pellet press which produce about one tonne of dried product from five tonnes of green feed stock.

Heat for the drying process had been supplied by condensing steam at 170°C in finned tube air heater coils. In order to reduce the total steam consumption of the plant, the air heaters were modified to accept separated water from the Ohaaki reinjection system at an inlet temperature of 148°C.

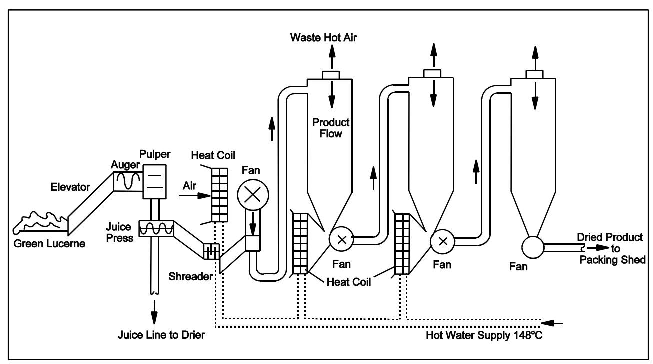

Figure 3. Production flow diagram for the De-Hi plant.

At this temperature, the water is very close to the silica saturation temperature. Pressure from the reinjection system is initially around 10 bars; but, this reduces to approximately 5-7 bars as the water is circulated through the finned heat transfer coils, tow to each drying stage, operating in series with the water then discharged to waste.

The modification involved use of the original steam coils along with the installation of additional coils to approximately double the heat transfer area. Hot water flows in two passes through the two set of coils; whereas, previously, steam was condensed in a single pass. New temperature controls were required to complete the change-over to hot water use. As a result of this conversion, overall steam consumption dropped from 14 tonnes per hour (10.8 MWt) to 4 tonnes per hour (3.1 MWt). Current steam usage is now restricted to the juice coagulator and the timber drying chamber. In both of these operations, the steam is injected directly into the chamber and cannot be easily replaced by a hot water source.

The water temperature drops from approximately 140°C at inlet to 100°C at the outlet of the air heater coils, and although this results in the water becoming super saturated with respect to silica, no deposition problems have been noted in the heat exchanger coils. It is thought that a fairly low residence time (on the order of minutes) and the rather slow kinetics of silica deposition are the main reasons for the lack of scaling. Silica deposition can be clearly seen, however, in the surface discharge channel which is fed by the heat exchanger outlet. Some silica scaling problems were expected after the change over to using separated water through the heat transfer coils instead of dry steam. At the time of conversion, it was suggested by ECNZ, who supply the geothermal fluids, that a purge of steam during non-operating hours would remove this deposit and this practice has been followed, proving successful to date. The extend to which this steam purge is required for the successful control of silica is not known. It serves the additional purpose of preventing the cooling of the heat transfer coils while they are still filled with silica-laden water, which would allow scale formation, and excludes air from the heat exchangers during short-term shutdown.

LPC Production

After pulping the lucerne, the juice extracted is dried in a separate operation to obtain lucerne protein concentrate (LPC). This product is a fine dark green powder consisting of the solids originally suspended in the juice. The juice is pumped from the screw press to a coagulator stage where geothermal steam is injected into the juice line to coagulate the solids before centrifuging and drying. Centrifuging concentrates the solids present in the juice before final drying of the juice in a multiple fixed bed type dryer. Heated air for this dryer is supplied from hot water coils in the air supply system (Figure 4). After drying, the product is pelletized to allow easy handling and distribution.

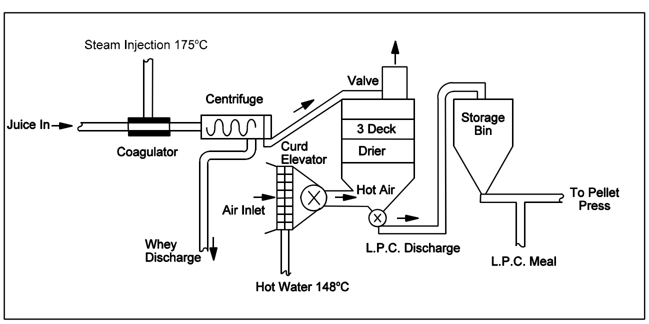

Figure 4. **Production flow diagram for the LPC plant.**

The steam still used in the production of the high protein concentrate is sourced from the hot separated water from the low volume bore previously used to supply the whole plant (BR27). This supply of two-phase fluid is at a higher temperature and pressure (192°C, 13 bars) than the water in the reinjection system (148°C, 9.8 bars); since, it is supplied directly from the wellhead, before the first stage of flashing for the Ohaaki power plant. Ideally, the steam needed for coagulation could be produced by flashing a further quantity of how water at 148°C to produce the required four tonne of steam per hour. Obtaining flash steam from the lower temperature separated water would, however, take the silica saturation to a higher level and would also result in a higher surface discharge of silica-laden water. It is anticipated that discharge consents for such an operation may be difficult to obtain; although, mitigating factors to be considered include reduced discharge from the onsite separator and an increase in overall efficiency of use of the geothermal resource.

Timber Drying

high enthalpy steam generated from the 13 bar two-phase fluid supply is also used for drying round woods (pinus radiata) in a batch-type direct steam drying system. Dry steam at approximately 170°C in injected directly into the drying cylinder at an initial rate of two tonnes in the first 15 minutes to raise the cylinder temperature after which a quarter of a tonne per hour is feed in to maintain temperature. Kiln temperature is maintained at 120°C for between 6-12 hours depending on the size of the round wood being dried. Up to 1000 cubic meters can be dried monthly. The steam softens the wood fiber allowing the sap to drain out and after a period of 48 hours to allow for cooling, the timber is ready for use or treatment (Figure 5).

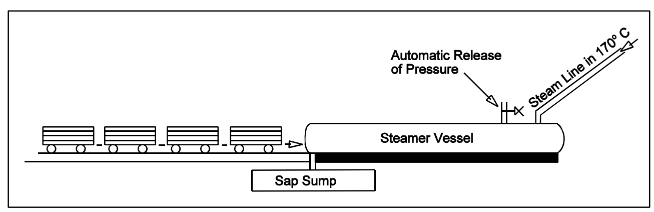

Figure 5. **Timber drying cylinder operation.**

During initial heat up period, the heat flow rate to the timber drying cylinder is high (5-6 MWt); but, this rate of heat flow is only required for a short period and the flows required to maintain kiln temperature throughout the cycle are around 150-200 kW.

Kiln drying of timber using geothermal hot water is currently being explored. The intention is to produce high-grade finishing timber for framing and joinery. Hot water from the reinjection system would be used in this system which would also operate as a batch-type operation, drying approximately 50 cubic meters of timber every two to three days. Average hot water use will be 35 tonnes per hour at 148°C with a temperature drop across the coils of approximately 20ºC to meet a heat load of around 800 kW. It is intended that, whenever possible, hot water discharged from the kiln air heaters will be piped for use in the lower temperature heating coils of the lucerne drying plant to further use the residual heat before discharge. Precautions to be taken against silica scaling will be similar to those used in the pneumatic conveying drying system. In view of previous experience, no serious scaling problems are anticipated. The main drawback of such a system is that the uniform kiln temperatures essential for the even drying of timber are difficult to obtain when heat is obtained by sensible cooling of hot water.

Both the domestic and export markets for high-quality dried pine products are expected to strengthen with growing acceptance of radiata pine as a finishing-grade timber. The provision of a low-cost energy source, geothermal separated water (which is currently disposed of as a waste product), and the location of the Ohaaki power station within plantation forests provide a strong basis for expansion in this area of operation.

OPERATION

The presence of corrosive geothermal gases (H_2S) means that electrical and control systems require protection from atmospheric conditions, as do some items of exterior pipe work. However, location of sensitive items of equipment within onsite buildings and protective painting, and sheathing of outdoor equipment have eliminated most problems. Maintenance on the geothermal equipment is moderate, with the main replacement items being operating valves. In comparison to maintenance of material handling equipment, the geothermal equipment is not considered to have any particular maintenance difficulties. Fortunately, the gas levels are low enough that it has not been necessary to provide filtered air to any of the electrical control systems.

The system is relatively simple to operate and only one operator is actually required to run the plant; although, two are used for safety reasons. Since the system was designed to minimize fluid residence time within the heat exchangers, the plant has a short warm up period, and responses to changes in load can be compensated for quite quickly. This allows considerable variations in product flow rate to be handled without loss in product quality. Six full-time staff manage and maintain the plant on an annual basis; but, during the growing season, the plant runs a double shift, providing seasonal work for another four workers. Growing, harvesting and transportation related to the lucerne plant also provide employment during the growing season.

Because of the seasonal nature of the operation, the annual load factor for the plant is rather low. Annual energy use is estimated at 14 TJ (excluding timber drying), and with an installed thermal capacity of 7 MW t, this gives at load factor of 6.5%. Calculating a sensible load factor for the timber drying operation should be used. The maximum heat flow rate to the drying chamber is quite high (6 MWt); but, it is of such short duration (15 min. in a 12-hour cycle) that the usual design constraints do not apply. When the nominal kiln heat load is used, the plant capacity factor increases considerably. The current timber drying operation uses just 200 kW; but, this is on an almost continuous basis. Annual energy use for timber drying is about 6 TJ, giving a load factor of about 9% for the operation overall. Expanding the plants capacity to dry timber, which is a twenty-four hour, year-round operations, has the potential to greatly improve the annual load factor. Currently, timber drying accounts for almost one third of the annual energy use, while representing less than 3% of the plant thermal capacity.

CONCLUSIONS

The geothermal drying of agricultural crops at Taupo Lucerne Limited has evolved from a proof of concept pilot plant into a successful commercial operation. Using the heat of the geothermal fluid directly in the process increases the efficiency of use of a natural resource. Recently, modifications have been made to existing heat exchanger equipment to enhance the inherent efficiency of the direct use system. By using separated water instead of saturated steam to provide a large proportion of the direct heat needs, the lucerne plant has provided a means of cascading a portion of the waste fluid available after generation of electricity. Cascading improves the overall efficiency of resource use at Ohaaki by utilizing a waste product and any future development will focus on using rejected water in this manner.

A further reduction in steam requirement could be obtained if the steam for the coagulator were suppled by flashing a quantity of water at 148ºC. Discharge consents would have to be altered to allow this improvement, as additional quantities of silica-laden water will be discharged. A reduced discharge from the onsite separator and an improvement in the efficiency of overall use of the Ohaaki resource are mitigating factors in such a proposal.

An expansion in the timber drying operation is the most likely form for future developments. Timber drying operations can achieve much higher load factors than lucerne drying, because the harvesting of timber is not seasonal in New Zealand. A growing interest in the use of pnus radiata as a high-grade finishing timber is the main motivation to increase the use of geothermal energy for timber drying in the central North Island.

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PRAWN PARK - TAUPO, NEW ZEALAND

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New Zealand's only freshwater prawn farm was established in 1987 to take advantage of geothermal waste heat from the Wairakei power generating field on North Island. Since approximately 2000 tonnes (2200 tons) per year of prawns are imported annually into New Zealand, the motivation was to try and capture some of this market with a domestic product.

Giant Malaysian Freshwater Prawns (Macrobrachium Rosenbergii) were imported from Malaysia in 1988. Half of these were lost in transit due to delays in lifting import restrictions. A second import of 25 breeding males and females had to be quarantined for 15 months to assure that they were disease free. Also, officials required that if prawns escaped into the adjacent Waikato River, they would not survive and reproduce. It turns out that the prawns will die in 14ºC (57ºF) water, and since the river water is at 10ºC (50ºF), there was no chance of survival. Thus, a license was issued in 1989 for the firm to start commercial production.

The original farm consisted of five outside pools totaling one hectare (2.5 acres), and a small hatchery and nursery. Shortly, another four ponds were added to bring the total area to 2.5 ha (6.2 acres).

In 1993, the New Zealand Enterprise Board joined New Zealand Prawns Ltd., in partnership, and another 10 ponds were developed bring the total pond surface area to 5.8 ha (14.3 acres), with the entire facility occupying 10.2 ha (25.2 acres)(Figure1).

Figure 1. Prawn Park with Wairakei Power plant and Waikato River.

The present 19 ponds vary in size from 0.2 to 0.35 ha (0.5 to 9.9 acres) and have a depth of 1.0 to 1.2 m (3.3 to 3.9 ft), providing a slope for ease of harvest. The length to width ratio of the pond surface is approximately 20:1. The sides are sloped for stability and the bottom material is composed of an impermeable volcanic ash that also stores nutrients for the prawns (Figure 2).

Figure 2. Detail of outdoor pond.

Ideally, the ponds should be kept at a temperature of 28ºC (82ºF); but, presently, they are at 24ºC (75ºF) with a temperature variation from one end of the pond to the other of 1ºC (2ºF). A temperature probe controls the flow of water into the ponds and an aerator is used to obtain vertical mixing of the pond water. Without the vertical mixing, the pond becomes temperature stratified, reducing the production of prawns.

Water for the ponds comes from two sources, the plate heat exchanger at 55ºC (131ºF) and river water at 10ºC (50ºF). Water is circulated throughout the system from a storage and settling pond that is kept at 21ºC (70ºF). Approximately 90% o the water is recirculated, with the 10% makeup water coming from the river. Water is circulated through the plate heat exchanger at a rate of 250 tonnes per hour (1100 gpm) (Figure 3) in summer and 400 tonnes per hour (1760 gpm) in winter. The primary side of the plate heat exchanger takes waste water from the Wairakei power plant just before it flows in to the Waikato River. Approximately 4000 tonnes per hour (17,600 gpm) of over 90ºC (194ºF) waste water is discharged from the plant and flow across the pumps supplying the plate heat exchanger. The geothermal water cannot be used directly in the ponds due to the presence of detrimental sulphur, lithium and arsenic. However, there is an experimental project nearby funded by ECNZ (Electricity Corporation of New Zealand), that is attempting to extract these elements for commercial use.

Figure 3. Hot water intake and plate heat exchanger.

The Prawn Farm pays a royalty to ECNZ for the heat source; however, the Prawn Farm is still the third largest annual electricity consumer in the Taupo District. The farm would not be economically viable if electricity were used for heating, instead of the Waikato River water, and this is reviewed on an annual basis.

Presently, the farm is capable of producing up to 30 tonnes (33 tons) of prawns per annum of prawns (Figure 4); however, presently only 16-17 tonnes are produced. The life of the prawn starts in salt water inside in breeding tanks and end in the freshwater ponds outside where they are harvested after nine months averaging 30 to 40 per kg (14 to 18 per lb) or about 30 g (1 oz) each. They are sold at $NZ 25/ kg wholesale and $NZ 40/kg retail ($US 17 to $US 27 per lb).

Figure 4. Harvested prawns.

The life cycle and stocking rates of the prawns start with the breeding tanks. These hold between 100 to 150 breeding stock at a ratio of one male to five or six females. The males last about 18 months at which time they are replaced. A female prawn spawn five times a year in brackish water (1/3 saltwater and 2/3 freshwater), and produce between 20,000 to 80,000 larvae per spawning. A total of one million larvae are produced per cycle giving total production of post larvae per year of nine million.

After spawning, the larvae are attracted by light where they are siphoned off into a catching bucket and placed in the larval tanks. The larvae undergo eleven different moults to metamorphose into a post larvae in 30 days. They are fed three times a day with a mixture of crushed mussels and scrambled eggs (Figure 5).

The larvae are then moved to nursery ponds holding up to 200,000 animals each and kept at 28ºC (82ºF) (Figure 6). Here they grow from 0.01g to 4 - 6 (0.004 to 0.14 - 0.21 oz) in four months. They are fed a diet of pellets containing fishbone, minerals, etc., still at three times a day.

Figure 5. Larval tank.

Figure 6. Nursery ponds.

After four months in the nursery, the prawns are transferred to the outdoor growout ponds for their final growth of a further five months. The prawns are moved manually using a net with mesh openings that catches only the largest ones.

They are again fed pellets, with zooplankton growing in the ponds providing additional food. Prawns are voracious eaters and will turn cannibalistic if undernourished. Two kilograms (4.4 lb) of food produces one kilogram (2.2 lb) of prawns.

At the end of the five months, the ponds are drained and the prawns picked up manually from the bottom by four to six harvesters. The prawns are then transferred to the hatchery for washing before they are taken fresh to the restaurant (Bar and Grill) or snap frozen for future use (Figure 7).

The stocking rate in the outdoor growout ponds are approximately 30 per square meter (3 per square foot) or 20 to 30,000 prawns per pond, depending upon the size. At harvest time, 400 to 500 kg (880 to 1100 lbs) are produced from the smaller ponds, and 800 to 1000 kg (1770 to 2200 lbs) produced from the larger ponds.

Figure 7. Bar and Grill Restaurant.

Ninety percent of the harvested prawns are sold to the Bar and Grill next door, with the rest going to gourmet restaurants in Queenstown, Wellington and Whakatane. Over a recent three year period, the restaurant has served more than 30 tonnes (33 tons) of prawns to more than 45,000 visitors (Figure 8). This is 10 percent of the prawns consumed annually by Kiwis. The restaurant offers a plate of 16 prawns for NZ$ 22 (US$ 15) or a half plate of 8 prawns for NZ$ 12.50 (US$ 8). This past year, with a full-time marketing manager and half-hour hatchery tours operating five hours a day (at NZ$ 4 - US$ 2.7 per head), more than 25,000 tourists, 50 percent domestic and 50 percent overseas, have been attracted.

Figure 8. A satisfied customer.

Prawn farming is labor-intensive with high overheads. Six hectares (14.8 acres) cost NZ$ 500,000 (US$ 330,000) a year to operate–compared to farming dairy cattle yielding NZ$ 2500 per hectare (US$ 660 per acre). Prawns return NZ$ 150,000 per hectare (US$ 40,500 per acre).

Recent plans are to tap into an Wairakei injection well at 120ºC (248ºF) and 6 bar (87 psi) pressure, instead of using the waste water in the adjacent stream. 400 m^3/hr (105,600 gph) will be used on the primary side with a peak capacity of 35 MWt which will supply 28ºC (82ºF) water to the ponds. Economics dictate that for economic operation a minimum of 20 ha (50 acres) are needed

GEOTHERMAL ORCHIDS

Alistair McLachlan
Geotherm Exports New Zealand Ltd.
Taupo, New Zealand

LOCATION

Geotherm Exports is located on Tukairangi Road, approximately 5 km from the Taupo Township. It is situated on the Wairakei Geothermal Reservoir.

HISTORY

Geotherm Exports was formed in 1981 to grow the tropical orchid Phalaenopsis.

Phalaenopsis grow in the wild in the jungles of southwest Asia with a few species extending northwards to Taiwan and Sikhim, and southward to northern Australia. The plants are epiphytic (living on the surface) on trees and they grow upside down (in nature) with the flow stems hanging downward, and the leaves arranged in a spiral fashion. Under cultivated conditions, the flower stems are tied vertically.

Figure 1. Orchid Phalaenopsis.

They are shade-loving plants, requiring a light intensity of only 1000 foot candles or 1/10th of full sunlight.

This orchid was first discovered by western botanists in 1750 when a German botanist, Rumphius, found them on the island of Ambon (now call Sulawesi). Two years later, they were discovered on the island of Teneli, west of Java, where only Princesses were allowed to wear the blossoms. The name Phalaenopsis was given by Dr. C. C. Blume in 1825 because he mistook the flowers for a flock of butterflies when he first saw them through his field glasses.

The flowers are also known as moth orchid, mariposa, butterflies, and are also known in Indonesia as the moon orchid.

GEOTHERM EXPORTS

Geotherm Exports has the largest single concentration of these orchids grown for cut-flower production in the world and the only one using geothermal energy for heating. There are two other growers in the United States who grow more plants; but, these are sold as potted plants.

The company has created a world first by inducing artificial monsoon conditions, similar to those experienced by the plants in their natural habitat. This enables us to produce crops at any time of the year to meet market requirements in Japan and elsewhere.

The company has approximately 250,000 plants in its greenhouses, laboratory and quarantine area; of these, 30,000 are mature plants. Each plant produces on average two stems of blooms per annum upon reaching maturity (two years old), and these blooms are packed using the most modern inspection and packing techniques to produce the best possible return from overseas markets.

Figure 2. Potted plants with lighting system.

A further world-first in commercial orchid production has been the plant-performance recording system introduced by Geotherm to enable individual records of production and performance for every mature plant to be kept. This now enables the company to breed selectively from plants identified by this method. In addition to good breeding, parent plants must also have good color, shape of bloom, and be prolific in their bloom production per stem, to qualify as breeding stock. The company now produces its own replacement stock through its laboratory and plant-breeding system.

CONTROL SYSTEMS AND FEEDING

Computers

The company uses an Apple Ile Computer for controlling day-to-day growing conditions in the production greenhouses, laboratory, growing-on room and plant quarantine area.

This computer enables accurate monitoring of temperature (day and night), humidity, watering, fertilizing, ventilation, the addition of CO_2 and the application of artificial light.

In addition to the Apple Ile, the company also has two Mac XL computers used for accounting and analysis work, and a Macintosh II business computer used for word processing, spreadsheet projections and drafting.

Heating

Heat is controlled by the Apple Ile computer, and is supplied to the greenhouse by large hot water heaters (using fans and finned heat extractors) or by steam radiators and fans. The geothermal energy used in this way was the first geothermal-horticulture system in New Zealand.

Figure 3. Forced air heat exchanger.

The company originally had two geothermal hot-water wells to 300 meters in depth, and a dry steam well to 250 meters in depth which produced steam at 200 psi (13.8 bar) and 210ºC. The greenhouses now receive their steam from three wells used for the Mercury Geotherm power plant. These well are 450 to 500 m deep and each can produce 120 tonnes/hour at 7.2 bar. Some of the steam is supplied to the greenhouse through a shell-and-tube heat exchanger (Figure 4). The energy supplied to the greenhouse is equivalent to 20 average homes or about 200 MJ/hr (peak). This is equivalent to an installed capacity of about55 kW. The greenhouses, which cover two acres (0.8 ha), are kept at 26ºC during the day and 21ºC at night.

Figure 4. Main heat exchanger.

Fertilizer

Fertilizer is applied every day through a series of electric solenoids by the computer so that each plant can take both water and fertilizer up through the capillary watering system used on the growing tables. This enables the plants to be fed and watered without lying in the leaf joints, which would cause plant rot and subsequent death.

Lighting

The imported Phillips lighting system is the most sophisticated available in the world. The light fittings produce light in an oblong pattern, so that light is not wasted on the pathways. The amount of light applied is measured by comparing light received by an exterior light sensor and light sensors in each growing area. If light does not reach a pre-set level in each growing area, the computer turns on the lighting system, until the amount of light applied reaches the required level for maximum growth.

CO_2

CO_2 is required by the plant to enable cell growth. Geotherm has installed systems originally built in the United States for the space shuttle, designed to work in extremely harsh conditions in space, and for periods of many years with no maintenance. The CO_2 system consists of a vacuum pump which draws samples of air from selected plants in each greenhouse every 15 minutes, passes these samples through a gas analyzer and assesses the level in each greenhouse compared with pre-set levels in the computer. If additional CO_2 is required, this is applied to each orchid table through micro tubes.

MARKETING

The company has designed its packaging system to enable the blooms to be displayed in the best possible manner. Extra cost is incurred by using boxes with a white interior and exterior, because white to Japanese symbolizes purity. Only first-grade flowers are exported, and every bloom (8-10 per stem) is inspected under a 10x magnifying light to ensure that it is top quality. Approximately 55 blooms are packed per box.

Shipments are from Taupo to Auckland by company truck, and then by jet from Auckland to Tokyo. Time elapsed from picking to marketing is 3 days.

The company employs a manager and part-time staff in Tokyo. Blooms are sold every week through 25 outlets in Japan. Flowers are produced each week of the year, but are not exported for two weeks at Christmas, and one other week which is a Buddhist “green week,” when only green colored items can be purchased by Buddhists. The majority of Japanese are Buddhists.

ELECTRIC POWER PLANT

A geothermal electric power plant, operated by Mercury Geotherm, Ltd., is located about one kilometer from the greenhouses. The greenhouses receive their steam supply for the power plant wells as mentioned earlier–wells #4, 5 and 6 located in the Waiora Valley. The power plant has a capacity of 55 MW and was purchased from the Northern California Water Board. California Governor Jerry Brown had planned to installed the plant at the Geysers; but, this did not happen. Instead, it was purchased, moved to New Zealand and commissioned in 1996.

Figure 5. Mercury Geotherm turbine-generator building.

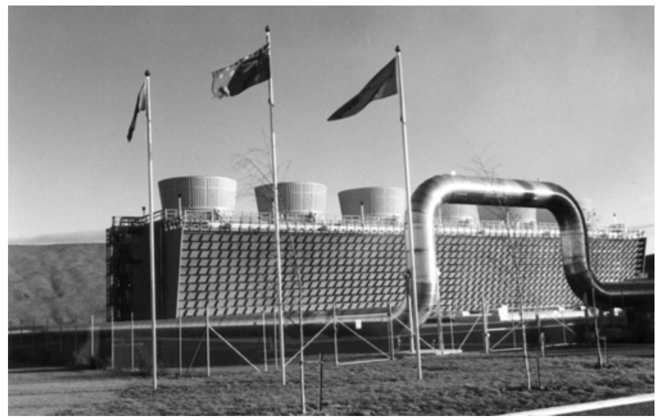

Figure 6. Mercury Geotherm cooling tower.

MIRANDA HOT SPRINGS

Derek Freeston
Geothermal Institute, University of Auckland

John W. Lund
Geo-Heat Center

The Miranda Hot Springs are located near the western head of the Firth of Thames, and at the western margin of the Hauraki Depression. They lie on a flat area about one meter above sea level and approximately 700 m inland from the sea edge and some 3 km in a generally southerly direction from the site of the old Miranda township, in an area originally known as Pukorokoro. Miranda was named after a naval gunboat of that name which was dispatched during the Maori wars in 1863 to subdue a Maori Pa (village) located some 300 m to the south of the springs. The springs were apparently used in pre-European times; but, photographs of the region only go back to about 1910. They were also referred to as "Hauraki Hot Springs."

The hot mineral waters are moderately mineralized, alkaline, saline waters with a notably high concentration of borax. It has a pH of 8.9, 146 ppm chlorides, 18ppm silica and 43 ppm borax with a total solids content of 430 ppm.

GEOLOGY

The natural discharge features consist solely of a number of small warm and hot springs, localized in an area of 240 m x 90 m. The temperature of the springs range from 33ºC to 57ºC. No hydrothermally altered rocks have been found in the area, nor is there any silica or sinter deposition. The geology of the area, Sudarman (1981) consists of a basement of Mesozoic greywacke overlain by the impervious Waitamata group of sedimentary rocks. Andesite volcanics (i.e., Kiwitahi volcanics) outcrop to the north and west of the area. A thick mass of pumice (or ignimbrite) is exposed on low scarps (15-20 m) about 150 m west of the springs. Hochstein and Nixon (1979) concluded that the Hauraki Depression is an active rift feature giving rise to horst and graben structures controlled by three parallel faults. These faults are believed to control the appearance of hot springs at the margins and center of the depression. The genisis of the springs is due to deepseated circulation of groundwaters. The open fractured Mesozoic greywackes along the fault zone facilitate the circulation of groundwater to the surface.

THE POOLS

Early in this century, there were about 100 springs over a 40 ha area, of which 30 originally supplied the pool. The original name for this area is Pukorokoro and the springs were used by the Ngati Paoa people. Because of the lack of road access, this group of springs remained undeveloped much longer than others in the area well into this century. One of the first European owners was J. Pond, who carried out many of the early analyses of spring water throughout the country (Rockel, 1986). Unfortunately, the government refuses to purchase the springs in 1903 and 1913. A 1910 photograph showed the largest natural pool set in a peat swamp. The swamps were drained in the 1940s and the present pool built in 1959-60.

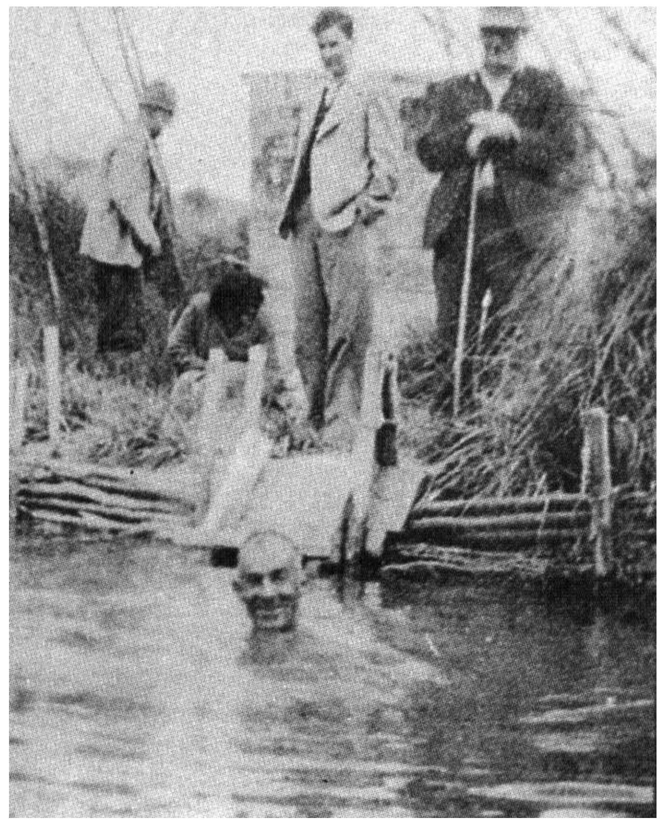

Figure 1. "Hauraki Hot Springs" - 1939

The pool complex consists of the main 1.14 million litre pool, which is 47 m long, and 17 m wide and 1.3 m deep; a public sauna pool together with a children's pool and 4 private spa tubs. The large pool has steps around both sides and is constructed of concrete. The flow rate into the pools is 30,000 litres per hour. The pools were used with minimal development until the late-1950s when the concrete walls and the tiered steps were put around the large excavation encompassing the larger hot springs. On October 4, 1973, the bottom of the pool was sealed with concrete. This was done, which without water pressure build up, allowed the a collection and distribution of the percolating waters within a 3000 mm layer of coarse scoria to 380 mm concrete pipes. The whole arrangement was then covered with a polyethylene sheet followed by an average of about 200 mm of solid concrete. No reinforcing steel was used for fear of corrosive staining of the floor of the pool. A bore of 150 mm was drilled to about 76 m at about that time, and a stainless steel submersible pump was located about 30 m from the surface, which has boosted the supply to the pools. The main pool is maintained at 35-37ºC with the sauna at 40-41ºC. It is the largest geothermal bath in the country.

Figure 2. Main pool.

Figure 3. Public sauna pool.

Figure 4. The authors enjoying a swim.

Figure 5. Maori children enjoying the pool.

ACKNOWLEDGMENTS

Material for the above article was abstracted mainly from a leaflet produced by the owners of the pool complex.

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GEOTHERMAL PIPELINE

Progress and Development Update
Geothermal Progress Monitor

WASHINGTON

Mount St. Helens Quakes on the Increase Under Dome

Mount St. Helens is Twitching again. Earthquake activity below the mountain gradually has increased in recent months, with the pace accelerating in May. Seismic activity has increased from about 60 quakes a month last winter to 165 in May, scientists at the Cascades Volcano Observatory in Vancouver, WA report. The earthquakes are small and unfelt, with only three of them greater than magnitude 2, according to William E. Scott, acting scientist in charge of the observatory. He stressed that no evidence indicates the closely monitored volcano is heading fro a return to large explosive eruptions. None of the quakes is typical of the large number of shallow quakes that typically occur before an eruption.

The quakes are occurring in two clusters below the 920-foot-high lave dome in the volcano's crater. One cluster is about 1.25 to 3 miles below the dome, and the other is about 4.75 to 5.5 miles beneath the surface. Scott said the most recent quakes might indicate that new magma is entering the volcano or that cooling magma from a series of eruptions in the 1980s is releasing gas and building up pressure. The last steam and ash plume from the lava dome occurred in February 1991. The last dome-building eruption, in which magma reached the surface and added to the huge mound of lava on the crater floor, was in October 1986. (Richard L. Hill - Oregonian, 3 June 1998).

GERMANY

Use of Earth Heat in Germany (Erdwärmenutzung in Deutschland)

By the end of 1995 direct thermal use of geothermal energy in Germany amounted to an installed thermal power of roughly 323 MWt. Of this sum, approximately 48 MWt are generated in 24 major centralized installations. Small, decentralized earth-coupled heat pumps and groundwater heat pumps are estimated to contribute an additional 285 MWt. By the year 2000 an increase in total installed power of about 144 MWt is expected: 115 MWt from major central and 29 MWt from small, decentralized installations. This would bring direct thermal use in Germany close to an installed thermal power of 467 MWt. At present no electric power is produced from geothermal resources in Germany, who annual final energy consumption at present amounts to about 9,200 PJ (8.73 quads). Final energy is defined as the fraction of primary energy which is supplied to the final consumer. It is less than the corresponding primary energy because of losses, mainly due to conversion and distribution. Related to one year this is equivalent to a total consumed power of approximately 290,000 MW. Almost 60% of this energy is required as heat.

The maximum technical potential for direct thermal use of geothermal energy in Germany is estimated to be 2,580 PJ/yr (2.45 quad/yr) from hydrothermal applications and shallow heat exchanger systems; this is equivalent to a maximum thermal power generation of about 81,800 MWt. This corresponds to about 29% of the country's annual final energy consumption, or roughly 49 % of it demand for heat. However, at present only about 0.4% of the existing maximum technical potential for direct thermal use of the geothermal energy meets the demand for heat. If the vast potential of geothermal energy for direct thermal use was utilized to substitute fossil fuels, roughly 110 million tonnes less of CO_2 would be released to the atmosphere annually, equivalent to about 12% of Germany's CO_2 output in 1994. (Christoph Clauser - Geothermische Energie, nr. 21, May 1998).

JAPAN

Efficient Use of Geothermal Hot Water

Kokonoe Town in Oita Prefecture, Kyushu, is the largest geothermal power generation area in Japan. It hosts three commercial geothermal power stations, totaling 147.5 MW, belonging to the Kyushu Electric Power Co: the 12.5 MW Otake station, operational since 1967; the 110 MW Hatchobaru station (the biggest geothermal power station in Japan); and the 25 MW Takigami station which began operation in 1996. In addition, there are two small-to-medium-sized demonstration test plants operated by the New Energy and Industrial Technology Development Organization (NEDO) for binary cycle power generation. The town government of Kokonoe intends to exploit as far as possible the geothermal hot water from these power stations, together with thermal energy from the many hot springs existing in the town, to develop agriculture and tourism, and to improve the living environment.

The use of geothermal hot water associated with geothermal power generation started in 1965 when, in response to a request from a local farmer, Kyushu Electric Power Co made hot water from exploration wells available in the Yutsubo area of the town to heat greenhouses. In the beginning, raw geothermal hot water was supplied to users but, because the geothermal hot water contains arsenic, regulations were introduced which stated that all raw geothermal hot water must be reinjected deep into the ground. As a result, since 1974, river water heated by heat exchange from the geothermal fluid is supplied to a large number of users for horticulture, domestic heating and hotel and leisure facilities. Since 1988, the Kokonoe Bio Center has been using hot water supplied at a flow rate of 20 tonnes/hour from the Otake Station about 5 km away to produce inexpensive, virus-free seed and saplings for farmers in the town.

A floriculture partnership organized by five farmers invested JPY 153 million (approximately US$1.2 million) in constructing an energy-saving rose farm consisting of 10 greenhouses with a total floor area of 5,723 m^2 (1.4 acres). The farm grows roses all year round, and started shipments of flowers in 1984. The rose farm is provided with hot water (inlet temperature at 73^o C - 163^{o}F), exchanging heat with geothermal hot water at a flow rate of 16 tonnes/hour. The partnership now enjoys sales of roses exceeding the planned sum of JPY 38 million/year (approx. US$0.3 million/year) and completed the repayment of investment in 12 years.

In 1994, a new floriculture partnership organized by 10 farmers began to grow roses in 20 newly-built greenhouses with a total floor area of 19,278 m^2 (4.8 acres) using geothermal hot water. JPY 678 million (approx. US$5.2 million) was invested in this new farm, which is expected to sell roses worth JPY 180 million (approx. US$1.4 million) annually. Because the supply of geothermal hot water to the new farm is limited to 6 tonnes/hour, the farm receives hot water in a storage tank and then circulates the water repeatedly through heating circuits (finned tubed radiators), thereby making hot water at 50^{o}C (122^{o}F) flow through the greenhouses at a rate of 37 tonnes/hour.

The changes in outdoor temperature at the site of the rose farms are similar to those in colder, more northerly regions. Thus, when the temperature inside the greenhouses is kept at 18^{o}C (64^{o}F) throughout a year, the degree-hours of heating are 60,210^{o}C-hours (4,516^{o}F-days). Each year, in total, geothermal energy saves 884 kL (5,560 bbl) of fuel oil and JPY 41.5 million (approx. US$0.32 million) of fuel cost (fuel oil price at JPY 47/ L - US$1.37/gal).

Geothermal energy is also supplied to a muncipal community center (75^{o}C - 167^{o}F at 3 tonnes/hour) and the prefectural recreational lodge for boys and girls (80^{o}C - 176^{o}F at 7 tonnes/hour). Waste water from all the uses is discharged at 28^{o}C (82^{o}F) when the outside temperature is 8^{o}C (46^{o}F). (CADDET - Renewable Energy Newsletter, May, 1998).